Subsurface Geology of the National Reactor Testing Station Idaho

GEOLOGICAL SURVEY BULLETIN 1133-E

Prepared in cooperation with the U.S. Atomic Energy Commission

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By EUGENE H. WALKER

STUDIES OF SITES FOR NUCLEAR ENERGY FACILITIES

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[Plates are in pocket]

SUBSURFACE GEOLOGY OF THE NATIONAL REACTOR TESTING STATION

By Eugene H. Walker

ABSTRACT

Surface geology and records from wells and test holes as deep as 1,497 feet are used to describe and interpret the subsurface geology of the National Reactor Testing Station.

The station is underlain, to depths still unknown, by the Snake River Group, which consists of basalt flows, and by some interbedded lake and stream deposits derived from the mountains to the north. A thick sequence of lavas with few and thin interbeds underlies the southeastern part of the station. Between this area and the mountains there is a belt about 10 miles wide in which considerable masses of sedimentary materials are interbedded in the lavas. The bulk of this material is silt with some fine-grained sand and clay; there are lesser amounts of coarser grained stream deposits.

The bulk of the sedimentary deposits occurs in large masses. One such mass is at and near the surface, another at intermediate depth, and the third at the greatest depths explored. These strata probably were deposited during wet periods of high runoff that coincided with substages of glaciation in the mountains.

Unsaturated deposits 50 feet or more thick underlie about 175 square miles of the station, and those at least 100 feet thick underlie about 110 square miles. One well shows 262 feet of unsaturated material. There probably are somewhat more than 4 cubic miles of unsaturated deposits beneath the station, counting only the area where the thickness is 50 feet or more. Most of this material is fine grained.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

This report presents the results of a study of the subsurface geology of the National Reactor Testing Station of the Atomic Energy Commission in Idaho (fig. 1). It is one of a series of reports describing the factors that control the movement of water beneath the surface of the station, because of the importance of such movement to problems of water supply and contamination.

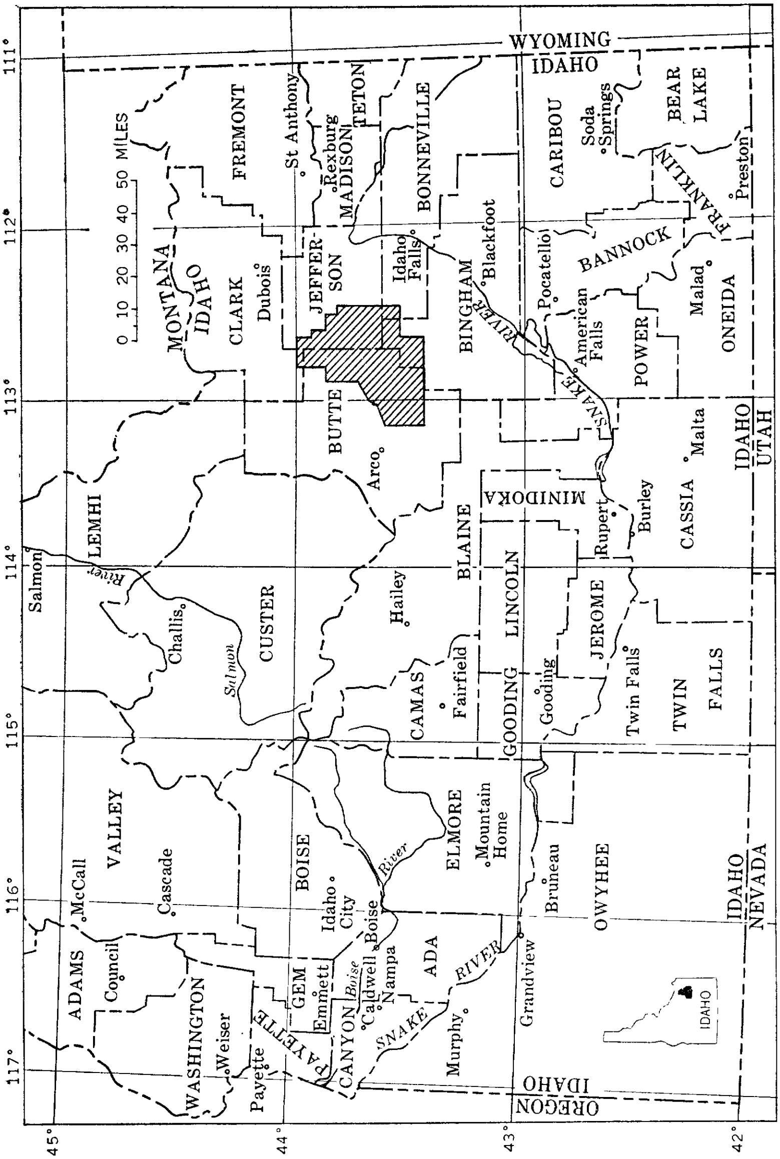

FIGURE 1.—Index map of southern Idaho showing area covered by this report.

The station is underlain, to depths still unknown, by basalt of the Snake River Group and interbedded sedimentary deposits. Movement of water is concentrated in the more permeable zones in the basalt. Some of the sedimentary deposits are thick and extensive and undoubtedly exert much control over the movement of ground water. The sedimentary materials are much less permeable than the lavas and certainly influence the vertical components of movement; for example, they create zones of perched water. The larger masses above the water level provide an environment for the disposal of liquid wastes.

The distribution and extent of lavas and sedimentary deposits in the subsurface are presented by means of six geologic sections. These sections (pl. 2) are based on several types of logs obtained from wells and test holes drilled for the Atomic Energy Commission, and from a few wells formerly or still privately owned. Drillers' logs and logs made by examination of cuttings usually furnish a satisfactory record of the material penetrated, especially the thickness and type of sedimentary deposits that may be interbedded with the lavas. Gamma-ray logs, made in almost all holes that are not equipped with pumps, provide more exact information on the position of contacts between basalt and sediments than either drillers' or sample logs, and have been used where available to strengthen interpretations.

Electrical-resistivity logs and caliper logs of hole diameter have been made in the uncased sections of a number of wells in the course of current studies of waste disposal. Such logs add detail not otherwise procurable. They do not alter the correlations of sedimentary masses previously made with geologic and gamma-ray logs, and because they have been made in a relatively few wells, mostly near the Idaho Chemical Processing Plant and the Materials Testing Reactor, they have not been used in the construction of the cross sections.

The production wells of the Atomic Energy Commission are at a number of facilities on the station, most of which are a considerable distance apart. These facilities are commonly referred to by abbreviations of their full names, as MTR for materials-testing reactor. The abbreviated titles are used in this report; a list of abbreviated and full names follows.

ANP	Aircraft nuclear propulsion area
CFA	Central facilities area
EBR	Experimental boiling reactor
EOCR	Experimental organic cooled reactor
ETR	Engineering test reactor
GCRE	Gas-cooled reactor experiment
ICPP	Idaho chemical processing plant
IET	Initial engine test

LPTF	Low-power test facility
MTR	Materials-testing reactor
NRF	Naval reactor facility
OMRE	Organic moderated reactor experiment
SPERT	Special power excursion reactor tests

Through the text of this report the production wells and test holes are primarily referred to by the well numbers of the U.S. Geological Survey, and secondarily by other designations in common use, for example, 3N–29E–14ac2 (MTR–2).

The well-numbering system used in Idaho by the Geological Survey indicates the locations of wells within the official rectangular subdivisions of the public lands, with reference to the Boise baseline and meridian. The first two segments of a number designate the township and range. The third segment gives the section number and is followed by two letters and a numeral, which indicate the quarter section, the 40-acre tract, and the serial number of the well within the tract. Quarter sections are lettered *a*, *b*, *c*, and *d* in counterclockwise order, from the northeast quarter of each section (fig. 2). Within

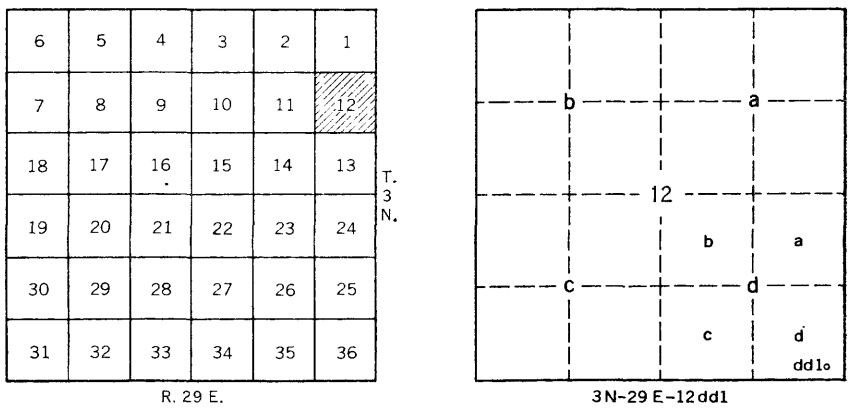

FIGURE 2.—Sketch showing well-numbering system.

the quarter sections, 40-acre tracts are lettered in the same manner. Thus well 3N–29E–12dd1 is in the SE¼SE¼ sec. 12, T. 3 N., R. 29 E. and is the first well visited in that tract.

PREVIOUS AND PRESENT WORK

Previous work by the Geological Survey consists of studies of the surface geology and the preparation of a geologic map covering most of the present area of the station, preparation of many well logs, and collection and interpretation of data on the hydrology of the area, especially the ground-water hydrology. The larger part of this material has been presented in administrative reports prepared for the Atomic Energy Commission by Nace and others (1956, 1959), Walton (1958), Peckham and others (1959), and Walker (1960).

An intensive study of the conditions affecting the disposal of wastes to the ground was begun in 1958 by Paul H. Jones. This study was restricted to the areas around a few of the facilities, notably the ICPP and the MTR.

In the course of this project the geology of the 220 square miles added to the station on the north and east in 1958 has been mapped. Special attention was given to the depiction of all detectable cones and small vents, and to the lines of fracture that show on air photos. All available well logs were studied and used in correlation of the larger sedimentary masses shown by these logs.

PHYSICAL SETTING OF THE AREA

The National Reactor Testing Station covers about 890 square miles on the northern side of the Snake River Plain. As shown on plate 1, there are two main elements in the landscape of this region: the northern mountains and their intermontane valleys, and the Snake River Plain.

Three large ranges end at the northern and northwestern boundaries of the station: the Lost River, Lemhi, and Beaverhead Ranges. Saddle Mountain, near the southern end of the Lemhi Range, reaches an altitude of 10,795 feet and is the highest point within the area on plate 1. The Little Lost River and Birch Creek descend southeastward to the plain in broad valleys floored with alluvium, and the Big Lost River, which enters the area from the west, descends a similar valley west of the map area.

The part of the plain occupied by the station may be separated into three minor physical subdivisions; a central trough that extends to the northeast through the station, and two flanking slopes that descend to the trough, one from the mountains to the northwest and the other from a broad ridge on the plain to the southeast. The slopes on the northwest flank of the trough are built mainly by alluvial fans from the mountains and the valleys of Birch Creek and the Little Lost River, but some basalt flows, like that on the west side of the valley of Birch Creek, have spread from the mountains toward the plain. The southeastern part of the station slopes broadly to the northwest on basalt flows that spread from a zone of eruption that extends northeastward from Cedar Butte in T. 1 N., R. 30 E. The lavas which erupted along this zone built up a broad topographic swell. Big Southern Butte and Middle and East Buttes are also alined roughly along this zone; however they are formed of volcanic rocks older than the basalt of the plain. The central lowland of the station broadens to the northeast and joins the extensive Mud Lake basin. The waters of the Big and Little Lost Rivers and Birch Creek drain into this trough and toward a broad depression between Howe and Circular Butte. The lowest part of the station, at an altitude of about 4,775 feet, is in this depression.

The elements of the climate of the station have been described by DeMarrais (1958). The average annual precipitation ranges from about 7.5 inches in the southeast to about 9 inches along the base of the mountains. Maximum precipitation is in the spring, reflecting spring rainstorms. Normal annual snowfall is about 23 inches and accounts for about 30 percent of the annual precipitation. Precipitation in the summer occurs as scattered showers.

The plain is generally windy; records from a number of places show periods of calm only about 10 percent of the time. The dominant wind is from the southwest at all stations out on the plain. Stations at the mouths of the Little Lost and Birch Creek valleys show dominant winds downvalley.

SURFACE GEOLOGY

The geologic formations of the station and its environs can be divided into two main groups: the basalt and associated stream and lake deposits of the Snake River Group that occupy lowland areas and are of Pleistocene and Recent age, and the distinctly older formations—the sedimentary rocks of Paleozoic age that form the mountains, and the Tertiary volcanic rocks that crop out in the northern foothills and in the three buttes on the plain.

FORMATIONS OF PRE-PLEISTOCENE AGE

The mountain ranges north of the plain are built of sedimentary rocks of Paleozoic age that were folded and faulted along northwestward-trending axes in the Laramide revolution of Late Cretaceous and early Tertiary times. These rocks are mainly limestone and dolomite, interbedded with some sandstone and shale.

Silicic volcanic rocks mainly welded tuffs, form foothills along the flanks of the mountains. They were deposited on an erosion surface that cuts across the folded sedimentary rocks. They have been dated as late Tertiary, probably Pliocene, by Ross (1961, p. 230) and may be correlative with the Idavada Volcanics farther west on the plain and assigned an early Pliocene date by Malde and Powers (1962). The volcanic rocks are somewhat faulted and generally warped toward the plain, presumably by the movements attending the sinking of the Snake River trough with respect to the uplifted mountain masses north and south of it.

The three prominent buttes on the plain, Big Southern Butte just south of the station, and Middle and East Buttes just within it, are the relics of a buried volcanic terrane. A small exposure of these volcanics also occurs about a mile southwest of East Butte, which is composed of light-colored rhyolite. Middle Butte is a block of basalt flows, tilted toward the south. Big Southern Butte includes a variety of silicic volcanic rock types, but no basalt. These volcanics, like those in the foothills of the mountains, are considered to be correlative with the Idavada Volcanics.

The exposures of Tertiary volcanics are of significance for two reasons: first, they probably represent the type of rock that floors the trough beneath the Snake River Group. Well 8N–31E–14aa1, between the southern end of the Beaverhead Range and the north boundary of the station, entered silicic volcanic rocks beneath about 380 feet of alluvial gravel. Second, the eroded remnants of this older volcanic terrane, found in the three buttes out on the plain, show that the floor of the trough has considerable relief, in this area at least, rather than being a level lowland between the mountains on the north and those on the south.

There are two primary structural trends in the area: northwest and northeast. The principal northwestward-trending stuctures are the lines of folding and faulting in the mountains, and faults showing late movement at the bases of these mountains. Principal northeastward-trending structures are the faults that are inferred to separate the mountain blocks from the downfaulted plain, and the alinement of the old buttes and many vents along the central part of the plain.

SNAKE RIVER GROUP

BASALT

The eruption of the basalt of the Snake River Group began in early Pleistocene time and continued until Recent time. The flow which extends into the southern part of the station in T. 2 N., R. 30 E. is so fresh that it is presumed to be no more than a few thousand years old. The basalt extends over an area of more than 8,000 square miles. The thickness of the mass ranges from a few feet on the margins to a known thickness of more than 1,500 feet, and the maximum thickness probably is considerably greater.

The basaltic volcanics seen throughout the station, as elsewhere throughout the Snake River Plain, are primarily lava flows. Pyroclastic rocks, such as cinders, slaggy fragments, and bombs, form accumulations near vents. However, such material amounts to a very small part of the material that issued as lava, as eruptions of basalt are far less explosive than eruptions of the more silicic rocks such as rhyolite.

During any given eruption, which may have lasted for weeks or many months, basalt was poured out spasmodically rather than continuously. The sheet of lava that spread out in each episode developed a crust or solidified completely before a new sheet was spread. Thus what is commonly referred to as a flow is normally found to consist of a few to several sheets, each with upper and lower chill zones and characteristic internal structures. The thickness of such sheets ranges from a few feet to a few tens of feet.

The molten basalt was sufficiently fluid to spread for many miles on relatively low gradients. Some of the lava flows on the station spread more than 10 miles. The slopes on the outer limits of such flows may be as low as 30 feet per mile. The slopes are steeper near the vents and may be as much as 400 feet per mile near the summits of lava domes. The vents, which may be inconspicuous craters as well as conspicuous cones, can be located by searching upslope.

The sites from which lava erupted, as shown on plate 1, may appear at first sight to be distributed at random, but actually a certain order prevails. First, all the events probably occur along fractures or fissures which were channels for the ascent of the lava from deep in the crust. Second, the fractures form a definite pattern with trends northeast, northwest, north, and east. The pattern is not everywhere obvious, because the only fractures that show at the surface are those on which there has been movement later than the local lava or sedimentary deposit occurring at the surface. All eruptions on the plain are thought to have commenced as eruptions along fissures, but later activity commonly was restricted to a single opening along a fissure and the extruded lava completely buried the fissure.

A set of northeastward-trending fractures is shown by the notable concentration of vents extending northeastward from Cedar Butte. The eruptions along this zone over a long period of time have built a broad ridge upon the plain. Fractures of northeasterly trend can be detected on aerial photos of the southwestern part of the station. This set of fractures is presumably related to the major fault, or zone of faults, that probably separates the great crustal blocks of the mountains and the plain.

Vents and craters are alined along northwestward-trending cracks in T. 3 N., R. 33 E., on the east side of the station, and also in Tps. 2 N. and 3 N., R. 28 E., on the western side of the station. The flow that is partly covered by alluvium on the west side of Birch Creek issued from two vents along a fault that cuts the alluvial fans on the east side of the Lemhi Range; the fault trace shows faintly on the alluvial fans themselves. Such northwestward-trending lines of weakness appear to be related to the Laramide trends of the mountain ranges.

Fracturing that trends to the north or slightly east of north is shown by a prominent and continuous rift which can be traced for 12 miles through Tps. 3, 4, and 5 N., R. 33 E. It probably continues to the south through the crater 2 miles north of East Butte. Lineation of vents along a northward-trending fracture occur in T. 2 N., R. 33 E. Cracks having this same trend are mapped in various other localities as well.

Eastward-trending lines of fracture are less evident, but some are discernable in the western part of the station. The three craters just within the southern boundary of the station and north of Big Southern Butte have an eastward trend.

SEDIMENTARY DEPOSITS

The surface of the station is widely mantled with sedimentary materials, if both the loess of wind-laid origin and the water-laid deposits are included. The geologic map (pl. 1) shows only the sediments deposited in water. The mantle of loess in most places is thin and discontinuous, and many knolls and prominences on the lava surfaces remain uncovered.

Most of the deposits shown on plate 1 were carried to the plain by the Big and Little Lost Rivers and Birch Creek. The deposits from these drainage basins merge in the northeastern part of the station with deposits of the Mud Lake basin that were derived from drainage basins east of Birch Creek.

The water-laid materials are gravel and sand deposited by streams as alluvial fans, channel fillings, and deltas, and the silt and clay deposited in the relatively still water of lakes. These materials interfinger at many places, as may be seen in pits excavated for construction materials, because the environments of both running and still water shifted in response to changes in runoff and lake levels. Therefore the boundary drawn on plate 1 between coarse-textured alluvium and fine-grained lake beds is an arbitrary placement of a gradational boundary.

The gradation from coarse-grained to fine-grained material takes place over a short distance along the lower courses of Little Lost River and Birch Creek. These streams lose transporting power rapidly where their intermontane valleys open onto the plain; their gradients decrease abruptly, as shown by the profiles of the Little Lost River and Birch Creek on sections *C–C′* and *E–E′* (pl. 2), and their carrying power is also reduced because they lose water through seepage. Big Lost River loses gradient more gradually as it descends a gentle slope on lavas for many miles before emptying onto the playa flats east of Howe.

The gravel spread in shifting channels as alluvial fans is notably cobbly and poorly sorted for many miles out from mountain fronts, and it has a large proportion of fine-grained material. Gravel deposited in streams that did not constantly shift their channels shows better sorting and more rounding of the larger particles, but even this gravel contains much silt in the interstices.

The fine-grained sedimentary materials, which are loosely referred to as lake beds in this report, consist mainly of silt and subordinate amounts of sand and clay. Sand occurs as beach and bar deposits and as thin sheets spread by wave action and longshore currents. Most of the material that well drillers call clay is actually silt containing only about 20 percent of clay-size particles having mean diameters of 0.004 mm or less (Nace and others, 1956, written communication), though some thin beds may contain as much as 40 percent of clay-size particles. Only a small fraction of the material termed clay is clay by mineralogic or chemical criteria; the fraction is small because in the mountainous source areas mechanical disintegration has long dominated over the chemical decomposition required to produce clay.

Depressions at many places on the surfaces of lava fields contain small bodies of water-laid material. These deposits are primarily silt washed down from loess-covered slopes. Some of the deposits are as much as 10 feet thick and cover many acres. The larger of these areas are shown on plate 1; a more detailed unpublished map presented by Nace and others (written communication, 1956) shows many smaller exposures.

The wind-laid deposits on the station include dune sand as well as the mantle of loess. Windblown sand occurs mainly as longitudinal dunes developed on the broad expanses of lake beds in the eastern part of the station. The longitudinal dunes are usually only a few feet high, but are 50 to 200 feet wide, and some individual ridges can be traced for several miles. They trend northeastward and are separated by strips of bare lake beds about as wide as the dunes themselves. These dunes are inconspicuous from the ground but form a bold pattern on aerial photos because sagebrush grows taller and much more thickly on the dunes than on the lake beds. Although there is some movement of sand on these dunes when strong winds blow, the dunes probably developed at some time in the past after the lakes dried up and when the covering vegetation was thinner than at present. The dunes may have been formed during the episode of higher temperature than the present which is dated from about 7,500 to 4,000 years before the present (Flint, 1957, p. 377).

The origin of longitudinal dunes like these is still disputed, but Bagnold (1941, p. 178) presents some evidence that they develop where there is a limited amount of sand, and a dominant wind is occasionally interrupted by a strong cross wind. Such conditions occur here, as the lake beds furnish only a moderate amount of sand and the prevailing southwest wind is interrupted by storm winds that blow southeast down the valleys of the Little Lost River and Birch Creek.

The bulk of the sedimentary material exposed on and surrounding the station was deposited at a time in the past when the climate was appreciably wetter and when there was more runoff and a large lake occupied much of the northern part of the station and the broad Mud Lake basin to the east. The area within the station that is mapped as lake beds amounts to about 130 square miles. More than three-quarters of this area has been above water long enough for the longitudinal sand dunes to form, and these, as suggested above, may be 4,000 years old. Deposition at present and in the historic past has been restricted to the playa basins that lie within the 4,800-foot depression contour between Howe and the ANP area (pl. 1), and together cover only a little more than 10 square miles.

The immense quantities of alluvial gravel spread in the valleys and out onto the plain for many miles also testify to a wetter period when the streams must have been much larger than they now are. The streams now spread little coarse alluvium, and in general they are slightly entrenched in sheets of cobbly gravel. A thin capping of loess on the gravel shows that the surface above the stream channels has not been flooded for a long time.

This wet period, when so much coarse gravelly alluvium was spread and fine-grained sediment deposited in a broad lake, probably reflects the last substage of the Wisconsin Glaciation in the mountains. Whether such deposition coincided with the maximum advance of the ice downvalley or with the period of melting is a question still in debate among glacial geologists.

SUBSURFACE GEOLOGY

The subsurface geology is shown by six cross sections (pl. 2), and also by columnar sections and isopachs, or lines of equal thickness of deposits, above the water level (pl. 1). In referring to the geologic sections, the great vertical exaggeration of 52.8 times the horizontal scale should be kept in mind. If a lesser vertical exaggeration had been used, either the sections would be unduly long or it would be difficult to show many of the thinner beds, and even with the exaggerated scale most of the beds of loess are shown diagrammatically as being thicker than they actually are.

The geologic sections show that there is considerably more information from the land surface to about 100 feet below water level than there is at greater depth. Few wells have needed to penetrate more than 50 to 100 feet below water level to obtain all the water that is required. Considerably deeper penetration has been necessary only in the area a few miles east of the CFA. For the purpose of exploration, a few test holes have been drilled many hundreds of feet below water level. The geologic sections have been drawn to include all the deeper wells that give information of special significance, such as the presence of thick alluvial and lake deposits.

Two features of the subsurface geology may be mentioned before proceeding to more detailed descriptions. First, basalt and sedimentary deposits like those at the surface underlie the station to the lowest level so far explored, 3,317 feet above sea level at the bottom of well 4N–30E–6ab1 (pl. 2), or a depth of 1,497 feet. Second, large bodies of these deposits occur at depth, and they appear to have been deposited in a trough between the mountains and a thick basalt sequence to the southeast, like the sedimentary deposits at and near the present land surface.

BASALT

The basaltic volcanics at depth are mainly lavas like those at the surface, as far as can be determined from drill cuttings and gamma-ray logs. The samples show basalt of monotonous character, varying only slightly in shade of gray, in degree of vesicularity, and in texture and mineralogy from one flow to another. Gamma-ray logs show that the basalt, as logged in typical test holes of 6-inch diameter, has a generally uniform radioactivity, usually less than 0.005 milliroentgens per hour (Jones, 1961, p. 5). Certain flows show perceptibly higher radioactivity, probably due to slightly higher proportions of such radioactive minerals as zircon.

Reports from drillers and evidence from caliper logs of hole diameter reveal zones of blocky or loose and caving basalt from place to place between the more normal solid lavas. The character of the materials in these zones can only be guessed from samples and other subsurface data. Certain of these zones must be formed by the loose cinders and slaggy fragments that occur near vents, and others by rough-crusted lavas. However, some of the blocky and caving zones probably reflect pillow lavas and the loose scoriaceous material produced when lava flowed into water.

The southeastern part of the station is underlain by lava flows and few and thin sedimentary beds to the greatest depths reached by wells, which is about 700 to 800 feet on the southeastern ends of sections *C–C′* and *D–D′* (pl. 2). These thin beds are loess, for they consist of silt, which is baked to a pinkish color by the lava immediately overlying them. The loess beds show up as distinct kicks on gamma-ray logs, as the radioactivity of the loess is 0.0075 to 0.0125 milliroentgens per hour (Jones, 1961, p. 5), appreciably higher than common values for the basalt. Thus, the subsurface data reveal that the southeastern part of the station has been a topographic high, as it now is, for a long period of time, built above the terrain to the northwest and southeast by many lava flows. Sufficient time elapsed between the spreading of many and perhaps most of the flows for sheets of loess to accumulate to thicknesses of a few inches to several feet. The two wells on the southeastern end of section *D–D′* (pl. 2) show, respectively, six and seven sheets of basalt and loess, including that at the present land surface. The average thickness of the sections of basalt between sheets of loess in these two wells is 115 feet, which may roughly represent an average thickness of individual lava flows in this locality.

The lava flows in the central and northern parts of the station are interbedded with sedimentary bodies ranging in size from small channel fills to thick and extensive lake deposits. Some flows, like the one on the west side of the valley of Birch Creek, spread southward from centers of eruption along the mountain front or in the valleys. Other flows spread from vents in the lowland, such as State Butte in T. 4 N., R. 30 E., that now stands above the alluvial gravel of the Big Lost River. In general, however, the lava flows have transgressed northward toward the foot of the mountains and up the valleys as the surface of the plain was built upward. Such northward-spreading flows covered existing deposits, blocked valleys, and dammed streams to create new basins in which new deposits gathered and were in turn buried by later flows. The transgression northward over sedimentary deposits is shown by the relations on the northern ends of section *C–C′* and *D–D′*, (pl. 2).

Some of the lava flows in the central and northwestern part of the station moved into fairly large lakes. In the subsurface of the ICPP area there are many thin layers of sedimentary deposits and basalt, as shown on the log of well 3*N*–29*E*–24dd1 of section *B–B′*, (pl. 2). With such intimate association of lava and sedimentary deposits, pillowed and scoriaceous steam-exploded lavas must occur, such as may be seen in the canyon of the Snake River. Drillers report that in some places the basalt directly over sedimentary beds is broken or cindery; and the cuttings from such zones show a little of the black basaltic glass produced by rapid quenching in water. Some of the zones reported by drillers as broken lava and clay or cinders and clay probably are lava spread into muddy water.

SEDIMENTARY DEPOSITS

The sedimentary materials found to a depth of 1,500 feet beneath the station resemble those at the present land surface. They include coarse-grained alluvial deposits ranging from cobbles to sand, and clay, silt, and fine-grained sand. They also include loess, and probably some dune sand which in the subsurface could not be distinguished from water-laid sand. These deposits, except for the sheets of loess and occasional beds of water-laid materials which accumulated in isolated playas, are found mainly in a zone along the front of the mountains where basins were enclosed repeatedly by flows of lava spread from sources to the south.

In the subsurface the presence of gravel indicates that deposits are alluvial more surely than does the presence of sand alone, for much of the sand is fine grained and probably was deposited in lakes. Streamlaid gravel is thickest in the intermontane valleys, as shown in section *C–C′* and *E–E′* (pl. 2), and become thinner with increasing distance from the mountains. Sheets of gravel occur at one depth or another as far as 10 miles out on the plain from a line connecting the ends of the mountain spurs. The gravel probably extends a few miles farther out at some places. Some of this gravel was deposited as fans, and some as deltas on the margins of lakes. A sequence of basin-filling deposits is shown between elevations of 4,270 and 4,390 feet in well 4*N*–30*E*–6ab1 (pl. 2). At this place gravel was spread by a stream entering a depression, then later lake beds were deposited in deeper water, and finally more gravel was spread as the basin filled and the stream renewed its course across it.

Some of the thin and isolated beds of gravel and sand shown on the sections represent alluvium deposited in narrow channels and later buried by basalt. Well logs are so widely spaced that they show only a few of the many channel fills that probably are interbedded with basalt.

The bouldery and poorly sorted gravel of alluvial fans, deposited by storm waters in shifting channels, occurs in considerable volume beneath the station. Large and steep fans are illustrated on the northwestern ends of sections *B–B′* and *F–F′* (pl. 2). Though outside the station and not shown on the geologic sections, the fans around Big Southern Butte in T. 1 N., R. 29 E., show that large masses of poorly sorted material may occur in the subsurface around buried hills. Smaller fans surround East Butte. Talus, predominates on the margins of Middle Butte, which is composed of basalt and so pervious that there is little surface runoff to build alluvial fans.

Most of the sedimentary material beneath the surface of the station is fine grained and was deposited in bodies of relatively still water that ranged in size from ponds to lakes having areas of more than a hundred square miles. These deposits consist mainly of silt, lesser amounts of fine-grained sand, and some clay. The coarsest fraction, the sand, was sifted by waves and currents in the shallow bodies of water and spread as thin sheets or concentrated along beaches and bars.

The sections give some evidence that the largest lakes formed along a trough a few miles from the mountains and that a locus of secondary importance was close to the mountains and in the intermontane valleys. The extensive lake beds at and near the present surface illustrate such distribution, and the large body of deposits between elevations of about 4,100 and 4,300 feet (section *B–B′*, pl. 2) accumulated in a depression several miles from the mountains. The log of well 5N29–E—4dc1 on the northern end of section *C–C′* (pl. 2) shows how lava flows spread into the valley of the Little Lost River and created lakes in which fine-grained deposits accumulated.

Most of the deposits are concentrated in a few large bodies; the many small scattered masses together amount to a small fraction of the total. Three large bodies have been identified: the near-surface deposits as much as 330 feet thick; the large mass along section *B–B′* (pl. 2) at intermediate depth (in relation to the total depth so far explored), having a maximum thickness of almost two hundred feet; and the continuous section of about 540 feet of sediment shown in well 4N–30E–6ab1 (section *C–C′*, pl. 2) between elevations of 3,410 and 3,950 feet.

All three of the bodies indicate that lakes covered large areas and existed long enough for hundreds of feet of sediment to accumulate. The uppermost body signifies an episode of accelerated movement of erosional wastes down the intermontane valleys and out onto the plain, probably correlative with a late glacial substage in the mountains to the north. The two lower masses may be correlative with earlier substages. If so, then it is likely that deposition was occurring elsewhere at the same times along the north side of the plain. The small amount of information does not prove that definite sedimentary zones exist at depth, but some evidence of extensions of the large bodies is presented in the descriptions that follow.

NEAR-SURFACE SEDIMENTARY DEPOSITS

The sedimentary deposits that occupy so much area at the present surface and extend to a depth of a few hundred feet are considered to represent a principal episode of deposition, and are referred to as the near-surface sedimentary deposits. Well 5N–31E–28cc1 (section *A–A′*, pl. 2) shows an uninterrupted thickness of 330 feet. The other smaller bodies of sediment between basalt flows to a depth of a few hundred feet throughout the station may be contemporaneous with one part or another of the thick section. These near-surface sedimentary deposits have accumulated under topographic conditions very much like those of the present, with the streams flowing more or less along their present courses to a depression that extended eastward from Howe. The nature of this sedimentary body is best revealed by examination of successive cross sections, beginning at the southwest.

The near-surface sedimentary materials in the southwestern part of the station are mainly gravel of the flood plain of the Big Lost River. Along section *B–B′* (pl. 2) the gravel forms a sheet about 5 miles wide that has a maximum thickness of about 50 feet. The sheet becomes narrower and thinner upstream to the southwest and west. Downstream to the northeast it broadens and is about 8 miles wide along section *C–C′* (pl. 2); here also the transition from gravel to lake beds may be observed. Occasional thin beds of gravel and lake beds occur interbedded with basalt below the surface sheet of sediment and denote deposition along channels and shallow short-lived lakes overrun by spreading lava.

Farther to the northeast the belt lies close to the mountain front, but is still 7 miles wide, excluding the fan-mantled slopes to the north. as seen in section *D–D′* (pl. 2). This section shows that the trough receiving sediments was considerably broader at depth than at the present surface, and that lava flows gradually spread northward into the trough and narrowed it. Well 5N–31E–28cc1 penetrated 330 feet of sediment before encountering basalt; this is the greatest thickness of near-surface sediment thus far found by drilling on the station; well 8N–31E–14aa1 (section *F–F′*, pl. 2), showing 390 feet of alluvial-fan gravel, is north of the station. The sedimentary materials in this thick section are mainly lake beds. Occasional beds of gravel indicate periods when no lake was present and alluvium was spread as sheets. The depression may have become filled with sediment several times, and then each time recreated at a higher level by new lava flows.

Sections *E–E′* and *F–F′* (pl. 2) illustrate the widening and thickening of the belt of near-surface sediments northeastward into the Mud Lake basin. The sections also show the transition from alluvial gravel, spread by Birch Creek and from the mountain slopes, to silt and minor amounts of sand. No eruptions have occurred in this part of the station for a long time; there is no lava interbedded with or lying upon the main sedimentary body.

INTERMEDIATE SEDIMENTARY DEPOSITS

A large body of sedimentary deposits at intermediate depth is best shown by the well logs along section *B–B′* (pl. 2). Well 2N–30E–1bd1 encountered about 180 feet of sticky silt and a little sand and gravel between elevations of 4,100 and 4,280 feet. The continuation of these deposits to the northwest is shown by a 130-foot section of silt and some sand in well 2N–30E–5dd1, and probably also by the two sedimentary beds near the bottom of well 3N–29E–14ac2. Lava flows spread into the lake and brought deposition to an end, first in the vicinity of the well 2N–30E–5dd1, and later in neighboring areas.

The sedimentary deposits of intermediate depth may have a length of 10 miles or more along section *B–B′*, as they probably extend several miles south and southeast of the 180 feet encountered in well 2N–30E–1bd1, and some distance northwest of well 3N–29E–14ac2. They also extend for several miles to the northeast and southwest, if sediments within about the same range of depth as those in section *B–B′*, that is, from 4,100 to 4,300 feet, may be considered as extensions, or evidence of contemporary deposition in other basins. The sedimentary beds in wells 4N–30E–6ab1 and 4N–30E–7ad1, (section *C–C′*, pl. 2) between the elevations of 4,140 and 4,390, probably represent a continuation 10 miles to the northeast. Section *D–D′* and *E–E′* (pl. 2) show few deposits at intermediate depth. The 210 feet of silt and sand and a little gravel below elevation 4,250 feet in the isolated deep well 5N–35E–4bd2 on section *F–F′* (pl. 2) may be correlative with the large body shown by section *B–B′*.

To sum up, the mass of deposits at intermediate depth in the south-central part of the station signifies the former occurrence of a lake with an area of at least 100 square miles. Other deposits at about the same horizon suggest that this lake extended to the northeast for many miles, perhaps beyond the borders of the station and into the Mud Lake area.

DEEP SEDIMENTARY DEPOSITS

The deep test well 4N–30E–6ab1 (section *C–C′*, pl. 2), a little more than 3 miles northwest of State Butte, penetrated about 540 feet of sedimentary materials between the elevations of 3,410 and 3,950 feet. Below this interval there is about 70 feet of basalt and then 20 feet of sedimentary material at the bottom of the hole. The deposits are mainly silt and some fine-grained sand; sand is more abundant toward the top of the section.

A sedimentary deposit as thick as this probably has considerable lateral extent. For example, it would extend outward for about 11 miles before pinching out, if deposited in a basin with slope of 50 feet per mile, which is about the average slope on the lava fields of the plain. However, few wells are deep enough to give any information on the actual extent. Wells 2N–30E–5dd1 and 1bd1 (section *B–B′*, pl. 2) penetrate to an elevation of about 3,700 feet, or 250 feet below the level of the top of the deep deposits, but show no considerable thickness at their location 13 miles south of the thick section. However, the 35 feet of lake deposits at an elevation of 3,970 in the well 2N–30E–5dd1, and the other thin beds of silt in this and well 2N–30E–1bd1 could represent the outer fringes of the thick body to the north. Well 6N–31E–27ba1 (section *A–A′*, pl. 2), which is 12 miles northeast of well 4N–30E–6ab1, penetrates to an elevation of 3,600 feet and shows about 120 feet of sediment in several beds separated by sheets of lava between elevations of 3,700 and 3,900 feet. The sediments are sand and gravel with a capping of silt. They also could represent a marginal sandy part of the thick body.

Considering the lack of evidence, only speculations may be made as to the extent of the deep sediments. They certainly extend toward the mountains and up the mountain valleys, merging into alluvial sand and gravel toward the source areas. It seems very probable that they extend to the northeast for many miles along the trough, which is an old feature of this part of the plain.

EXTENT AND VOLUME OF SEDIMENTARY MATERIAL ABOVE THE WATER TABLE

Deposits that lie above the water table and therefore are not saturated with water are potentially important with respect to disposal of wastes on the station. Through broad areas the unsaturated deposits are equivalent to the near-surface deposits, but in some places such as near the mountains the water level stands high enough to saturate the lower portion of the near-surface deposits. Also, the water level lies so deep through large parts of the station that some sedimentary beds below the near-surface body are unsaturated. The thickness and character of unsaturated material is shown by columnar sections, and the approximate limits of thicknesses of 50 and 100 feet by isopach lines (pl. 1).

The extent of the main unsaturated sedimentary body is best visualized by examining the 50-foot isopach (pl. 1). This isopach outlines an area that extends eastward from the mouth of the Little Lost River and then widens northeastward toward the Mud Lake depression. In the northeast part of the station the material 50 feet or more thick divides around an island of lavas poured out from Circular and Antelope Buttes.

A broad arm of unsaturated sediment extends up the valley of the Little Lost River. The 50-foot isopach probably does not extend more than about 10 miles up the center of the valley, because the water level rises closer to the surface upstream.

A large amount of unsaturated material lies beneath the surface of the fan that Birch Creek has spread at the mouth of its valley in the northernmost part of the station, but the thickness will not be known until more wells or test holes are drilled there. Lava probably is more widespread at depth than at the surface, because the two cones that rise above the surface of the fan indicate buried flows.

Well 8N–31E–14aa1 (section *F–F′*, pl. 2), just north of the boundary of the station, encountered 385 feet of unsaturated alluvial-fan gravel, which is the greatest thickness of unsaturated material yet found in the mapped area. This great thickness results from a relatively flat water table beneath the thick and pervious fans that slope upward toward the foot of the mountains. Comparable thicknesses of unsaturated alluvial-fan gravel probably occur elsewhere, such as on the east side of the mountains in T. 6 N., R. 30 E.

The main unsaturated sedimentary deposit of the central part of the station wedges out southward into basalt that spread from southern sources. Both the 50-foot and the 100-foot isopachs cut across the surface lavas in T. 4 N., R. 31 E., because here and in adjacent areas (sections *A–A′* and *D–D′*, pl. 2) considerable thicknesses of deposits occur below the uppermost basalt flows but above the water table. South of the 50-foot isopach the few thicknesses of 50 or more feet of unsaturated sediment mostly reflect two or more beds rather than continuous sections of 50 feet. An exception is the area at the MTR and ICPP facilities, where there is 50 feet of continuous deposits above water level. This area that is shown as isolated may be joined to the main body by a narrow neck to the northeast.

The unsaturated material in the main trough of deposition has a thickness of at least 262 feet in well 5N–31E–28cc1 (section *D–D′*, pl. 2). The unsaturated material probably is not much thicker anywhere in this trough, as the water level rises toward the mountains where the sedimentary section may be thicker, and the sedimentary deposits thin to the south. There are insufficient data for drawing isopachs of more than 100 feet, but probably a 150-foot isopach would enclose at least half the area of the 100-foot isopach, and isopachs of 200 and 250 feet would each enclose many square miles.

As the columns on plate 1 and the geologic sections (pl. 2) show, the bulk of the unsaturated deposits in the trough are fine-grained lake beds. Sheets and tongues of coarse-grained stream-laid deposits are present but are inconsequential in quantity south of a line drawn along the ends of the mountain ranges.

The total volume of the deposits more than 50 feet thick in the main trough south of T. 7 N. probably is not less than 4 cubic miles. The 50-foot and the 100-foot isopachs enclose areas of about 175 and 110 square miles, respectively. The volume within these areas to depths of 50 and 100 feet, including the prism between them, amounts to about 3 cubic miles. The unsaturated material at greater depth probably amounts to at least another cubic mile.

CONCLUSION

The information developed in this report reveals a geologic pattern rather than an indiscriminate interlayering of lava and sedimentary beds. As seen in three dimensions, the southern and southeastern portions of the NRTS are underlain by basalt lava with few and thin interbeds of sediment, and to the northwest, through a zone trending to the northeast, there is much sedimentary material interbedded with lava. This shows that lava was most plentifully erupted from vents on the south and southeast side of the station, creating a large depression, or series of depressions, that received the sediment brought down from the mountains and mountain valleys by the Big and Little Lost Rivers and Birch Creek.

Although there are many scattered bodies of sedimentary material along the main trough of deposition, the bulk of it, as shown in several cross sections, occurs as three large masses. The upper mass is shown by surface exposures and many well logs to be very extensive and to have a local thickness of more than 300 feet. Another large mass of deposits occurs at greater depth and has a thickness of about 200 feet between elevations of about 4,100 and 4,300 feet. The log of a solitary deep well shows that a body of deposits locally 550 feet thick occurs below elevation 3,950.

Locally thick sections of sedimentary deposits may reflect basins accidentally enclosed by but not flooded with lava for a long time, but the broad sheet of near-surface deposits records a period of more than normal runoff and transportation of sediment from the northern mountains rather than an accident of topography. This period may be most logically correlated with the Pinedale Glaciation in the Wind River Mountains of Wyoming as defined by Blackwelder (1915) during studies in western Wyoming and adjacent parts of Montana, and considered to be the latest major subdivision of the Wisconsin Glaciation in this area. Features attributed to the Pinedale Glaciation are evident in the Stanley Basin 100 miles northwest of the NRTS (Williams [1]), and will be recognized elsewhere in the mountains of Idaho

[1] Williams, P. L., 1957, Glacial geology of Stanley Basin, Idaho: Univ. Washington [Seattle], unpublished thesis, 67 p.

when more studies have been made. At least two advances of glaciers occurred in Pinedale time in the Wind River Mountains (Moss, 1951) and in Jackson Hole (Walker, 1954), and doubtless similar fluctuations of ice fronts and of stream runoff occurred in the mountains north of the NRTS area.

The two large bodies of sedimentary material at depth in the lava flows may also signify periods of increased runoff associated with glaciation. Following this line of thought, the deposits at intermediate depth and the thicker ones below elevation of 3,950 may tentatively be correlated with the Bull Lake and the Buffalo Glaciations of Blackwelder (1915). Deposits of the Bull Lake Glaciation can be recognized in the Stanley Basin. Drift attributed to the Buffalo Glaciation has been described by Stearns and others (1939, p. 39) along the south side of Henrys Fork about 50 miles east of Mud Lake. The great thickness of the lower body of deposits accords with the fact that the Buffalo Glaciation was on a larger scale than the later ones.

Though much information has been gained, many features of the subsurface geology of the station remain little known. The more important of these are briefly mentioned below.

1. The elevation and form of the floor beneath the lavas are unknown, and consequently, also the thickness of the aquifer. The nature of the rock that forms the floor is also uncertain.
2. The character of the lower part of the assemblage of lava and sediment in the Snake River trough remains to be determined. The lower part of this assemblage, laid upon an old land surface, may contain a higher proportion of sedimentary deposits and pillowed lavas than the upper parts that have been explored by wells.
3. Almost surely there are at depth many dikes along the fractures that served as channels for basalt to rise to the surface. The dikes presumably exert some control over the directions of ground-water movement at depth, but nothing is known of the matter at present.

As shown previously, the volume of unsaturated deposits more than 50 feet thick within the station probably amounts to at least 4 cubic miles. The hydrologic properties of the sediment need study to determine the potentialities for waste disposal.

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