Generalized Geologic Framework of the National Reactor Testing Station, Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 725-B

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

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Generalized Geologic Framework of the National Reactor Testing Station, Idaho

By RAYMOND L. NACE, PAUL T. VOEGELI, JAMES R. JONES,
and MORRIS DEUTSCH

Edited by SEYMOUR SUBITZKY

GEOLOGY, HYDROLOGY, AND WASTE MANAGEMENT AT THE NATIONAL REACTOR TESTING STATION, IDAHO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 725-B

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data

Generalized geologic framework of the National Reactor Testing Station, Idaho.
(Geology, hydrology, and waste management at the National Reactor Testing Station, Idaho)

(Geological Survey Professional Paper 725–B)
Bibliography: p. 49
Supt. of Docs. No.: I 19.16:725–B
1. United States. National Reactor Testing Station, Idaho Falls, Idaho. 2. Geology–Idaho Falls, Idaho. 3. Geology–Snake River Plain. I. Nace, Raymond Lee. II. United States. Atomic Energy Commission. III. Series. IV. Series: United States. Geological Survey. Professional Paper 725–B.
TK9024.I2G46 621.48'3 75-619044

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-001-02629-5

CONTENTS

ILLUSTRATIONS

TABLES

GENERALIZED GEOLOGIC FRAMEWORK OF THE NATIONAL REACTOR TESTING STATION, IDAHO

By RAYMOND L. NACE, PAUL T. VOEGELI, JAMES R. JONES, and MORRIS DEUTSCH
Edited by SEYMOUR SUBITZKY

ABSTRACT

The Geologic framework of the NRTS (National Reactor Testing Station), Idaho, controls the amount and availability of the water supply, the methods and efficiency of obtaining water, and the behavior of waste amterials that are disposed of on the ground and beneath the land surface. This framework also affects the selection of construction sites and the operation of reactors and other facilities.

The NRTS is at the central-northern edge of the semiarid Snake River Plain in southern Idaho, adjacent to the southern foothills of the Lemhi and Lost River Ranges. The plain was formed during the Cenozoic Era. It was formed by large scale crustal deformation in southern Idaho and by several associated episodes of volcanic activity.

The Snake River Plain commonly has been characterized as a great structural downwarp, modified by a complex system of block faulting. Actually, the plain is essentially a graben, downfaulted between horst blocks represented by mountains to the north and south. The depth through Cenozoic volcanic rocks and sediments to the basement floor is not known, but it has been estimated to range from 2,000 to 20,000 feet in the central part of the plain.

Rock units of sedimentary and igneous origin, Paleozoic and Cenozoic in age, crop out in the station area. No rock units of Mesozoic age are represented in outcrop. The known geologic materials underlying the station are volcanic rocks interbedded with alluvial sediments of Pleistocene and Holocene age. These in turn are underlain by basement rocks which are probably composed of an older sequence of igneous and sedimentary rocks.

The oldest rocks exposed on the NRTS are Paleozoic in age and consist chiefly of dark-gray to gray sandy limestone with chert nodules. Small amounts of siltstone, sandstone, and conglomerate may be present.

Volcanic rocks of Tertiary age crop out at the station and range in composition from basic to silicic. These volcanic rocks consist chiefly of welded rhyolitic tuff and silicic to basic flow rocks. Locally, beds of white to light-gray compact volcanic ash rest unconformably on Paleozoic limestone. Basalt of Tertiary age is relatively rare.

Basalt of the Snake River Group of Quaternary age is exposed in about three-fourths of the station area. The basalt, typically gray to black, bluish-black, brown and brick red, ranges from dense to porous and highly vesicular. It occurs in relatively thin interlocking flows; most of the flows are the relatively smooth ropy type (pahoehoe), but a few flows are blocky basalt (aa). Beds of cinders, scoria, and basaltic glass occur locally. Although basalt is the chief rock type of the Snake River Group, the unit also includes interflow beds of windblown, lacustrine, and alluvial sediments. A younger black basalt of Holocene age which consists of a single flow occurs locally in the station and seems to be lithologically similar to flows in the Craters of the Moon National Monument.

Petrographic study, megascopic examination, and chemical analyses of 14 representative specimens of these basalts indicate that in color, fabric, density, and other megascopic properties the basalt is diverse, but in mineral and chemical composition it is remarkably uniform.

Basalt flows have individual and internal structures which consist of layering, partings, joints and other fractures, and also various types of natural voids. These structures strongly affect their capacity to store and transmit water and determine their suitability for structural foundations.

Unconsolidated sediments of Quaternary age cover large areas of the station and also are present as interflow beds in the Snake River

Group. Unconsolidated materials, chiefly of Holocene age, consist largely of windblown deposits, playa deposits, slopewash, alluvium of Big Lost River and Birch Creek, alluvial fan deposits, and lake beds and associated beach and bar deposits. Some older unconsolidated deposits of undifferentiated origin are of Pleistocene age. At many places in the station the various types of unconsolidated deposits are intermixed, interfingered, and interbedded so that it is difficult to classify them into separate mappable units. This report contains information on particle-size composition, chemical composition, and mineral composition of selected samples of these sediments.

Special geologic factors of the earth materials were studied in relation to movement of fluids in the physical environment of the station. These included ion-exchange capacity of sediments and basalts, and the origin, distribution, and physical characteristics of large desiccation cracks in fine-grained sediments.

Study of the subsurface geology of the NRTS was limited to rock units about which direct evidence was available from test drilling and other subsurface exploration techniques, including electrical-resistivity and seismic surveying and radioactivity logging of wells. Rock units present include basalt of the Snake River Group, alluvium of Big Lost River and Birch Creek, Terreton Lake beds, and interflow sediments.

Detailed factors of the geologic framework that would directly influence site selection, engineering design and construction, and operation of reactors were studied chiefly at specific localities on the station. These factors included the behavior of earth materials during drilling, the availability of raw materials for construction, and the stability of earth materials in excavations— under stress and under a range in moisture conditions.

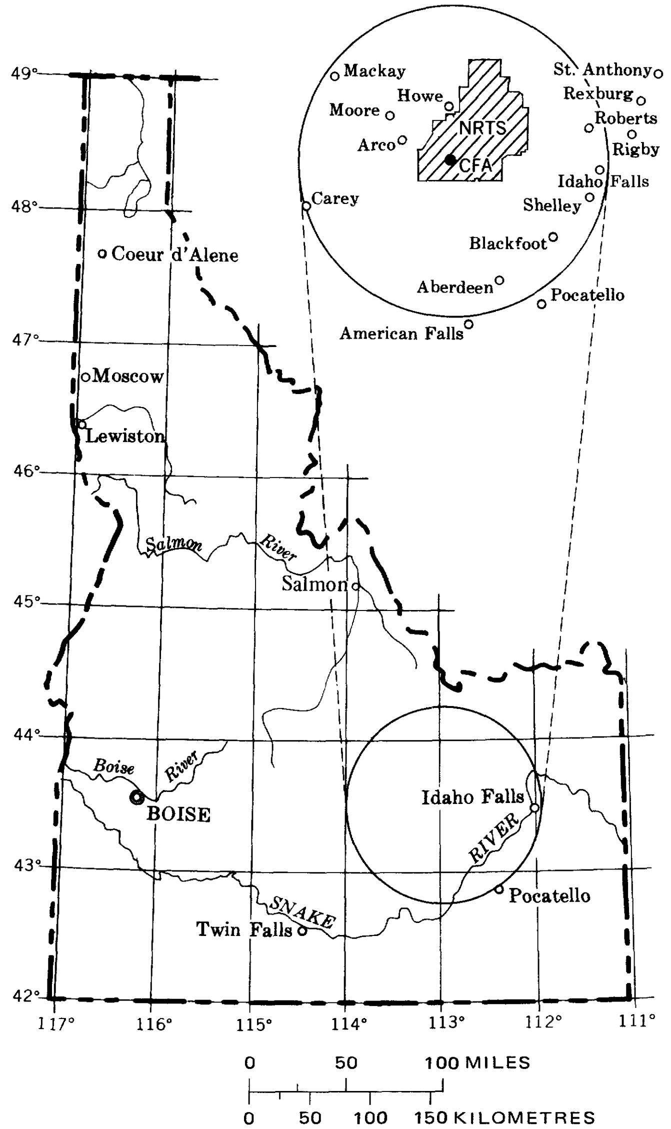
The Snake River Plain, including the NRTS, is subject to occasional seismic tremors; the oldest recorded shock occurred in 1884. Sixteen earthquakes in Idaho with an epicenter rating of V or more on the Rossi-Forel scale were recorded during the period 1894–1945. Epicenters of these quakes were more than 100 miles distant from the station.

Relatively recent volcanism has occurred in Craters of the Moon National Monument and in at least one place adjacent to the southwestern part of the NRTS. Recent activity has occurred at several other places on the Snake River Plain, such as at Hells Half Acre to the east. There is no assurance that cessation of volcanic activity in the plain is permanent. However, inasmuch as inactivity has endured for at least 100 years—longer than is ordinary for areas of active volcanism—renewal of activity seems unlikely.

INTRODUCTION

This report presents results of early studies (1949–1956) of the geologic framework of the NRTS (National Reactor Testing Station), Idaho, by the U.S. Geological Survey in cooperation with the U.S. Atomic Energy Commission. The geologic framework of the physical environment of the station controls the amount and the availability of the water supply, the methods and efficiency of obtaining water, and the behavior of waste materials disposed of on the ground or beneath the land surface. It also affects selection of construction sites and operation of reactors and other facilities.

Geologic mapping and study of basalt outcrops and surficial sedimentary deposits helped to delineate water-bearing properties of the geological formations.



Facilities at the National Reactor Testing Station

Name	Abbreviation	Name	Abbreviation
Advanced Test Reactor	ATR	Idaho Chemical Processing	ICPP
Argonne Fast Source Reactor	AFSR	Initial Engineering Test Facility	IET
Auxiliary	Aux.	Loss of Fluid Test Facility	LOFT
Army Reactor Area	ARA	Materials Testing Reactor	MTR
Boiling Water Reactor	BORAX	Naval Reactors Facility	NRF
Central Facilities Area	CFA	Organic Moderated Reactor Experiment	OMRE
Engineering Test Reactor	ETR	Safety Test Engineering Program	STEP
Experimental Beryllium Oxide Reactor	EBOR	Special Power Excursion Reactor Test	SPERT
Experimental Organic Cooled Reactor	EOCR	Test Area North	TAN
Experimental Breeder Reactor No. 1	EBR-I	Test Reactor Area	TRA
Experiment Breeder Reactor No. 2	EBR-II	Transient Reactor Test Facility	TREAT
Field Engineering Test Facility	FET	Zero Power Reactor No. 3	ZPR-III
Gas Cooled Reactor Experiment	GCRE		

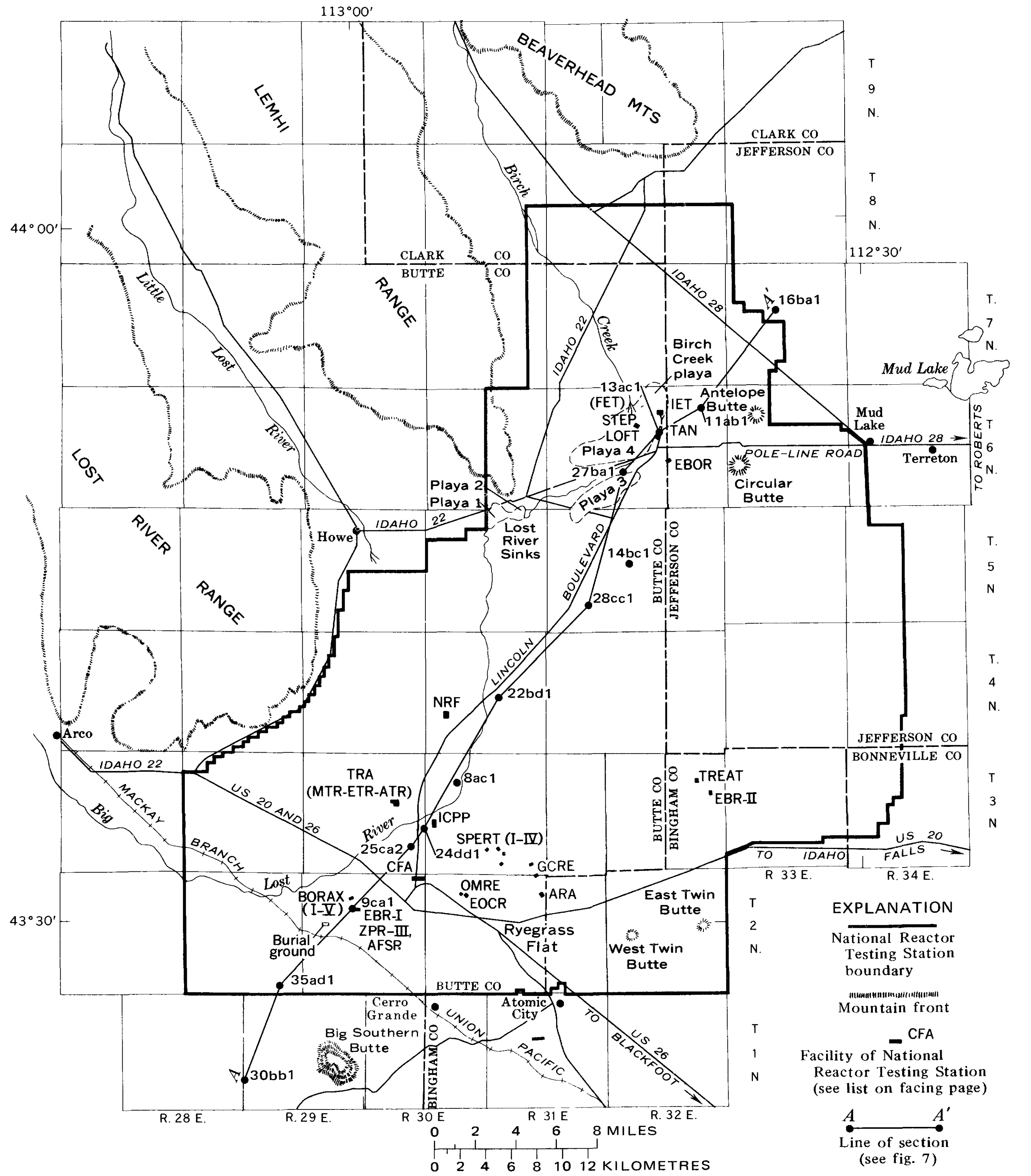


FIGURE 1.—Location of the National Reactor Testing Station and its facilities. Explanation on opposite page.

Test drilling aided the delineation, yielded information about the occurrence of ground water and the position and configuration of the water table, and provided a network of observation wells.

The NRTS is at the central-northern edge of the semiarid Snake River Plain in southern Idaho, adjacent to the southern foothills of the Lemhi and Lost River Ranges. (See fig. 1.) The station consists of about 900 square miles of so-called sagebrush desert and lava fields.

Locations of wells and test holes given in this report are cited by the well-numbering system used in Idaho by the U.S. Geological Survey. Wells are designated, for example, as 2N–31E–35c1. The well-numbering system is described in detail in Chapter A of this series (Nace and others, 1972); however, a brief explanation follows for use in this report.

The well-numbering system indicates the locations of wells within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of a number designate the township and range. The third segment gives the section number, and it is followed by two letters and a numeral that 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, beginning with the northeast quarter of each section. Within the quarter sections, 40 acre tracts are lettered in the same manner. Thus well 2N–31E–35dc1 is in the SW¼SE¼sec.35,T.2N, R.31E., and it is the first well visited in that tract.

Studies of the general ground-water geology of the station were under the general supervision of R. L. Nace, assisted by Morris Deutsch, R. O. Smith, P. T. Voegeli and S. W. West. Laboratory work in Idaho on geologic materials was done chiefly by I. S. McQueen and J. W. Stewart. Additional laboratory work on grain-size analysis, mineral composition, petrographic analysis, chemical analysis, and paleontologic examination was carried out at the Denver laboratory and at other laboratories of the Geological Survey in Washington, D.C.

SUMMARY OF LATE GEOLOGIC EVENTS

By R. L. Nace

The principal surface features of the NRTS area were produced by local geologic events comparatively late in the geologic history of the Snake River Plain. The plain as a whole, however, has a long and complex geologic history. The plain seemingly was formed during the Cenozoic Era, which began about 60 million years ago, accompanying and following large-scale crustal deformation in southern Idaho (Kirkham, 1931). Downwarping is indicated by the attitudes of Paleozoic sedimentary rocks in outcrops on the north and south flanks of the plain where many of the rocks dip toward the axis of the plain. Also, in central and western southern Idaho Cenozoic sediments in the trough and on its flanks dip toward the axis.

As early as middle Tertiary time, great volcanic eruptions occurred in the area now occupied by the Snake River Plain and in the mountains bordering the plain. A considerable thickness of tuff, welded tuff, and agglomerate accumulated during an episode of explosive volcanism. Silicic lava also flowed from vents on the plain, as is illustrated by silicic volcanic rocks in East Twin Butte and Big Southern Butte (pl. 1). Stearns and others (1938, p. 37) believed that the presence of basalt inclusions in the silicic rocks of the buttes indicates that basalt flows accompanied the silicic eruptions. The buttes are island (kipukas) of older volcanic rock in a "sea" of young basalt. West Twin Butte is composed of basalt which differs in its physical appearance from the younger basalt which has flowed around it. It is plausibly supposed that West Twin Butte, which rises a few hundred feet above the surrounding plain of Snake River basalt, is an inlier of pre-Snake River basalt, produced by the same eruptive episode that formed East Twin Butte and a small mass of siliceous rock that crops out between the Twin Buttes. Before eruption of the Snake River basalt, the heights of these buttes above the adjacent old lowland must have been at least 1,500–2,000 feet greater than their present height above the plain.

In parts of southern Idaho and eastern Oregon and Washington, extensive inland lakes were impounded; these lakes are partly contemporaneous with and partly follow the later stage of Miocene volcanism. Thus the Pliocene Epoch is well represented by thick accumulations of alluvial and lake beds in southwestern Idaho. Whether similar Pliocene lacustrine and alluvial deposition occurred in the part of the Snake River Plain here concerned is not known. Wells and test holes in some parts of the plain penetrate lake beds at depths exceeding 1,500 feet. Though these lake beds are underlain by basalt their age is not known. Lake beds older than the Snake River basalt, if present beneath the NRTS, undoubtedly are at greater depth.

The early episode of silicic and basic volcanism and lacustrine and fluviatile sedimentation was followed by a period of very active basaltic volcanism over the entire Snake River Plain. The eruptions were largely from local throat vents and Hawaiian-type volcanoes, with little explosive activity, but locally, as at Craters of the Moon National Monument, the eruptions were explosive enough at times to produce pyroclastic rocks.

The volcanic ejecta were consolidated to form the vast mass of Snake River basalt. This basalt is a complex sequence of interlocking flows and pyroclastic sediments; most of the flows are in layers only a few feet thick and occupy areas of a few tens or hundreds of square miles. Flood-type basalt flows, such as those covering thousands of square miles in the Columbia Plateau of Oregon and Washington, have not been found in the Snake River Plain.

Volcanism continued on the Snake River Plain into

Holocene time. The most recent eruptions near the NRTS were at Craters of the Moon, some 20 miles west of the station, and at Cedar Buttes, near the southern boundary of the station. Radiocarbon dates determined on charred wood obtained from Holocene lava in the vicinity of Craters of the Moon National Monument suggest that the last eruption may have occurred a little more than 1,600 years ago.

During numerous quiescent interludes in the volcanic episode, windblown, alluvial, and lake sediments were deposited locally. All types of materials—flow sheets, pyroclastic sediments, windblown sediments, and waterlaid sediments as well as cones, craters, and other features—were buried by later lava flows. The materials form an extremely heterogeneous accumulation. The aggregate thickness is not known.

Most of the basalt eruptions were relatively quiet outpourings of highly fluid pahoehoe lava. This lava tended to flow into the low-lying parts of the land and to flow around the higher land. Where the terrain was more regular, the pahoehoe flows spread rather evenly. Characteristically, however, owing to the sporadic and areally inequal mode of emplacement of the basalt and sediments, the terrain was irregular throughout the time of volcanic activity. Moreover, the warped and fractured surfaces of pahoehoe flows formed extremely complex microtopography (fig. 2). The less common flows of broken, blocky (aa) basalt formed extremely irregular terrain. Some eruptions that were mildly explosive produced extensive local deposits of cinders. During interludes between eruptions, sediments accumulated on some of the volcanic surfaces. Lake and alluvial beds were deposited in low areas, and windblown sediment formed a discontinuous mantle at all levels. The materials erupted or deposited on the highly irregular volcanic surfaces were correspondingly irregular in their thickness and distribution.

Some evidence indicates that the eruption of the Snake River basalt occurred during or after extensive regional faulting. The southern Lemhi and the Lost River Ranges were not studied for this report, but they seem to be basin-and-range-type mountains similar to those produced by block faulting in parts of Utah, Nevada, and southern Idaho. The fresh flows in the Craters of the Moon are adjacent to the mountain front west of Arco. The 10° monoclinal dip in West Twin Butte may indicate that the butte is a fault-block remnant. The more recent flows of the NRTS emanated from vents near Big Southern and Twin Buttes. Older and younger volcanic vents are roughly alined from Craters of the Moon to Big Southern and Twin Buttes and thence northward to Circular Butte. This alinement may be the present expression of a rift or line of weakness along which numerous vents were developed.

Most of the evidence that would disclose details of the regional and local geologic history of the Snake River Plain is buried by later basalt flows and sediments. Geologic investigations on the NRTS were too limited in areal coverage to disclose details of the late history of the plain. The following generalizations, however, are well supported.

Volcanic eruptions profoundly affected the surface drainage and ground-water hydrology of the Snake River Plain. Drainage from mountains immediately north of the Snake River Plain is generally southward, and presumably the principal streams once flowed across the area of the plain to join the Snake River somewhere north of its present position. The basalt eruptions probably are thickest along a central axis of the plain where they form a low divide along which many of the late eruptions occurred. The lava flows that spread southward forced the Snake River into a new course near the south edge of the plain. The flows that spread northward dammed back the streams debouching from the mountains. Lakes were impounded, but the supply of water was not sufficient for them to overflow and to cut outlets toward the south. Instead, the water sank into the ground.

Between Henry's Fork near Roberts and Malad River near Bliss, the Snake River Plain is not crossed by any streams that rise in the mountains to the north. Rather, the streams simply disappear by loss of water to the ground after they debouch onto the plain. For example, the Big Lost River, after reaching the plain near Arco, is deflected by basalt flows, follows an arcuate course southeastward to the NRTS, and then flows northward to playa basins in the northern part of the Station. The Little Lost River is blocked at the edge of the plain and terminates in a playa near Howe. Birch Creek follows a southward course directly from its valley into the Birch Creek playa, the lowest area on the central Snake River Plain.

Most of the water in the three streams noted above is diverted for irrigation, so the streams discharge only a small amount of water to the plain. Evidence is conclusive, however, that none of the streams ever discharged across the Snake River Plain after the emplacement of the latest lava flows.

Runoff from the mountains seemingly was considerably greater in the Pleistocene Epoch (ice age) than in the Holocene Epoch. Meltwater streams from alpine glaciers were heavily laden with sediment that was deposited on the flood plain of the Big Lost and Little Lost Rivers, the alluvial fan of Birch Creek, and many small alluvial fans along the flanks of the mountains adjacent to the NRTS. The alluvium probably contains a great deal of reworked glacial till and fluvioglacial outwash.

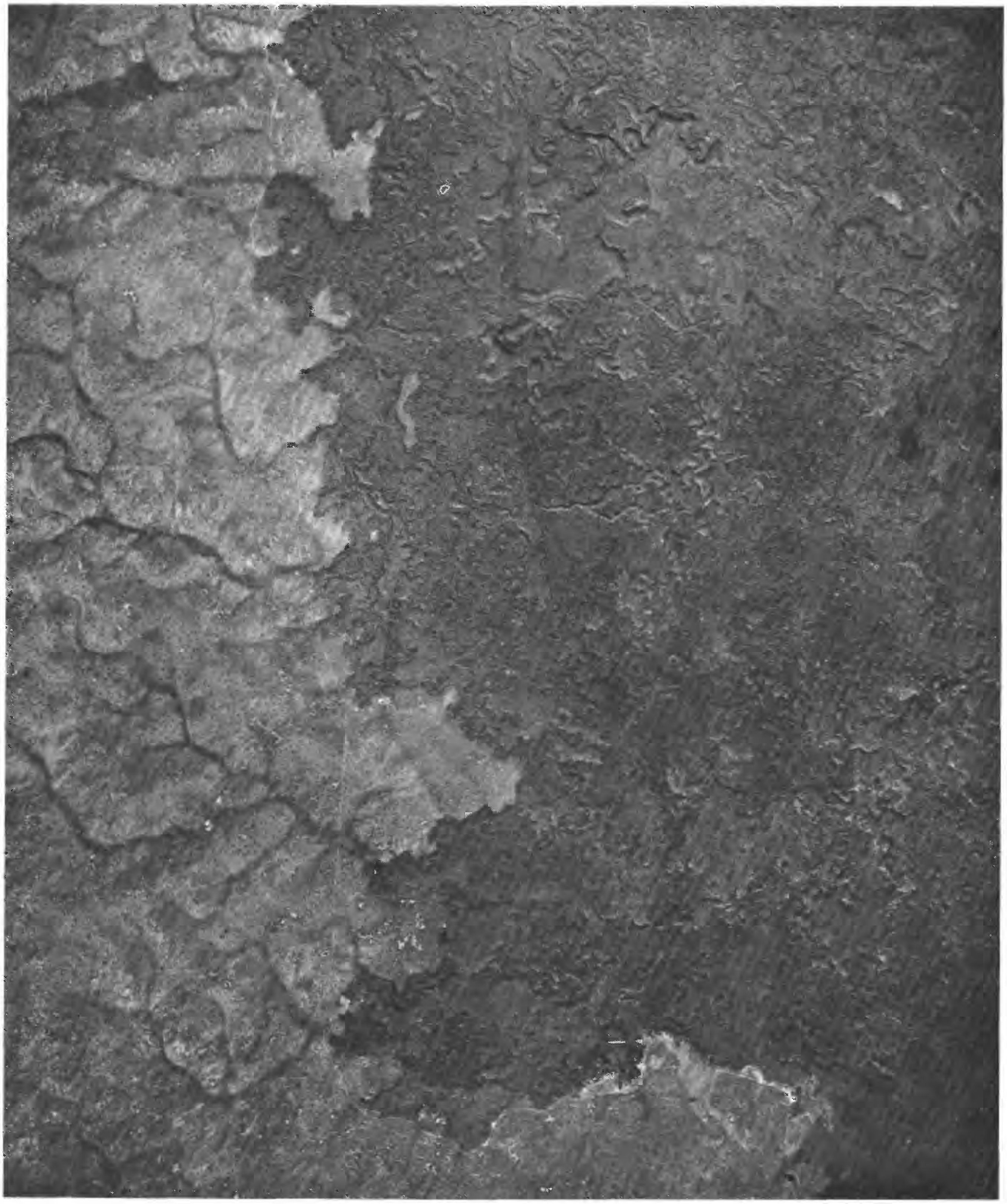


FIGURE 2.—Aerial photograph of intricate flow pattern of pahoehoe basalt several miles east of East Twin Butte. (Photograph by Aero Service Corp., scale 1 inch = about 2,000 ft).

At a late stage in the volcanic period, basalt flows impounded ancient Terreton Lake in the Mud Lake Basin. The lake, of which modern Mud Lake is a remnant, occupied a much larger area than Mud Lake and spread into the northern part of the NRTS. The maximum thickness of sediments that accumulated in ancient Terreton Lake is not known, but within the NRTS the greatest thickness disclosed by test drilling is 137 feet. Big Lost River, Little Lost River, and Birch Creek emptied into the lake and contributed fine-grained sediment that formed spits, hooks, and long curving bars, as well as bottom deposits.

After the arm of ancient Lake Terreton disappeared from the northern NRTS, part of its abondoned basin became the Birch Creek playa, which was occupied by an ephemeral lake fed by Birch Creek and the Big Lost River. The three Big Lost River playas and that of the Little Lost River also were ephemeral-lake basins.

Wind action has been strong in the NRTS and environs, probably from Pleistocene through Holocene time. Geologic evidence indicates that the prevailing winds have been from the southwest for a long time. Large parts of the plain are mantled by loessial deposits that seemingly were brought in from distant sources. Sand dunes are numerous in the northern part of the NRTS. Barchans (concentric dunes) at some places are as much as 25 feet high. Elongated low dunes occur in parallel rows up to several miles in length, and their long axes parallel the prevailing wind direction. These dunes are especially numerous south and southwest of Circular Butte. Irregularly shaped small patches of windblown sand occur throughout the NRTS, and wind action continues at the present time.

GEOLOGIC STRUCTURE

By R. L. Nace

The Snake River Plain has been called a great structural downwarp by Kirkham (1931), but the senior writer believes that the Snake River Plain is essentially a hugh graben that is downfaulted between complex horst blocks. These blocks are represented by mountain complexes to the north and south. The rocks within the graben obviously are downwarped somewhat, but the downwarping movement probably was incidental to the faulting rather than the principal movement. It is not necessary to review the downwarp theory for present purposes. If modified by inclusion of large-scale regional block faulting, the theory is acceptable and generally is agreeable with observed geologic features of the NRTS. The downwarp or graben is a trough formed in ancient crystalline rocks; it is buried beneath younger volcanic rocks and sediments having an aggregate thickness of some thousands of feet. The Snake River Plain, the floor of the modern trough, extends entirely across southern Idaho in a broad arc that is convex to the south. The principal earth movements that produced the trough occurred in remote geologic time. Some movement probably was continued into comparatively late time because volcanic and sedimentary rocks as young as Pleistocene have slight dips toward the axis of the trough. Successively older rocks reportedly dip at progressively steeper angles (Kirkham, 1931).

The depth through the Cenozoic volcanic rocks and sediments to the ancient rock floor is not known, but it has been estimated variously at 2,000–20,000 feet. The maximum certainly exceeds 2,000 feet. The greatest depth penetrated by drilling on the NRTS is 1,500 feet. The station is on the north flank of the trough and near the north edge of the region of basaltic lava eruptions. The basalt rests in angular unconformity on older rocks, including Tertiary volcanic rocks. Stearns, Crandall, and Steward (1938, p. 38) theorized (1) the presence of extensive masses of Tertiary volcanic rocks beneath the basalt, and (2) the existence of an ancient buried mountain range formed by those rocks beneath the area of Twin Buttes and Big Southern Butte. According to that theory, the buttes are the highest eminences on the buried mountains. Available evidence is insufficient either to confirm or to deny the theory.

Stearns, Crandall, and Steward (1938, p. 37) theorized further that the Twin Buttes may be on the upthrown southern block along a fault trending eastward. Direct evidence of the existence of such a fault has not been found, but if the fault is present, the faulting movement antedates late flows of the Snake River Group. So far as can be determined at this time, rocks within some hundreds of feet beneath the surface in the NRTS are not disturbed by significant faults or folds, and the general structure beneath the station is relatively simple. In detail, however, local geologic structures are complicated, though these structures express the mode of emplacement and adjustments of the basalt and sediments rather than earth movements. Local faults and shear zones have been noted but not mapped at many places.

Because regional geologic structures in and around the Snake River Plain have been little studied, only general facts and inferences are available. For example, the steep slopes on mountains adjacent to the north edge of the plain suggest a major fault or series of faults along the mountain front. Warm ground water commonly occurs in the vicinity of large probable block faults; warm water occurs in the vicinity of Arco and northeastward at Lidy Hot Springs in T. 9N., R. 33 E., Clark County, Idaho. Warm ground water also occurs southwestward in the vicinity of Carey, in Blaine County. The warm water may be associated with faults, and the faulting may have been contemporaneous with the downwarping of the Snake River Plain. Indeed, downward movement of the plains area may have been largely by faulting rather than by warping.

The most copious and numerous lava flows of Snake River Group seemingly originated along the central zone of the Snake River Plain. The plain was built up more rapidly than it was warped or faulted downward; hence, the highest areas of the plain generally are in its central part. Thus, although older flows may have acquired gentle regional dips toward the axis, younger flows commonly slope away from the axis toward the flanks. Locally, however, individual flows may slope in any direction. For that reason areal structural forms, if they exist, are not apparent from the attitudes of rocks exposed at the land surface.

GEOLOGIC MATERIALS AND THEIR SURFACE DISTRIBUTION

The sedimentary and igneous rocks that crop out in the NRTS are Paleozoic and Cenozoic in age. The Mesozoic Era is not represented. The principal characteristics and stratigraphic relations of the geologic units are summarized in table 1. The areal distribution of these geologic materials is shown on the geologic map (pl. 1).

The geologic map shows all the principal features and important details, but it does not show all the localized intricate outcrop patterns and minor overlaps of sediments. The boundaries between sedimentary units were drawn as specifically as possible but had to be generalized at some places.

From the standpoint of construction, less than 5 feet of sedimentary mantle (herein called overburden) on the basalt bedrock is generally considered to be undesirable. Therefore, where the overburden is known or believed to be less than 5 feet thick, or where it occurs only in a very small area, the sediments were not mapped. Where sediments overlap and feather out on basalt, the boundary between the two was drawn within the area covered by sediments. The map shows basalt where the overburden thins to a veneer. The thickness of overburden could not be determined merely by inspection, so many shallow auger holes were drilled to determine the thickness. In much of the area mapped as basalt, there are small patches of sediment more than 5 feet thick, and somewhat more extensive tracts are mantled by a thin overburden that is chiefly windblown. Inasmuch as the bedrock surface beneath the mantle of sediments is quite irregular everywhere, test boring would be required to verify the suitability of a given area as a construction site.

PALEOZOIC ROCKS

By Morris Deutsch and P. T. Voegeli

The oldest rocks exposed on the NRTS are Carboniferous in age and consist chiefly of limestone. Small amounts of siltstone, sandstone, and conglomerate may be present. The rocks crop out in an area of about 2 square miles on an eastern spur of the Lemhi Range in the northwestern part of the station (within T. 6N., R. 30 E.). Less than a fourth of a mile west of the station, along State Highway 22 between Arco and Howe, Paleozoic rocks crop out at several places in foothills of the Big Lost River Range. Presumably, these and other ancient crystalline rocks form a troughlike floor beneath the younger rocks in the Snake River Plain. The older rocks are related only indirectly to water-supply and operational problems on the NRTS, and for that reason they were not studied in detail.

The limestone is darkgray to gray, sandy, and has chert nodules. It is thickbedded and contains numerous solution cavities. Seams of secondary white calcite are common. The rock is quite hard and competent and seemingly is slightly metamorphosed. Fossils from the limestone indicate that the rock is Carboniferous in age. The most numerous fossils are corals and bryozoans. They were described by Helen Duncan – (written commun., Oct. 27, 1952) as follows:

Of the four collections submitted, two (Arco 3J and Arco Re2) consist exclusively of colonial corals. These fossils are types commonly found in the Upper Mississippian rocks of the region.

The remaining lots (Arco Rel and Arco 12J) contain bryozoans that are indicative of the Carboniferous period. Several elements in the assemblages suggest that the faunules may be of Pennsylvanian age, but additional evidence from other types of fossils is needed before such an assignment can be confirmed or denied.

Collection No. Arco 3J: NW¼SE¼NE¼ sec. 15, T. 5N., R. 30 E.; from highest point on ridge. Collector: P. T. Voegeli, 1952.

Lithostrotion (Diphyphyllum) sp.

Collection No. Arco Re2: NW¼SE¼NE¼ sec. 15, T. 6N., R. 30 E.; from highest point along ridge. Collectors: P. T. Voegeli, R. O. Smith, 1952.

Lithostrotion (Diphyphyllum) sp.

The corals in both lots belong to a single species of diphyphyllid *Lithostrotion*. These corals are characteristic of the Upper Mississippian limestone in south-central Idaho. Although larger and more diversified collections of fossils would be desirable to verify this stratigraphic assignment, determination of the rocks as Upper Mississippian is fairly certain.

Collection No. Arco Rel: SE¼ sec. 15, T. 6N., R. 30 E.; lower part of exposure of formation. Collectors: P. T. Voegeli, R. O. Smith, 1952.

Meekoporella? sp. indet.

TABLE 1.—*Summary of principal characteristics and stratigraphic relations of geologic units*

Geologic time: Era	Period or system	Series	Lithologic unit	Thickness (ft)	Physical character	Areal distribution	Origin
Cenozoic	Quaternary	Holocene	Windblown deposits	0–30	Fine sand and silt.	Mantles large areas in various parts of the NRTS.	Loess transported from distant sources. Dune sand derived from local sources.
			Playa deposits	0–10±	White to light-tan clay, silt, and sand. Chiefly poorly sorted clayey, sandy silt. Some is quite calcareous.	Covers about 22 square miles within the NRTS, in Big Lost River and Birch Creek playas and numerous scattered small playas.	Sediments derived chiefly from local unconsolidated older deposits.
			Slopewash and talus	0–25±	Slopewash is chiefly reworked windblown sediments; minor amount of detrital basalt. Talus of West Twin Butte is blocky, black to brown, generally dense basalt. Talus of East Twin Butte consists of fragments of welded tuff, pumice, and miscellaneous volcanic rocks, ranging in size from sand grains to boulders.	Slopewash occupies numerous depressions and sideslopes. Talus and slopewash occur together around the flanks of East Twin Butte and on the northern flank of West Twin Butte.	Slopewash is derived from windblown materials, local products of weathering, and erosion. Talus is derived from adjacent rock outcrops.
			Alluvium of the Big Lost River	0–120±	Consists chiefly of pebble and cobble gravel with varying amounts of silt and sand matrix. Coarsest in the southern part of the station; progressively finer-grained northward, becoming fine sand and silt.	Covers about 60 square miles within the NRTS, in a belt up to several miles wide on either side of the river.	Derived principally from mountains in the headwaters area of the Big Lost River outside of the Station.
			Alluvium of Birch Creek	0–32+	Sandy pebble and cobble gravel; about 80 percent by weight of gravel and 20 percent sand and silt matrix. Particles are rounded and are similar in composition to those in the alluvium of the Big Lost River. Thirty-two foot thickness penetrated at test well 7N–31E–34bd1.	Covers about 15 square miles in the extreme northern part of the NRTS, north of the Birch Creek playa.	Derived chiefly from the drainage area of Birch Creek outside the NRTS, on the eastern slope of the Lemhi Range and the western slope of the Beaverhead Range.
			Alluvial-fan deposits	0–100+	Noncompacted boulder and cobble gravel in a matrix of fine materials ranging in size from clay to coarse sand.	Covers about 16 square miles within the NRTS adjacent to foothill slopes near the western boundary.	Derived from the mountains, foothills, and basalt ridges adjacent to and on the NRTS.
			Black basalt	0–20±	Dark-gray to black pahoehoe. Texture ranges from aphanitic to porphyritic. Vesicles, crevices, joints and other fractures, and open contacts between layers are common.	Covers about 5 square miles in the extreme south-central part of the NRTS.	Extruded from vent near Cedar Butte.
			Lake beds and associated beach and bar deposits	0–140+	Sandy and clayey light-colored silt, with a few layers of relatively pure sand, silt, and clay.	Covers about 60 square miles in the northern NRTS. Thickness of 137 feet was drilled in test hole 6N–33E–26dd1.	Sediments derived principally from south slopes of the Beaverhead, Centennial, and Lost River Ranges, transported by the Big Lost River, Birch Creek, and intermittent local streams.
		Holocene and Pleistocene	Snake River Group (undifferentiated)	0–1, 500+	Chiefly olivine basalt. Texture ranges from glassy to porphyritic. Gray and black are the most common colors. Vesicles, crevices, joints, fractures, open contacts, and other voids are common. Basalt similar to that at surface was drilled at depth of nearly 1,500 feet in test well 4N–30E–6ab1. Locally includes interflow beds of windblown, lacustrine, and alluvial sediments.	Covers about 570 square miles within the NRTS, with outcrops in all parts of the station.	Extruded from cones and fissures, some within and some outside the NRTS.
			Unconformity				
	Tertiary	Pliocene? and Miocene	Basalt	0–900+	Basalt, blocky, black to brown, generally dense. Thickness at West Twin Butte is about 900 feet.	Covers about 1 square mile in West Twin Butte.	Extruded from depth in outcrop area.
		Upper Tertiary	Volcanic rocks (undifferentiated)	0–800+	Welded tuff, ash, pumice, and various types of flow rocks. Exposed thickness at East Butte is about 800 feet.	Occupies about 10 square miles at East Twin Butte and "Howe Point."	Flows originated from vents at or near the outcrop areas. Pyroclastic materials probably from same or related vents.
			Unconformity				
Paleozoic	Carboniferous		Paleozoic rocks	1,500+	Principally limestone. May include minor amounts of sandstone, siltstone, and conglomerate. Estimated exposed thickness in this vicinity exceeds 1,500 feet.	Occupies about 2 square miles in northwestern part of NRTS.	Deposited in an ancient sea.

Fistulipora sp. (laminar zoarium)
Tabulipora sp. (ramose zoarium)
Tabulipora sp. (laminar zoarium)
Rhombotrypella sp.
Fenestellid bryozoan (fragments)

Collection No. Arco 12J: NE¼SE¼ sec. 15, T. 6N., R. 30 E. Collector: P. T. Voegeli, 1952.

Tabulipora sp.(ramose zoarium)
Ascopora sp.
Rhabdomeson sp.

Thin sections were made of the bryozoans in the slabs numbered Arco Rel and Arco 12J. The two assemblages are not identical, but I believe they are of approximately the same age. From data now available on geologic ranges of certain bryozoan genera and their occurrences in faunas of western North America, I suspect that the material came from Pennsylvanian rocks, rather than Mississippian. So far as I know, *Rhombotrypella*, which is relatively abundant in collection no. Arco Rel, did not occur before Pennsylvanian time. The genus is one of the most common and characteristic bryozoans in the Pennsylvanian rocks of the West. *Rhabdomeson* occurs in the Lower Carboniferous of Europe and Asia. It has not been reported in the Mississippian of North America, but it is common in the Pennsylvanian. The *Ascopora* in collection no. Arco 12J is an advanced form, very close to the type species, from the Upper Carboniferous of Russia. Although these bryozoans suggest that the rock is Pennsylvanian, that is not definite. The Upper Mississippian limestone contains a diverse bryozoan fauna, but it has not been described or studied comprehensively. Possibly the Pennsylvanian faunal elements discussed above had their inception in the Upper Mississippian. Representative collections of other classes of fossils associated with the bryozoans might give evidence needed for finer discrimination, but the bryozoa alone do not permit an age assignment more precise than Carboniferous.

Near the south-quarter corner of sec. 15, T. 6N., R. 30 E. is a small outcrop of siltstone and sandstone overlying conglomerate. The sandstone is poorly bedded and friable, but the siltstone is well lithified. The conglomerate contains rounded to angular limestone pebbles firmly joined by calcareous cement. The outcrop is surrounded by undifferentiated Cenozoic volcanic rock. These sedimentary rocks may be part of the Paleozoic sequence in this area, but internal evidence of their geologic age was not found. They may be totally unrelated to the Paleozoic rocks and, so far as lithology is indicative, could be as young as Tertiary.

CENOZOIC VOLCANIC ROCKS

By Morris Deutsch and P. T. Voegeli

In the vicinity of the NRTS, volcanic rocks of Cenozoic age range in composition from basic to silicic. The chief rock types, welded tuff and silicic to basic flow rocks, have an aggregate outcrop area of about 10 square miles. Silicic flows and welded tuff crop out at East Twin Butte (in T. 2N., R. 32 E.), in a small area about three-fourths of a mile southwest of the butte (near the center of sec. 22, T. 2N., R. 32 E.), and in the foothill spur at "Howe Point" north of Big Lost River playa no. 1 (southwestern part of T. 6N., R. 30 E.). The volcanic rocks at "Howe Point" and East Twin Butte are believed to be late Tertiary in age, but the basalt of West Twin Butte may be Miocene or Pliocene (Stearns and others, 1938, p. 35). The Miocene(?) and Pliocene(?) age references are based on regional geologic history and on the relative ages of similar rocks at other localities.

The principal importance of the Cenozoic silicic volcanic rocks on the NRTS is their relation to groundwater development. The rocks are generally poor in water-bearing properties. Thus, though outcrops in the NRTS are small, their presence indicates that similar materials probably are buried by the Snake River Group in other parts of the NRTS. Their presence in a drillhole suggests that the base of the copiously water-bearing basalt of the Snake River Group has been reached. Criteria for the recognition of these rocks, therefore, are important.

SILICIC VOLCANIC ROCKS

The most abundant rock type in East Twin Butte, according to Stearns, Crandall, and Steward (1938, p. 36), is "trachyte." It has "phenocrysts of glassy feldspar (mainly orthoclase) and a few of quartz, in a fine-grained white groundmass composed mainly of orthoclase.* * *No vestige of any crater remains on the summit, but the character of the rocks indicates that they accumulated near the top of a volcano."

The most abundant flow rock in an outcrop half a mile southwest of East Twin Butte is slightly porous, purplish-gray, and aphanitic. C. S. Ross (written commun., Dec. 4, 1952) studied a thin section of this rock and reported as follows:

Has been devitrified and contains much calcite. Phenocrysts, seemingly of two generations, are present and also small indistinct spherulites. Coarse-grained tridymite is very abundant. The true character of the rock is obscured, but it appears to be a flow rock. Pumiceous and rhyolitic-appearing igneous rocks in lesser quantity occur in association with the above-described rock.

In the south flanks of the foothills of the Howe Point area in the northwestern part of the NRTS, the dominant type of Tertiary rock is welded tuff. Volcanic ash and flow rocks also are present. Their composition and physical condition are such that it is commonly difficult to distinguish between fine-grained compacted ash, flow rock, and welded tuff. Positive identification of some rocks was not made. Many of the specimens from the northwestern NRTS, however, are excellent examples of welded tuff. A thin section of light-gray aphanitic igneous rock was described by C. S. Ross (written commun., Dec. 4, 1952) as follows:

Specimen 7J. (center of sec. 35, T. 6N., R. 30 E.)
Contains a few large phenocrysts in a very fine-grained groundmass; abundant calcite has been introduced. There is little to go on in deciding its origin, but it could be either a flow rock or a fine-grained ash. There is no evidence that it is a welded tuff.

WELDED TUFF

Welded tuff is the dominant volcanic-rock type that crops out along the northwest edge of the station; it occurs in lesser amounts associated with silicic flow rocks in East Twin Butte. The welded tuff is in compact layers having a wide variety of colors, including reddish-brown, gray, purple, and white. The texture ranges from glassy to porphyritic. The fracture pattern and weathering features are quite varied. C. S. Ross (written commun., Dec. 4, 1952) studied the thin sections and provided the following descriptions:

Specimen 4J. (NE¼NE¼ sec. 2, T. 6N., R. 30 E.).
An unusually fine example of welded tuff. All the ash shards are perfectly preserved. Hematite and calcite are present.

Specimen 14J. (SW¼NE¼ sec. 35, T. 6 N. R. 30 E.)
Welded tuff with unusually coarse-grained shard structures and large included pumice fragments. The interspaces between glass fragments are filled with calcite. The pumice fragments also contain abundant calcite.

Specimens 1, 2, 5, 6 and 8J, respectively (NW¼SE¼SE¼ sec. 15. T. 6 N., R. 30 E., SW¼NW¼SW¼ sec. 14, T. 6 N., R. 30 E. NE¼NW¼NE¼ sec. 3, T. 6 N., R. 30 E., center sec. 35, T. 6 N., R. 30 E., and center sec. 22, T. 6 N., R. 30 E.)
Group of specimens is considered together. Only 5J has well-preserved structures. This specimen is made up of devitrified shards, which show very marked stretching. This is so extreme that it resembles a flow rock. However, there is discontinuity of the structures and greatly flattened V- or Y-shaped forms are abundant. These are fully diagnostic of stretched welded tuffs. Specimens 1, 5, and 6J have been devitrified with the development of very coarse-grained secondary products, and later calcite has been introduced. Taken by themselves, the identification as welded tuffs would be a little difficult, but taken together with 5J, there seems to be no doubt that these are greatly stretched, devitrified welded tuffs. In 2J the original structures have been destroyed. However, the rock retains a laminated structure, and it probably was also a welded tuff. In all these sections tridymite, some of it in quite large crystals, is very abundant.

Two specimens of welded tuff were studied in this section by R. A. Bailey (written commun., Oct. 20, 1953) who reported as follows:

Specimen CP–12. (NE side of East Twin Butte, NW¼NW¼ sec. 13, T. 2 N., R. 32 E.)
Rhyolitic welded tuff. Devitrified welded tuff containing phenocrysts of high-temperature quartz, sanidine, plagioclase, and oxyhornblende in a groundmass of radiating and spherulitic intergrowths of cristobalite, potash feldspar, and minor plagioclase, with accessory zircon and magnetitie. Occasional collapsed and devitrified pumice fragments show marked differential compaction around some of the phenocrysts. Plagioclase phenocrysts are sodic oligoclase, a few of which have vermicular intergrowths of quartz. The oxyhornblende phenocrysts are pleochroic-green to greenish-brown, have unusually high birefringence, and extinction angles ranging from 0° to 20°. Commonly they have reaction rims of magnetite, now partly or completely altered to hematite, and large grains of zircon are commonly associated with them.

Specimen CP–13. ("Howe Point," SW¼NE¼ sec. 35, T. 6N., R. 30 E.)
Rhyolitic welded tuff. Extremely fine-grained rock originally composed almost entirely of ash and rare phenocrysts of sodic oligoclase. The ashy groundmass is now completely devitrified to a fine intergrowth of cristobalite and feldspar, and fine-grained secondary calcite has been introduced in streaks and blotches. Wedge-shaped twins of tridymite occur as encrustations on cavity walls. Small reddish-brown crystals of oxyhornblende with magnetite reaction rims are in the groundmass.

RHYOLITE

For comparison, a specimen was collected from Big Southern Butte. Concerning this , R. A. Bailey (written commun., Oct. 20, 1953) reported as follows:

Specimen CP–11. (Big Southern Butte, SE¼NE¼ sec. 16, T. 1N., R. 29 E.)
Rhyolite. This rock is a fine-grained granular aggregate of very small crystals of quartz, potash feldspar, and plagioclase, with accessory zircon and magnetite. Quartz occurs as rare phenocrysts and also as abundant small interlocking grains in the groundmass. Potash feldspar occurs as small irregular grains interlocking with the quartz and also as small lathlike crystals. The plagioclase is probably oligoclase and is in small polysynthetically twinned laths. The marked interlocking texture and complete crystallinity suggests that this is a flow rock which crystallised from a gas-rich lava. There is no evidence in this section to suggest that the rock is of pyroclastic origin. The apparent bedding in the hand specimen probably is flow-banding.

VOLCANIC ASH

Beds of volcanic ash occur in several small areas along the foothills in the northwestern part of the NRTS. Some ash beds are easily recognized, but those that are directly associated with welded tuff are commonly difficult to identify in the field. Beds that are unquestionably volcanic ash are white to light gray, compact, and fairly resistant to weathering. Near the east quarter corner of sec. 15, T. 6 N, R. 30 E. a layer of white to light-gray ash rests unconformably on Paleozoic limestone.

BASALT

Tertiary basalt is relatively rare on the NRTS; it is present only in West Twin Butte in a tilted block that possibly was raised by faulting before emplacement of the Snake River Group. The texture is ophitic, like much of the Snake River basalt, but the rock differs from the basalt of the Snake River Group in that its feldspar is more abundant and its pyroxene is nearly colorless. Secondary calcite is abundant. Thin sections show "abundant feldspar, olivine, and pyroxene, with a little interstitial, partly recrystallized brown glass. Abundant calcite has filled vesicles and replaced [part of] of the glass. The minerals are all very fresh." (Stearns and others, 1938, p. 37)

QUATERNARY VOLCANIC ROCKS

By R. L. Nace and P. T. Voegeli

Basalt is exposed in about three-fourths of the NRTS area. Many of the younger basaltic rocks originated from vents within the station area. For example, Circular and Antelope Buttes, in the northeastern part of the station, were sources of basalt flows covering about 20 square miles in the northeastern part of the area. On the other hand, much of the basalt originated from sources outside the station, such as the flows that almost completely cover the southern row of townships. About 10 square miles in the northwestern corner of the station is covered by basalt flows from sources immediately northwest of the station.

SNAKE RIVER GROUP

Basalt of the Snake River Group typically is gray to black, bluish black, brown, and brick red and ranges from dense to porous and is highly vesicular. It occurs in relatively thin interlocking flows, most of which are of the smooth, ropy type of basalt (pahoehoe, fig. 2), but a few are rough and blocky (aa).

The basalt characteristically occurs in interlocking layers of pahoehoe a few inches to a few tens of feet thick. The layering is conspicuous. The thicker flows may have well-developed columnar joints in areas where lateral compressional stresses are released. The flows also are commonly fractured and creviced as a result of movement of the fluid interior of flow sheets after a solid crust was formed. Many flows are only a few feet thick and cover a few square miles or less. Cinders, scoria, and basaltic glass are prominent locally.

Although basalt makes up the chief rock type of the Snake River Group, the formation also includes interflow beds of windblown, lacustrine, and alluvial sediments. The relative volume of these is small, but they strongly affect the hydrology of the basalt and the construction and performance of wells.

The texture of the basalt ranges from glassy through aphanitic to porphyritic; extensive beds of cinders and scoria also occur. The variations of texture express a wide range of conditions of origin, extrusion, and emplacement. Considerable variation in texture occurs even within individual flows. For example, the bases of many flows are glassy to fine grained and minutely vesicular; the central parts may be coarse grained and coarsely vesicular with sparse vesicles; and the uppermost part of the flow may be aphanitic or very fine grained and finely vesicular. Vesicles in the basalt were formed by gas bubbles that were trapped in the lava as it congealed, and most flows are at least slightly vesicular. Within a few feet below the land surface or below buried ancient land surfaces, vesicles in the rock commonly are filled with secondary calcite leached from overlying sediments and redeposited to form amygdules.

Basalt flows of Snake River type may have been extruded as early as late Pliocene time and possibly as late as historical time, but the main mass of basalt of the Snake River Group is Pleistocene in age. Some local flows have been separately named in parts of the Snake River Plain (Stearns and others, 1938; Malde and Powers, 1962), but for the purposes of this report all upper Cenozoic basalt is here called the Snake River Group. A flow of "black basalt", seemingly quite recent in age, emanated from Cedar Butte and covers about 5 square miles in the south-central part of the station area. This was mapped separately as "black basalt," and the main mass of the Snake River Group was mapped as "undifferentiated basalt" (pl. 1)

BASALT PROVINCE OF THE SNAKE RIVER PLAIN

The petrographic province of the Snake River Plain consists chiefly of olivine basalt. This petrographic province is distinct from that of the Columbia River Plateau, which is also a basalt province, but its basalt is older and differs in mineralogic and physical properties. The fact of the difference is emphasized here because in much published literature it is asserted that the two areas constitute a single petrographic province (cf., Turner and Verhoogen, 1951). The distinction has practical value because the two types of basalt are quite unlike in their water-bearing properties and undoubtedly differ in their ion-exchange capacities. Owing to these differences, problems of construction engineering, ground-water development, liquid-waste disposal, and other phases of the atomic energy industry differ in the two petrographic provinces.

Detailed comparison of the Snake River Group and the Columbia River Group is beyond the scope of this report. The two are similar in basic mineralogic and chemical composition (as are all basalts), but the Snake River Group is comparatively rich in olivine and its minerals are fresh and practically unaltered. The Columbia River Group is appreciably altered at most places. Although its plagioclase and augite seem fresh and little altered, its olivine is altered to green chloritic material and magnesium(?) carbonate (Charles Milton, written commun., Oct. 11, 1949). Vesicular cavities in the rock are lined with secondary minerals, commonly carbonates. The abundant alteration products greatly affect the physical, chemical, and hydrologic properties of the basalt.

The Columbia River rock is a so-called flood basalt ("plateau basalt") formed from enormous volumes of lava that was highly fluid. Individual flows erupted from fissures and inundated hundreds to thousands of square miles. Thus, individual flows have extensive continuity and can be correlated for considerable distances, even where they have been disturbed by folding and faulting. The Snake River Group lava flows, on the other hand, poured from local vents and covered relatively small areas. Volcanic cones and domes are common, and many of the layers have strong original slopes with a pronounced lineation of the rock structures. Finally, the Snake River Group on the whole is an excellent aquifer, whereas many of its interflow sediments are aquicludes. The Columbia River Group, on the other hand, is a comparatively poor aquifer at many places, and many of its layers are aquicludes; interflow contact zones are the main sources of ground-water in the Columbia River Group area, and some of the interflow sediments are good aquifers.

PETROGRAPHY OF THE BASALT

In this report the term, basalt, is used in the common sense, denoting dark-colored eruptive rock, composed essentially of calcic plagioclase and pyroxene, in which the constituent grains other than phenocrysts are too small to be identified with the naked eye and mostly too small to be recognized under the hand lens. Magnetite is a common accessory mineral. Olivine and rarely biotite or hornblende may be present. Rock containing an appreciable percentage of olivine is called olivine basalt, and this is the principal rock-type in the Snake River Group.

In color, fabric, density, and other megascopic properties the basalt is diverse, but in mineral and chemical composition it is remarkably uniform. Petrographic study has been made of thin sections from only 14 specimens, but these were selected to represent the principal types of basaltic material in the vicinity of the station. The mineralogic uniformity of the specimens indicates that they originated from a common magma reservoir. The megascopic physical differences result chiefly from differences in the place and method of eruption and emplacement and in the conditions under which solidification occurred.

The common basalt on the NRTS is estimated to contain 35–60 per cent of calcic plagioclase, 25–50 percent pyroxene, 5–10 percent olivine, and small amounts of accessory magnetite and ilmenite. The plagioclase occurs in lathlike crystals and anhedral grains. Most of the pyroxene is augite or titanaugite. Some flows contain enough olivine to give fresh rock surfaces a greenish cast. Iddingsite is a common reaction-rim alteration product of olivine. Porphyritic basalt with megascopically recognizable phenocrysts of plagioclase and olivine is fairly common. The phenocrysts of plagioclase generally are subhedral or euhedral multiple twins and typically are colorless, but reddish crystals occur in some of the reddish and purplish basalt. Most of the mineral grains are fresh appearing and essentially unaltered. Some specimens have a stony groundmass. Glassy zones are common. Secondary mineralization in the basalt is uncommon, except where calichelike deposits fill vesicles near the land surface. In some flows the vesicles are drusy and are lined with crystals, chiefly feldspar. Zeolite minerals are rare.

The following petrographic descriptions of representative basalt samples from the Snake River Plain were prepared by Charles Milton (written commun., Oct. 11, 1949) and R. A. Bailey (written commun., Oct. 20, 1953) from thin-section studies. Specimens are from near the center of sec. 9, T. 2N., R 29 E.:

Core No. P–2; depth, 69 feet: olivine-augite basalt.

Hand specimen: Porous gray basalt contains feldspar phenocrysts about one-eighth of an inch long and a fresh-appearing ferromagnesian mineral. Pores much smaller than those from core at depth of 84 feet.

Thin section: Holocrystalline olivine basalt or diabase. Constituent minerals are white calcic plagioclase, purplish augite, pale-green olivine, and black magnetite, the relative abundance of which is in the order named. The minerals are fresh and unaltered except for slight alteration of some olivine to iddingsite. There are no secondary minerals.

Core No. P–1; depth, 84 feet: olivine-augite basalt.

Hand specimen: Highly porous basaltic rock with about 15 percent pore space. Pores are as much as one-fourth of an inch wide and are distributed throughout the core. The rock is purplish-brown and contains white feldspar laths up to ⅛-inch long in a stony groundmass. There are no secondary minerals in the pores.

Thin section: Mineralogy same as in core no. P–2. The larger vesicles are lined with black, poorly crystallized, almost glassy, ferruginous material that evidently was produced by reaction of gas in the vesicles with the magma.

Core No. P–5; depth, 25 feet: olivine basalt.

Hand specimen: Resembles core no. P–1. Most pores less than 1/32–inch wide but a few are more than ½–inch.

Thin section: There is much black glassy material in which olivine and plagioclase feldspar are embedded. The glass may have the chemical composition of the augite which failed to crystallize. Olivine is abundant, but augite is very scarce. Presumably this rock cooled and consolidated too rapidly to permit crystallization of the more fluid part of the magma.

Core No. D–3; depth, 28 feet: olivine-augite basalt.

Hand specimen: Moderately porous light-gray holocrystalline even-grained basalt. Pore space is about 5 percent or less of the mass.

Thin section: Practically indistinguishable from core no. P–2, but olivine is less abundant.

Specimens from various parts of NRTS and vicinity. (Mineral percentages estimated from visual inspection of thin section.)

Specimen CP-8. Rock from cliff in wind gap, NRTS, NE¼SE¼ sec. 13, T. 2 N., R. 28 E: olivine-titanaugite basalt.

The rock contains olivine phenocrysts in a coarsely crystalline matrix of randomly oriented calcic labradorite (An 68) laths, interstitial titanaugite, and ilmenite. Magnetite and apatite are minor constituents. Olivine constitutes about 10 percent of the rock, plagioclase about 60 percent, titanaugite about 25 percent, and ilmenite about 2 percent. The titanaugite is practically unaltered. The apparent order of crystallization was (1) magnetite, (2) olivine, (3) plagioclase, and (4) titanaugite and ilmenite.

Specimen CP–10. Rock from NE¼NE¼ sec. 26, T. 5 N., R. 33 E.: olvine-titanaugite basalt.

The rock is vesicular and consists chiefly of olivine, labradorite (An 62–68), and titanaugite. Most of the titanaugite has been altered to a acicular, brown clinopyroxene and ilmenite. About 5 percent of the rock is olivine, 40 percent is plagioclase, and the rest is a network of acicular climopyroxene and ilmenite plates with scattered remnants of titanaugite. Some of the vesicles are lined with very fine needles of an unidentified zeolite, possibly thompsonite.

Specimen CP–9. Rock from road cut near Circular Butte, north eastern NRTS, SE¼NW¼ sec. 18, T. 6 N., R. 33 E.: porphyritic olivine-titanaugite basalt.

This rock is vesicular and consists of large phenocrysts of olivine and plagioclase in a groundmass of olivine, plagioclase, and altered titanaugite. The olivine and plagioclase phenocrysts commonly are associated in inter-penetrating clusters, and some of the olivine occurs as small, optically continuous blebs in the plagioclase, suggesting that the two minerals crystallized simultaneously. The plagioclase in the phenocrysts is calcic labradorite (An 68) and constitutes about 15 percent of the rock. In the groundmass olivine and plagioclase are in small skeletal crystals. The plagioclase in the groundmass is less calcic than that in the phenocrysts and ranges from An 54 to An 58. Titanaugite, much altered to acicular, brown clinopyroxene and ilmenite plates, fills the interstices between the olivine and plagioclase crystals. The groundmass is about 80 percent of the rock, of which about 1 percent is olivine, 40 percent plagioclase, 10 percent titanaugite, and 30 percent acicular, brown clinopyroxene and ilmenite.

Specimens from other parts of the Snake River Plain.

Specimen CP–3. Sand Springs basalt from cliff face on Blue Lake road, sec. 28, T. 9 S., R. 17 E.: olivine-titanaugite basalt.

[Note: The Sand Springs Basalt is a pahoehoe flow on the north side of the Snake River in the southern parts of Jerome and Gooding Counties.]

Finely vesicular rock containing olivine phenocrysts in a groundmass of olivine, bytownite (An 72–76), and titanaugite, with accessory apatite and magnetite. Olivine constitutes about 10 percent of the rock, plagioclase about 60 percent, and titanaugite originally about 25 percent. As in specimen CP–2, much of the titanaugite is altered to acicular, brown clinopyroxene and ilmenite. The apparent order of crystallization was (1) magnetite, (2) olivine, (3) plagioclase and (4) titanaugite. A few partly reacted xenocrysts of andesine are present.

Specimen CP–4. Black pahoehoe basalt from cliff face adjacent to U.S. Highway 30, south side of Snake River about three-fourths mile upstream from Thousand Springs, NE¼SE¼ sec. 18, T. 7 S., R. 14 E.: olivine-titanaugite basalt.

Very similar to specimens CP–2 and –3. The main constituents are olivine, plagioclase, and titanaugite, with accessory apatite and magnetite. Olivine constitutes about 10 percent of the rock and is variable in grain size. The plagioclase, constituting about 50 percent of the rock, is mostly calcic labradorite (An 68), but a few grains of bytownite (An 74) are present. Titanaugite, constituting about 30 percent of the rock, is pleochroic, brown to purplish brown, and occurs both as large and small irregular grains. The larger grains commonly completely surround randomly oriented plagioclase laths. The titanaugite shows considerably less alteration to ilmenite and brownish clinopyroxene than in specimens CP–2 and –3. The apparent order of crystallization was (1) magnetite, (2) olivine, (3) plagioclase, and (4) titanaugite.

Concerning the nine basalt specimens, R. A. Bailey (written commun., Oct. 20, 1953) stated that all are mineralogically very similar and have undergone similar sequences of crystallization and lateration. Olivine, titanaugite, and plagioclase (ranging from calcic labradorite to sodic bytownite) are present in nearly all the rocks. The chief differences are in the texture and degree of alteration. The general sequence of crystallization was (1) magnetite, (2) olivine, (3) plagioclase, and (4) titanaugite and ilmenite. In all specimens except CP–9, olivine forms the only phenocrysts. Most of the plagioclase and practically all the titanaugite apparently crystallized after the lava was erupted and after the flow movement stopped because these minerals show no flowage alinement and commonly are intergrown. In most of the specimens, titanaugite is partly or almost completely altered to a network of acicular, brown clinopyroxene and plates, granules, and dendritic growths of ilmenite. This alteration was deuteric and probably consisted of recrystallization of titanaugite with the separation of TiO_2 to form ilmenite.

BLACK BASALT

Black basalt of Holocene age covers about 5 square miles in the extreme southern central part of the station area. It consists of a single flow that originated from a vent near Cedar Butte. The range in texture is similar to that in undifferentiated basalt of the Snake River Group, but the average color is darker—bluish black to black. Other flows occur at Craters of the Moon National Monument, near Wapi (about 60 miles southwest of East Twin Butte), and elsewhere on the Snake River Plain. Cinder beds at Craters of the Moon and elsewhere are associated with the black basalt.

PETROGRAPHY OF THE BASALT

The basalt has essentially the same mineralogic composition as the undifferentiated basalt of the Snake River Group. Petrographic descriptions from thin sections were prepared by R. A. Bailey (written commun., October 20, 1953.

Specimen CP–1. Black basalt from SE¼SE¼ sec. 9, T. 3 S., R. 18 E.: olivine-augite basalt.

The rock consists mainly of olivine, brownish augite, and plagioclase (An 68–72) in a nearly opaque matrix of fine-grained unidentified minerals. The only phenocrysts are olivine, and they are rare. Plagioclase is in small, randomly-oriented laths which commonly are included within larger irregular grains of augite. The augite is pale brownish, faintly pleochroic, and may be titaniferous. Magnetite occurs as inclusions in olivine. The apparent order of crystallization was (1) magnetite, (2) olivine, (3) plagioclase, and (4) augite.

Specimen CP–2. Minidoka basalt from cliff face about ⅜ mile downstream from Minidoka Dam on north side of Snake River, NE¼NE¼ sec. 2, T. 9 S., R. 25 E.: olivine-titanaugite basalt.

Specimen CP–5. Rock from cinder cone at Craters of the Moon National Monument, SW¼NW¼ sec. 35, T. 2 N., R. 24 E.: basaltic cinders.

Composed largely of brown basaltic glass with refraction index of 1.590 ±0.002.

Specimen CP–6. Rock from top of cinder cone at Craters of the Moon National Monument, SW¼NW¼ sec. 35, T. 2 N., R. 24 E.: basaltic clinkers.

Composed largely of brown basaltic glass with refraction index of 1.590±0.002.

Specimen CP–7. Rock from Craters of the Moon National Monument, SW¼SE¼ sec. 35, T. 2 N., R. 24 E.: olivine-augite basalt.

Very dense fine-grained basalt containing small skeletal crystals of olivine and skeletal microliths of labradorite (An 50–54) in a nearly opaque groundmass of dusty oxide, clinopyroxene granules, and brown glass. The clinopyroxene probably is titanaugite, but the grains are too small for the determination of optical properties.

CHEMICAL COMPOSITION OF THE VOLCANIC ROCKS

Oxygen is the most abundant element in igneous rocks, whose chemical compositions commonly are expressed in terms of various oxides. According to Turner and Verhoogen (1951, p. 51–52), the percentage, by weight, of silica in typical volcanic rocks ranges from 35 to 75. Based on silica content, rocks commonly are grouped in four general categories: acidic (>66 percent), intermediate (52–66 percent), basic (45–52 percent), and ultrabasic (<45 percent). The amount of alumina, which ranges from 12 to 18 percent in most volcanic rocks, is highest in those of intermediate composition. Iron oxide, magnesia, and lime together constitute about 20–30 percent of basic rock. The amount of sodium oxide commonly is less than 4 percent in basic rocks, and potassium oxide ordinarily is less than 1 percent.

TABLE 2.—*Chemical composition of basalt from southern Idaho*
[From published records of the Geological Survey]

Constituent	1	2	3
SiO_2	51.14	45.17	48.47
Al_2O_3	13.95	10.02	16.07
Fe_2O_3	2.15	3.55	4.12
FeO	12.97	5.03	7.47
MgO	2.21	19.84	5.96
CaO	6.56	8.57	4.84
Na_2O	3.59	3.11	2.43
K_2O	2.33	1.61	1.41
H_2O+	.22	1.58	4.63
H_2O-	.12	.69	2.30
TiO_2	2.41	.54	1.51
P_2O_5	1.59	.28	.44
MnO	.44	.13	.23
ZrO_2	.12	------	------
Cl	Trace	------	------
F	.10	------	------
FeS_2	.15	------	.24
NiO	Trace	------	Trace
BaO	.25	.07	.03
SrO	Trace	.06	Trace
V_2O_3	Trace	------	------
CO_2	------	None	------
S	------	.06	------
Cr_2O_3	------	.11	------
Cw	------	------	Trace
Sum	100.30	100.42	100.15

1. Basalt: Craters of the Moon National Monument. Big Cinder Butte, sec. 13, T. 1 N., R. 24 E.
2. Nephelite basalt: Fort Hall Indian Reservation, Idaho.
3. Basalt: Blackjack Mine, Silver City, Idaho.

TABLE 3.—*Average composition of some volcanic rocks*
[Percent, by weight. After Daly, 1933]

Constituent	Rhyolite	Trachyte	Andesite	Phonolite	Basalt
SiO_2	72.77	60.68	59.59	57.45	49.06
TiO_2	.29	.38	.77	.41	1.36
Al_2O_3	13.33	17.74	17.31	20.60	15.70
Fe_2O_3	1.40	2.64	3.33	2.35	5.38
FeO	1.02	2.62	3.13	1.03	6.37
MnO	.07	.06	.18	.13	.31
MgO	.38	1.12	2.75	.30	6.17
CaO	1.22	3.09	5.80	1.50	8.95
Na_2O	3.34	4.43	3.58	8.84	3.11
K_2O	4.58	5.74	2.04	5.23	1.52
H_2O	1.50	1.26	1.26	2.04	1.62
P_2O_5	.10	.24	.26	.12	.45
Total	100.00	100.00	100.00	100.00	100.00

Only a few chemical analyses have been made of basalt and related rocks from southern Idaho. The results of three such analyses (Washington, 1917), shown in table 2, represent rock from widely separated places in southern Idaho. The average chemical composition of several classes of volcanic rock is shown in table 3.

ROCK STRUCTURES IN BASALT

Basalt flows have individual and collective internal structures that strongly affect their capacity to store and transmit water. These structures are important also in relation to construction engineering. The basalt is the only important aquifer on the NRTS, and it is the sole type of bedrock for a considerable depth beneath practically all the station. The principal internal structures of the basalt flows are layering, partings, joints and other fractures, and various types of natural voids. These structures differ. in the various types of basalt—pahoehoe, aa, pillow lava, scoriae, and cinders.

LAYERING

Extrusion of lava in successive flows which solidified individually caused conspicuous layering. The thickness of flows exposed at various places in the Snake River Plain ranges from a fraction of a foot to about 50 feet. The area covered by individual flows is relatively small. Very few have been measured, but a representative flow probably covers about 50–100 square miles. Many are much smaller, and some are much larger. The area of some of the more recent flows may be as little as 10 square miles. Most of the flow layers had appreciable original dips, and successive flows from separate eruption centers overlapped. Hence, a vertical section through the rocks discloses a complex of interlocked layers. Commonly there are interflow layers of cinders and of windblown, lacustrine, and alluvial sediments.

PARTINGS

Partings in volcanic rocks consist of two types: (1)

Separation planes between flows and flow units, and (2) separation planes between parts of the same flow. The two types are not always distinguishable.

The heat in lava flows was not sufficient to melt adjacent frozen lava and cause fusion with successive flows. On the contrary, the bases of new flows cooled rapidly, adjacent to their contacts with the cold substratum, leaving a well-defined parting plane. In some places chilling was so rapid that glassy, vesicular, or granulated rock formed at the bases of flows.

Some lava eruptions seemingly were pulsational with successive waves of extrusion. The surfaces of individual waves often had time to harden between pulses, however, and partings developed between the successive waves. The small layers that thus make up an essentially single flow have been called flow units. The partings between flow units vary from indistinct to distinct.

Partings occur also within what seem to be single flows. Some of these may have formed in the following manner: A thick lava flow was emplaced; it developed a basal and surface crust some inches or feet thick while the interior was still liquid. Thereafter, hydraulic pressure breached the congealed front of the lava flow and allowed the interior fluid to drain out. The surface crust thus was lowered to touch the basal crust, but a parting between flows and flow units.

JOINTS AND OTHER FRACTURES

Relatively slow cooling of solidified lava flows produces characteristic fracture joints. Shrinkage of the rock during cooling set up tensional forces that were

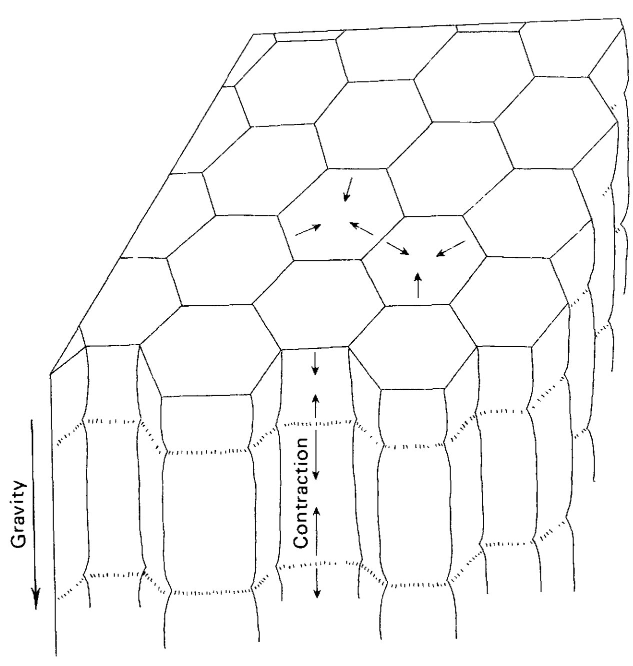


FIGURE 3.—Vertical and incipient horizontal joint systems in basalt.

relieved by tension joints (fig. 3). Horizontal tension produced vertical joints that radiate from more or less evenly spaced centers; three joints commonly originate at each center. As contraction continued, fractures from adjacent centers intersected and divided the basalt layer into polygonal columns. Ideally, these columns are hexagonal prisms, but in the Snake River Group they are commonly imperfect. Vertical tension in cooling lava flows was compensated largely by gravitational settling, but residual tension sometimes caused incipient horizontal fracturing. The horizontal fractures rarely completely transect the columns.

Miscellaneous joints and fractures also developed in cooling lava flows. Some were caused by rupture of the solid shell of a cooling flow when movement in the still-fluid or plastic interior caused differential movement of the crust. Fracturing commonly occurred when the crust of a moving flow was thrown into ridges in which the bending caused fracturing. A common feature along the front or edge of a flow is a curving to a sinuous, long, narrow ridge having its long axis normal to the direction of flow. These ridges, herein called border swells, characteristically have an axial fracture along their entire crest. The fractures are as much as 6 feet wide at the top and become narrow downward, but they extend downward through a substantial thickness of the flows. In those observed the fractures were partly filled with loess, and the full depth was not determinable. Border swells also are broken by numerous transverse tension fractures; these tension fractures probably are caused by spreading of the flow front. The origin of border swells is not established. Presumably when a flow was emplaced and the front became static, the frontal crust curved smoothly forward and downward. If fluid lava were bled off from the interior of the flow through a rupture, the main crust area would be lowered, and the border swell would develop as its crust settled over a congealed core. Lowering of the main area of crust might occur also by loss of volume of the liquid lava through evolution of gas and shrinkage during cooling.

MISCELLANEOUS NATURAL VOIDS

Natural voids in basalt range in size from minute pores between mineral grains to lava tubes with a volume of many thousands of cubic feet. Much basalt is quite porous, owing to the voids left between interlocking tabular and prismatic mineral grains. These types of openings have little importance to waste-disposal operations on the NRTS except that they provide effective area on which ion exchange and adsorption can occur.

Voids left by gas bubbles in cooling lava are called vesicles. Vesicles range in size from minute to several inches across. A few basalt layers contain tubular vesicles as much as a foot or more long. These vesicles are formed by gas bubbles that moved or expanded upward through congealing lava leaving a tubular opening. In some flows the vesicles are perhaps 15–20 percent of the volume or rock. Secondary mineral deposits in vesicles are called amygdules. Very little of the basalt of the Snake River Group is amygdaloidal, and most vesicles are open. Vesicles in lava are not ordinarily important in relation to ground water because most vesicles are nonconnecting and add little or no permeability to the basalt. Rare layers of extremely vesicular spongelike lava may be quite permeable if the vesicles are interconnected.

Lava tubes range from pencil size to tunnels 15 feet or more in diameter and a few yards to some miles in length. Some tubes formed when a partly congealed lava flow ruptured at its front or edge and allowed a core or river of liquid to drain off. Tubes formed also where a river of lava flowing down a slope formed a crust beneath which flow continued for a time, eventually draining out when no more lava is supplied to the tube from the source. Well drillers relate spectacular stories about drilling into large tubes beneath the Snake River Plain, but the writers do not know of verified instances. Large tubes at depths of a few hundred feet probably are old enough to be largely filled by blocks fallen from their roofs and from overlying flows.

Crevices and open joints in buried basalt flows seldom are completely filled by later lava flows because the lava erupts at relatively low temperatures. Much of the high fluidity of the lava is caused by its high content of water vapor and other gases. As these are lost, the lava stiffens rapidly and flows over openings without completely filling them. The undersurface of a new flow, as noted above, may cool so rapidly that the lower few inches become brecciated or granular. Thus, much of the void space in pahoehoe lava occurs in the parting zone. These and open crevices impart considerable porosity adjacent to flow contacts. The interiors of flows, especially thick ones, are apt to be massive and relatively impermeable except along columnar joints.

Most of the preceding remarks apply chiefly to pahoehoe basalt. The other principal structural type of basalt, aa, consists of a jumbled mass of small to very large blocks of lava. Aa flows are conspicuous at Craters of the Moon and elsewhere. Emplacement of aa by movement analogous to the flow of pahoehoe is difficult to visualize, but the process has been observed directly at active modern volcanoes. The method of emplacement prevents effective packing of lava blocks and the effective porosity of aa is greater than any other type of lava. Numerous zones of broken basalt that have been drilled at depth in the Snake River Plain are believed to be buried aa.

QUATERNARY SEDIMENTS

Unconsolidated sediments cover large areas of the NRTS and also are present as interflow beds in the Snake River Group. The materials are largely alluvial, lacustrine, and eolian in origin. The younger parts of the beds are late Cenozoic in age, chiefly Holocene; the older parts of the beds are Pleistocene. Loess is the most widespread material, and alluvium is next in abundance. Dune sand, playa-lake beds, slopewash, and talus also are present. Lake beds are locally prominent. At many places the various types of sediments are intermixed, interfingered, and interbedded, so that it is difficult to classify them for mapping. At those places they were mapped according to the apparent dominant type of material. Parts of the boundary shown on the geologic map between the alluvium of the Big Lost River and the Terreton Lake beds are arbitrary because the contact is laterally gradational. At such places the boundary was drawn adjacent to the former shoreline of the lake. Also, the boundary between Terreton Lake sediments and sediments deposited by modern ephemeral lakes is indefinite.

TERRETON LAKE BEDS

"Terreton Lake Beds" is not formally accepted by the Geological Survey as a stratigraphic term, but the name is used here for convenience in designating sediments laid down in ancient Terreton Lake. The Terreton Lake beds are largely sandy and clayey silt, with lesser amounts of relatively pure clay, silt, and fine gravel. The coarser sediments accumulated near inlets of the lake. The beds as mapped (pl. 1) include sandy beach and bar deposits.

The principal exposures of Terreton Lake sediments within the station occur in an area of about 60 square miles; this area includes the Birch Creek playa beneath whose sediments there are lake beds. Discontinuous exposures were mapped in a considerably larger area. At some places, playa beds and windblown sand mantle part of the old lake floor. The principal lake-bed outcrops in the NRTS are in a lowland belt that trends eastward across the northern part of the station. To the east, the belt of lake beds is constricted between Circular Butte on the north and a salient of basalt projecting northward in T. 5 N., Rs. 31 and 32 E. Much more extensive exposures of the lake beds occur east of Circular Butte in the Mud Lake Basin. The lake beds interfinger with alluvial and windblown deposits.

The part of the ancient lake that was in the NRTS probably was fed chiefly by Birch Creek and the Big Lost River. The distribution of the lake beds shows that the high stage of the lake was at an altitude of about 4,800 feet above mean sea level. Fluctuations of the lake level and of the shoreline caused lake beds to interfinger with alluvial and eolian sediments that were accumulating around its borders. Locally, basalt flows may interfinger with the lake beds. Bars, spits, and hooks that were formed in the lake by waves and currents are well preserved on the modern landscape. Bars range in height up to 25 feet, in width up to about 1,500 feet, and in length up to 5 miles. The largest bar extends northward through the TAN (Test Area North) and forms a natural embankment between the administration area and the operation and maintenance area.

The lithology of the Terreton Lake beds is very similar to that of the playa beds which overlie it, and the two are difficult to distinguish. Moreover, eolian and alluvial or delta sediments interfinger with lake beds, so that samples from many boreholes probably include sediments of all three kinds. Scattered sparsely over the surface of the lake beds are stream-worn pebbles and angular blocks of basalt as much as two feet in diameter. In the southern part of the lake plain, the basalt blocks are of a distinctive lithologic type that has been observed only on the upper slopes of Circular Butte. Presumably, talus blocks from the Butte fell onto shore ice that subsequently broke loose and rafted the blocks to their present positions. The pebbles probably were rafted also, though at some places, where the lake beds are thin, pebbles could have been thrown upward from underlying gravel by frost heave.

The gross mineralogy of the Terreton Lake beds was not studied in detail. X-ray diffraction determinations were made of the mineralogy of the clay-size fractions in connection with ion-exchange capacity studies. These determinations show that the clay-size material is largely clay and hydrous mica. There are small amounts of quartz, chlorite, and vermiculite, and traces of feldspar and hydrobiotite. Both montmorillonite and kaolin are present, but montmorillonite is the more abundant clay mineral.

Vertebrate fossils from the upper part of the Terreton Lake beds in the Mud Lake Basin indicate that its age is Pleistocene (Stearns and others, 1939, p. 37). Very likely deposition of the lake beds began in the Pleistocene and continued in Holocene time.

MECHANICAL COMPOSITION

Size-grade analyses were made of a large number of samples of Terreton Lake beds. The five samples (1–5) represented by cumulative logarithmic curves in figure 4 show the range of variations in composition. Many of the lake-bed samples are similar to number 1 in the diagram, a well-sorted sandy, clayey silt containing about 18 percent sand and about 25 percent clay. Samples like number 2, largely silt, are fairly common; those like number 3, sandy silt, are not rare. Samples 4 (silty fine-grained sand) and 5 (nearly pure silt) are extreme departures from the ordinary lake sediments.

Beach and bar sediments associated with the Terreton Lake beds are almost as fine grained as the sediments from lake beds but are less well sorted and somewhat erratic in the distribution of sizes. The samples (6–9) shown in figure 4 are representative of these sediments. Material like number 6 is most common, containing about 30 percent sand or less, 50 percent silt, and about 20 percent clay. The distribution of sizes suggest two agents of sorting—wave action or longshore currents and wind action. Sediment like sample 7 is almost as common as number 6, but relatively few samples resemble numbers 8 and 9.

CHEMICAL COMPOSITION

Two samples of Terreton Lake sediments from the TAN site were analyzed chemically for the Atomic Energy Commission by O. J. Porter and Co.[1] Sample P2–1–1 was from a depth of 7 feet in test hole P2; sample P3–1–1 was from a depth of 3 feet in test hole P3. The following results were reported.

Constituent or property	Amount (percent)	
	P2–1–1	P3–1–1
Loss on ignition	13.32	15.27
Silica (SiO_2)	53.75	47.58
Iron (Fe_2O_3)	5.26	5.48
Aluminum (Al_2O_3)	12.14	13.78
Titanium (TiO_2)	.08	.08
Calcium (CaO)	9.62	11.84
Magnesium (MgO)	2.36	2.78
Sodium, total (Na_2O)	1.61	1.08
Potassium, total (K_2O)	2.41	2.17
Sodium, water-soluble (Na_2O)	.035	.054
Potassium, water-soluble (K_2O)	.014	.030
Boron (B)	[1].2	[1].15
Nitrogen (N)	.072	.054
Phosphorous (P_2O_5)	.25	Trace
Chloride (Cl)	[1]10	[1]461
Carbonate (CO_3)	0	0
Bicarbonate (HCO_3)	[1]525	[1]455
Sulfate (SO_4)	0	[1]336
pH	8.08	7.80

[1]In parts per million.

ALLUVIAL-FAN GRAVEL

Conspicuous local piedmont alluvial fans were deposited by ephemeral runoff from foothill slopes of the Lemhi and Big Lost River Ranges adjacent to the western boundary of the NRTS. Parts of these fans extend into the western border area of the NRTS and slope generally eastward and southeastward about 100 feet per mile. The largest fan, covering an area of about 10 square miles within the station, extends from the slopes

[1]O. J. Porter and Company, Consulting Engineers, Sacramento, California; Report to the U.S. Atomic Energy Commission, Foundation and area, National Reactor Testing Station, Idaho, September 22, 1952.

of the Lemhi Range in T. 6 N., Rs. 30 and 31 E. Small unmapped fans are adjacent to the slopes of Twin Buttes. Fans cover about 20 square miles in the station.

The fan deposits are pebble to boulder gravel; the boulders are up to 2 feet in diameter and occur in a matrix of sand. Cobble and pebble gravel predominate. The pebbles and cobbles, locally derived, consist chiefly of detrital limestone, sandstone, metamorphic rocks, basalt, and silicic volcanic rocks. The materials are generally coarser and more angular than those in the alluvium of Birch Creek and of Big Lost River.

MECHANICAL COMPOSITION

The degree of size sorting ranges from excellent to poor. Facilities were not available for screening complete gravel samples containing boulders and cobbles. Inasmuch as the gravel is a potential source of concrete aggregate and road metal, the size-grade distribution of material smaller than cobble size in several representative samples (10–14) is shown in figure 4. Some of these, like no. 11 in figure 4, seem to indicate an admixture of windblown fine-grained material. All the curves illustrate the rather poor sorting that is characteristic of alluvial-fan deposits. The alluvial deposits were not studied in sufficient detail to disclose the predominant types of size-grade sorting.

GRAVEL OF BIRCH CREEK

Birch Creek drains parts of the Lemhi Range and the western slope of the Beaverhead Mountains. Stream detritus forms an extensive valley fill in the Birch Creek Valley and a broad alluvial fan that extends onto the Snake River Plain in the northern part of the NRTS. These fan deposits are sufficiently distinctive to be represented on the geologic map (pl. 1; Qaf in the extreme northern part of the map) separately from other alluvial fans.

The average slope on the surface of the fan is southeastward about 50 feet per mile. The surface is cut by a series of small channels, but no main central channel was found. There has been no runoff from Birch Creek into the NRTS for many years because most of the water is diverted upstream for irrigation. Seemingly, however, even before the advent of artificial diversion, runoff was intermittent and the stream broke up into a number of small distributary channels on the alluvial fan.

Detrital material in the Birch Creek alluvium is similar to that in the alluvium of the Big Lost River. Scattered sparsely on the surface of the fan are angular cobbles and boulders of basalt. The fan was formed by alternate cut and fill and torrential deposits, and individual beds of sediment are irregular in form, thickness, and extent. Some beds are loosely cemented by calcium carbonate coatings which tend to be thickest on the undersides of grains and pebbles.

Fossil camel remains,[2] provisionally referred to *Camelops* after study at Idaho State College (Marie L. Hopkins, written commun., Oct. 12, 1953), were excavated from a few feet below the surface in Birch Creek gravel. The fossils suggest that the gravel is Pleistocene in age.

MECHANICAL COMPOSITION

Because some construction may be done partly on the Birch Creek alluvial fan, the relation of the mechanical composition of the gravel to subsoil drainage is important as well as the potential use of the gravel as road metal and concrete aggregate. The size-grade distribution of material smaller than cobbles is illustrated by samples 15–19 in figure 4. The diagrams disclose a wide range in the mechanical composition of individual beds, but the material as a whole is about as uniform as the Big Lost River gravel. Many samples that were graded were very similar to samples 15 and 16 in figure 5; those samples show 81 and 78 percent of gravel respectively. Sediment similar to number 17 (71 percent gravel) is fairly common. Material similar to numbers 18 and 19 is less common but not rare. Number 19 seems to contain a substantial amount of windblown silt.

ALLUVIUM OF THE BIG LOST RIVER

The alluvial plain of the Big Lost River occupies about 60 square miles in the NRTS and extends about 25 miles northeastward through the western-central part of the station. The width of the plain varies from a few tens of feet in the southwest to about 4.5. miles in the central part of the station. In the north half of T. 4 N. and the south half of T. 5 N., the alluvium merges with sediments from other sources, and from there northward the plain broadens to a wider composite plain. The alluvium and associated sediments cover a large part of the geologically more favorable construction area in the NRTS, and therefore, the deposits, were studied in considerable detail.

The alluvium of the Big Lost River originated chiefly from upstream areas in the Lost River Range west of the NRTS. The sediment in the central and southern segments of the plain is chiefly gravel, with locally varying amounts of silt and sand matrix and a few lenses of silt and sand. Northward the sediment is fine gravel, sand, and silt. In the coarse gravel, cobbles as large as 10 inches in maximum diameter are rare and boulders are few. The degree of size-sorting ranges from excellent to very poor, but much of the material is moderately well sorted. The amount of matrix ranges up to about 80 percent, but in some layers there is so little matrix that

[2]Exhumed by an excavation contractor working for the Atomic Energy Commission.

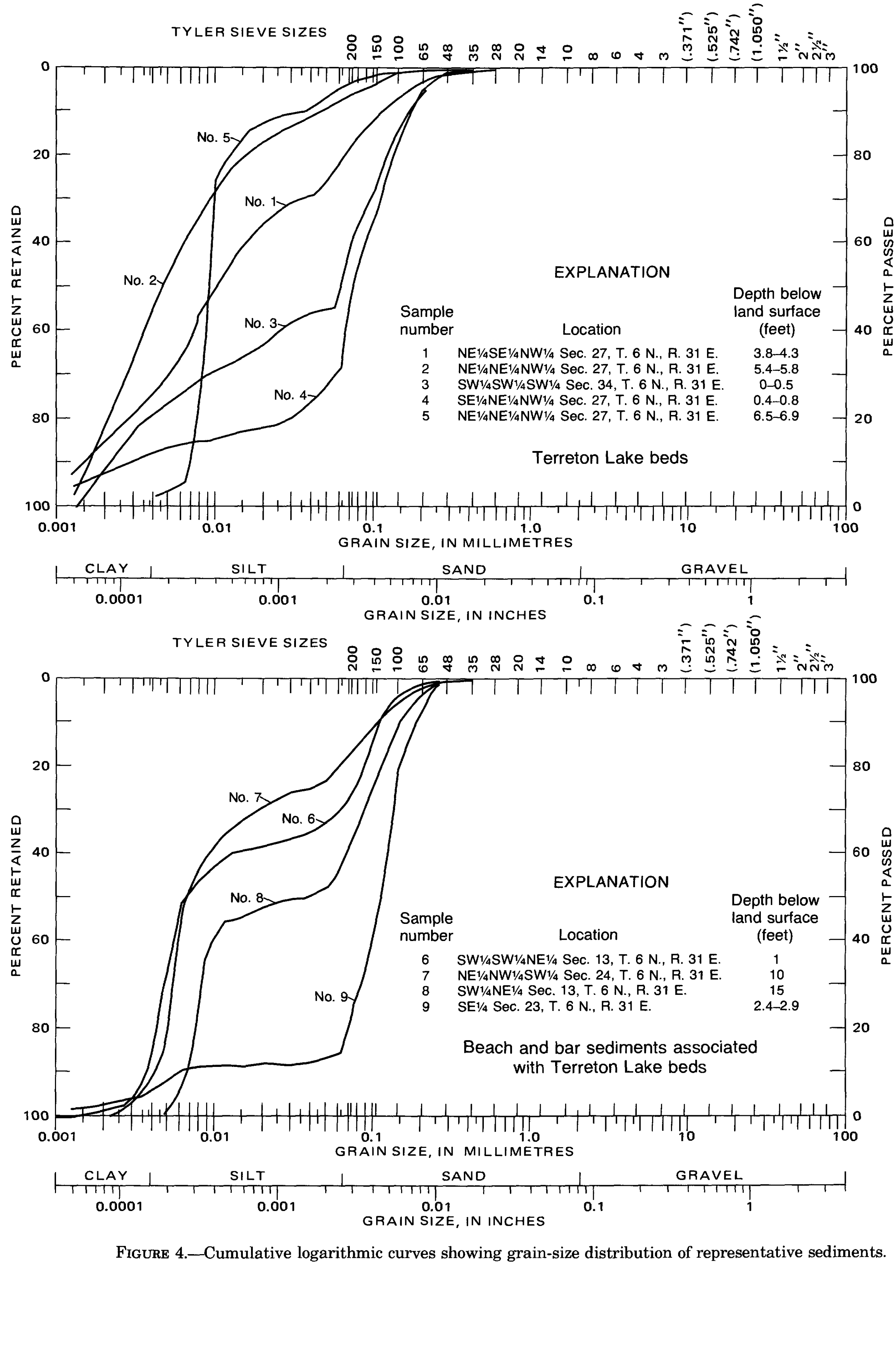
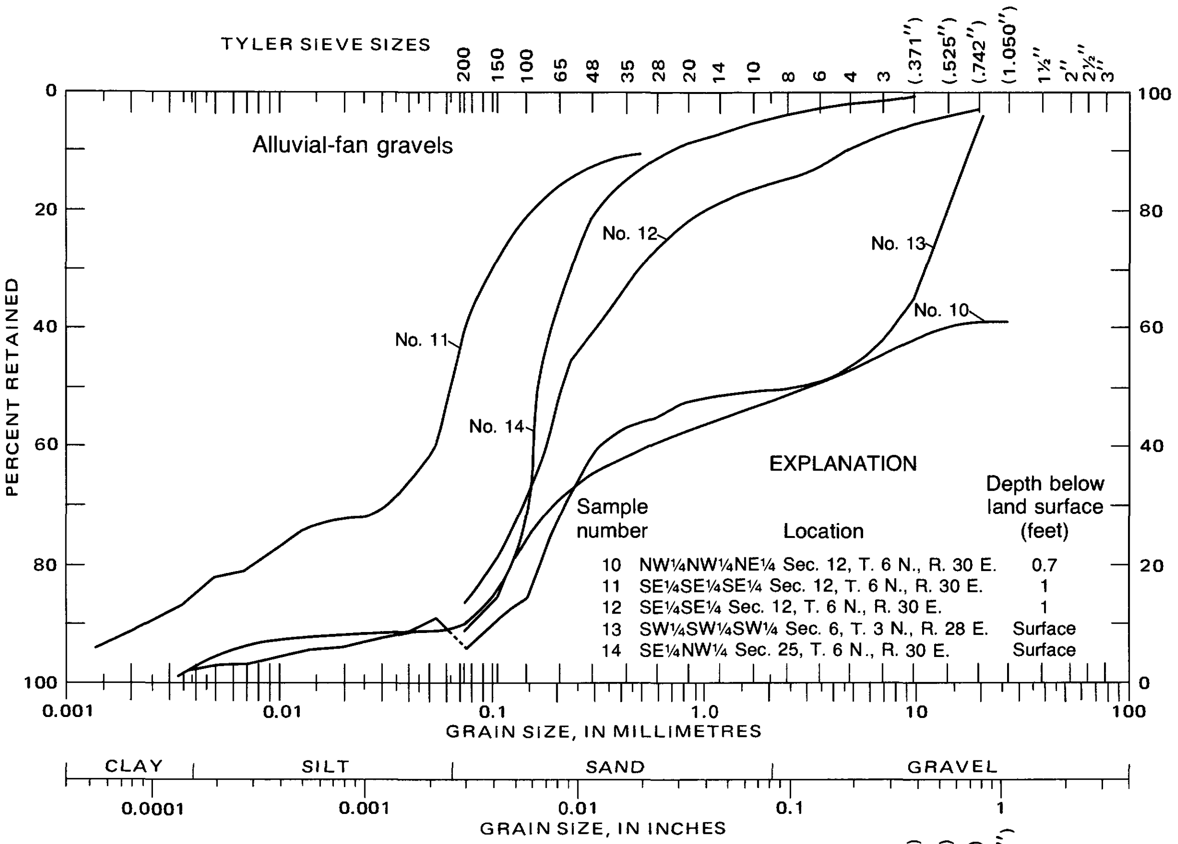


FIGURE 4.—Cumulative logarithmic curves showing grain-size distribution of representative sediments.



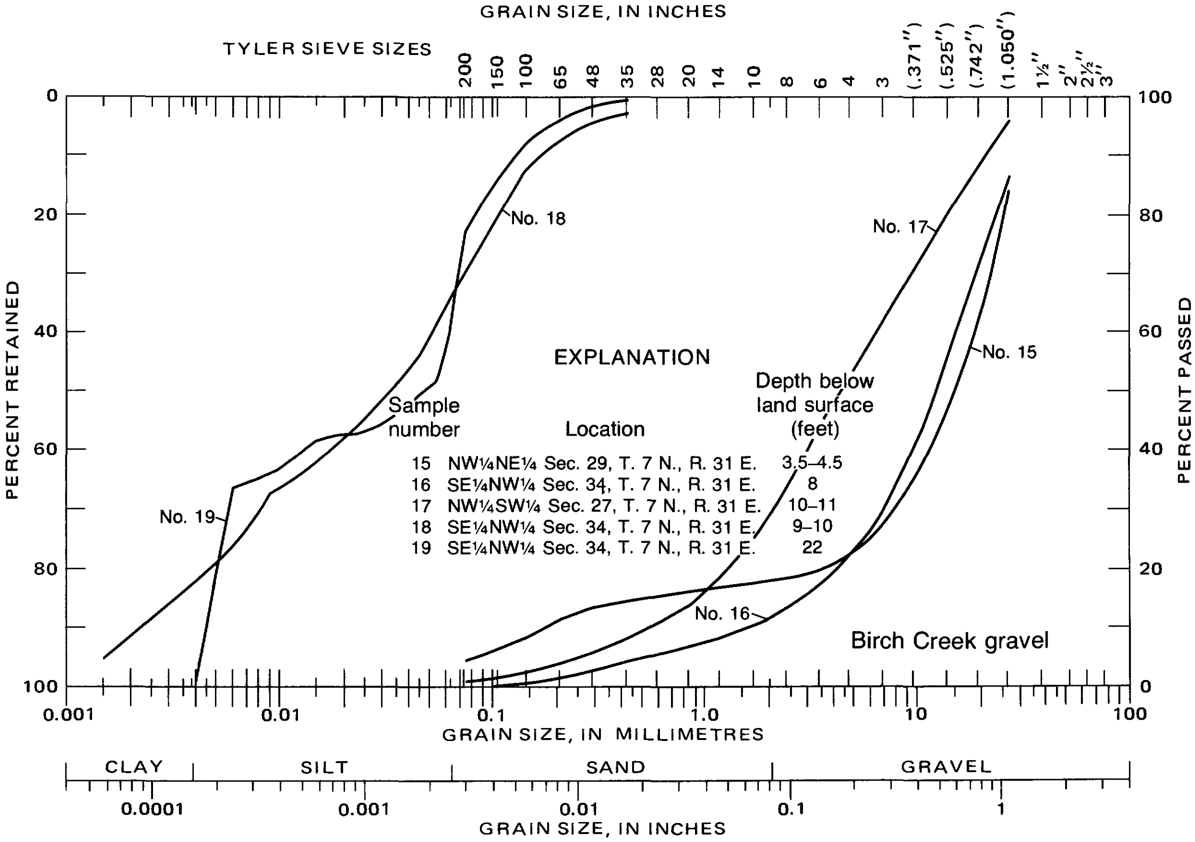
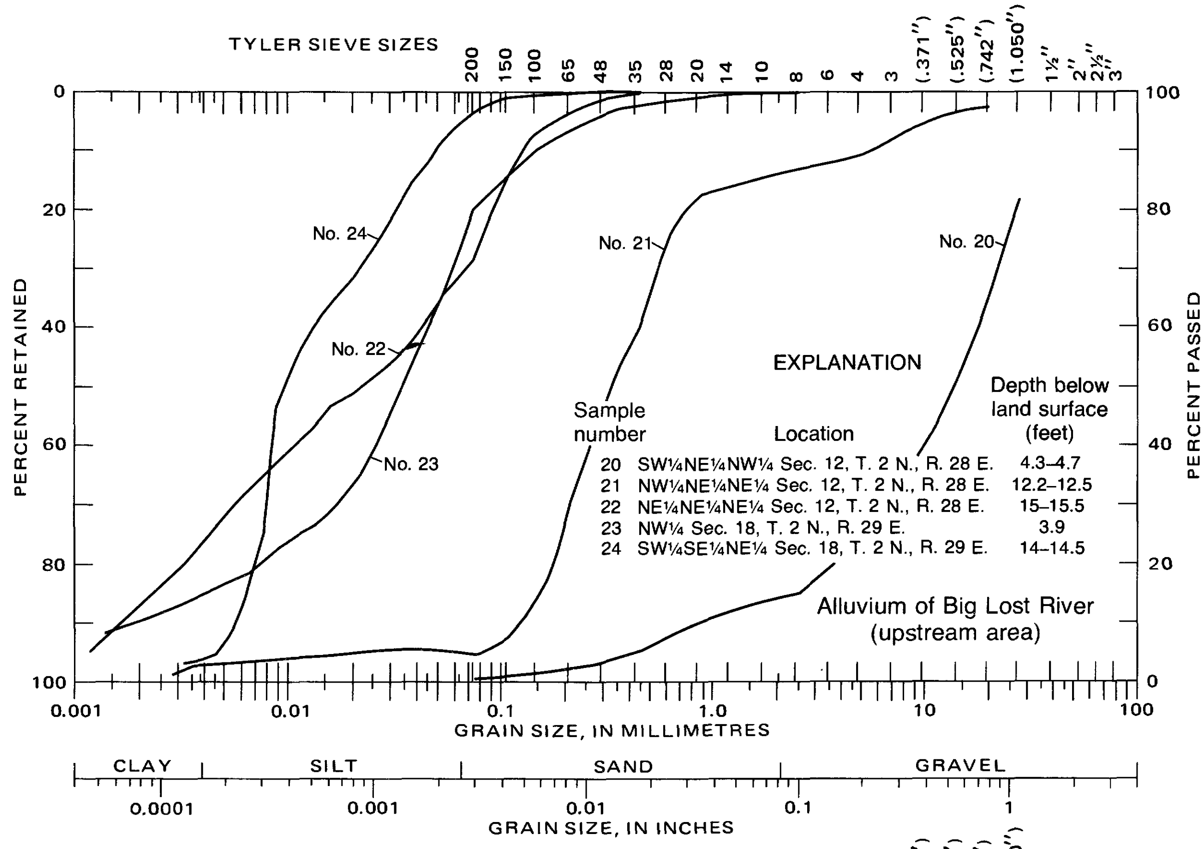


FIGURE 4.—Continued.



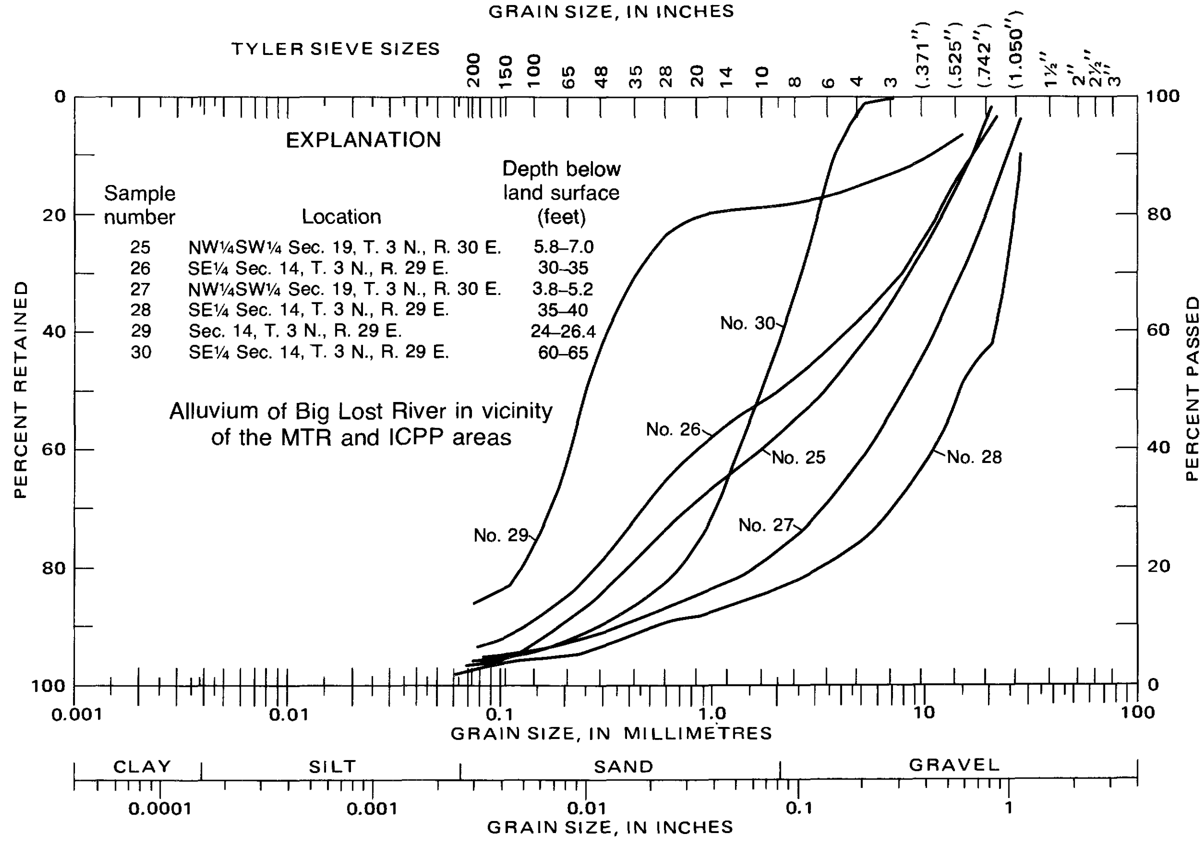


FIGURE 4.—Continued.

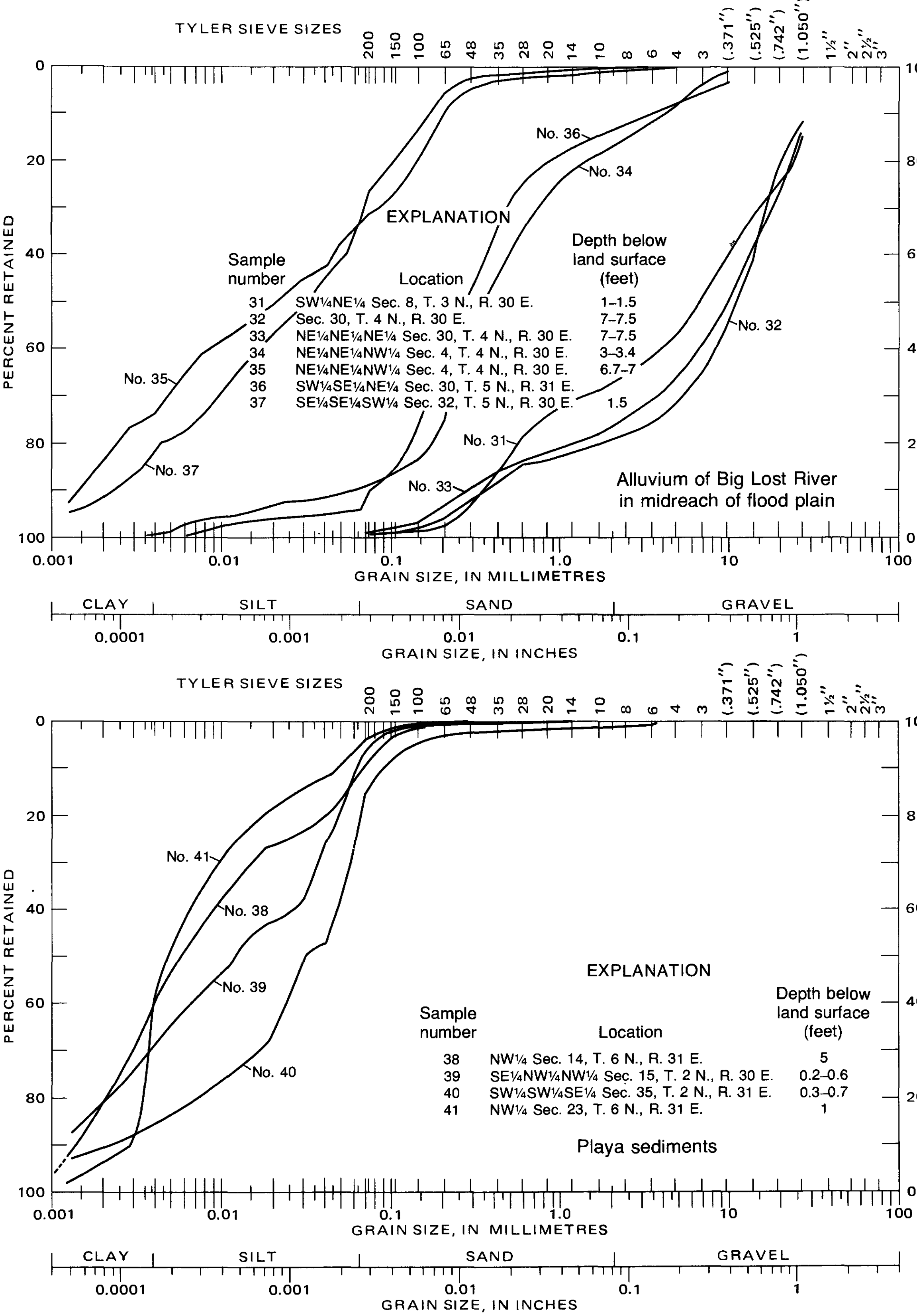
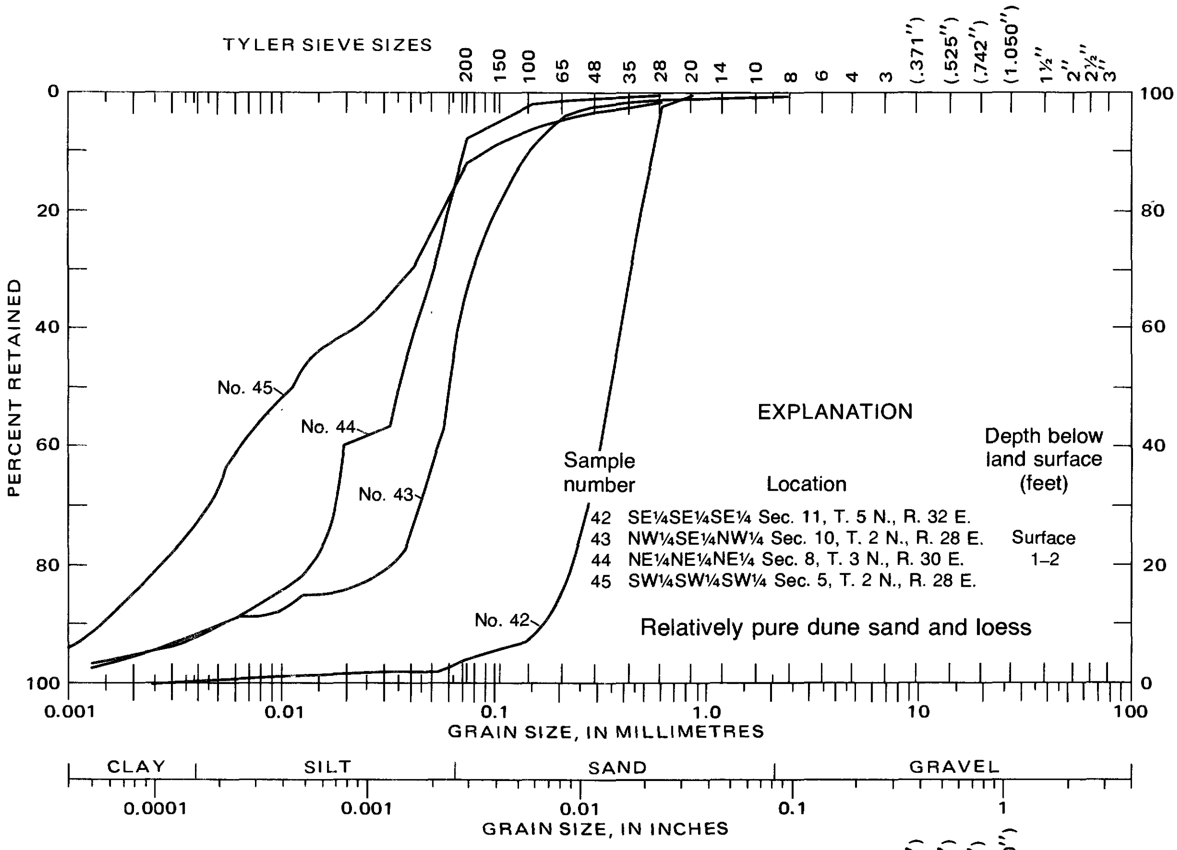


FIGURE 4.—Continued.



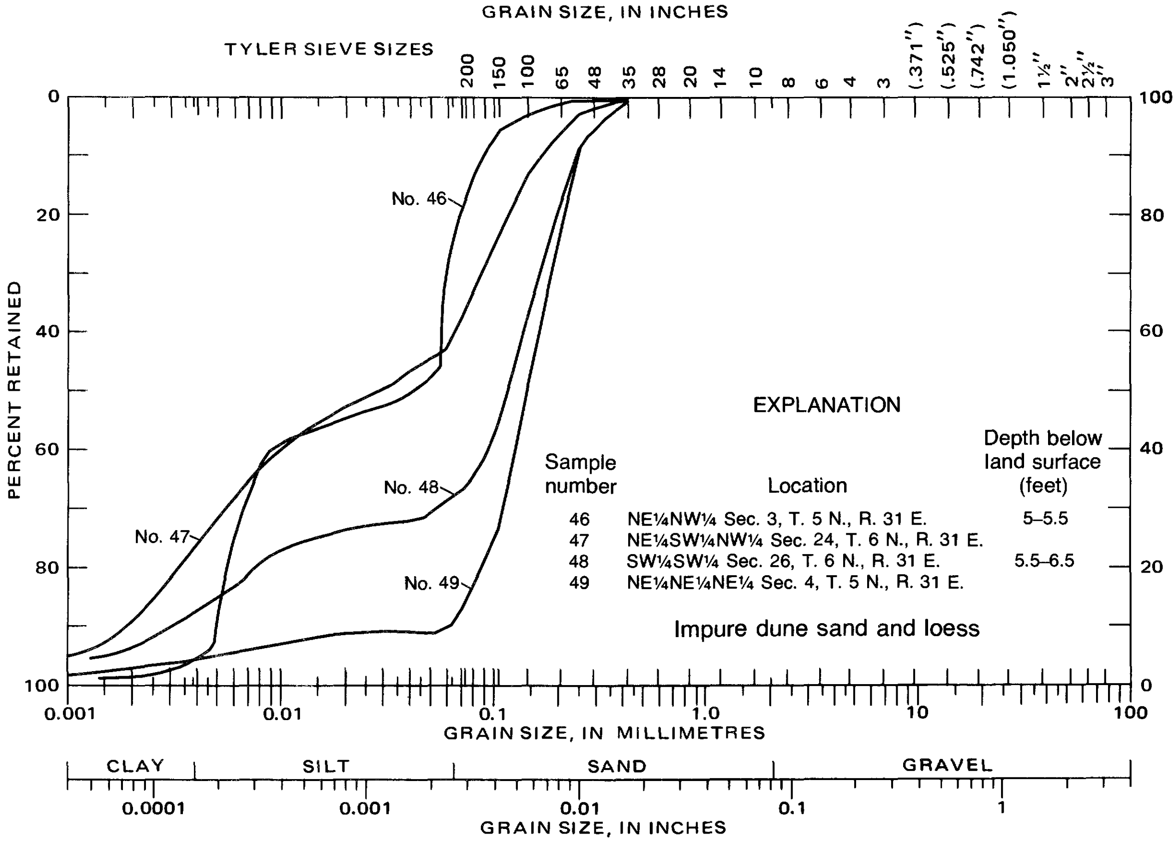


FIGURE 4.—Continued.

pebbles form openwork gravel. Pebbles and cobbles are of welded tuff, rhyolite, andesite, basalt, volcanic glass, granitic rocks, quartzite, limestone, chert, and chalcedony. Sand particles are similar but include numerous grains of feldspar. Individual grains commonly are subrounded to rounded, but angular grains of comminuted basalt are common. Single beds of gravel are lenticular to irregular in form and vary greatly in their thickness and extent. Most of the sand lenses are crossbedded and similar in form to the gravel beds, but the lenses are thinner and less extensive than the beds. The irregularities were caused partly by constant shifting of the river channel and by truncation of the earlier deposits.

The gradient of the Big Lost River channel is relatively low throughout the NRTS, but there is an appreciable flattening north of the State Butte bridge on Lincoln Boulevard. Southward (upstream) from that location the dominant sediment in the present stream channel is coarse pebble to cobble gravel; northward (downstream) the sediment is finer, grading into sand and sandy silt. Similar river-grade conditions probably prevailed during deposition of the whole mass of flood-plain alluvium, because there is a similar northward decrease in the coarseness of sediments wherever test holes have been put down.

Though single beds of the alluvium of the Big Lost River are lenticular to irregular in form, the deposit as a whole is a flat and nearly level sheet or mantle on the underlying basalt. Owing to considerable irregularity and relief on the surface of the basalt, there is wide local variation in the thickness of the mantle. The maximum thickness of gravel that has been penetrated by test holes is about 70 feet. Drilling has not adequately sampled the entire flood-plain area, but the average thickness probably is not more than 40–50 feet.

At some places part of the gravel is lightly cemented by secondary calcite, principally as grain coatings in the upper 30 feet. The amount of cement tends to diminish with depth, and nowhere is it sufficient to form conglomerate.

DEPOSITIONAL PHASES OF THE GRAVEL

Physiographic features of the Big Lost River flood plain show that at least three phases of gravel deposition occurred. A possible fourth phase also may have occurred. The distinctions between the three phases of the gravel are entirely physiographic, no internal lithologic differences having been found. Hence the various phases probably have no engineering importance. They do, however, relate to comparatively recent events in geologic history and may assist in the eventual deciphering of details of that history.

The youngest gravel (phase one) occupies a belt along the present main river channel. It is distinguished by branching and anastomosing abandoned river-channel scars as much as 7 feet deep. Vegetation on the gravel is very sparse, and accumulations of windblown mantle are thin and sporadic. In general, the original erosional and depositional features of the gravel have been modified only slightly by wind and weathering. This combination of features indicates very recent age.

A somewhat older gravel (phase two) occurs in belts some distance from the river, along the flanks of phase one, and forms the principal part of the alluvial plain. Abandoned channel scars and other inherited features are less conspicuous than on phase one because they have been extensively modified by wind and weathering. Most of the preserved channels are less than a foot deep. There is also a moderate stand of vegetation. These features suggest deposition somewhat earlier than deposition of phase one.

Phase three of the gravel, representing the earliest recognized stage of deposition of the modern Big Lost River, occurs at some places along the margins of the alluvial plain adjacent to basalt outcrops. It is typically represented in sec. 14, T. 3 N., R. 29 E., and sec. 2, T. 2 N., R. 29 E. It is distinguished by the absence of river-channel scars, which have been obliterated, and by a relatively good stand of vegetation. The surface of the gravel is marked by low mounds about 2–4 feet high and up to 75 feet in diameter at the base. The origin of the mounds is not known, but they occur in a rather regular pattern and are rather evenly distributed. Their presence suggests the operation of an unusual geologic agent because such mounds are not known to be forming in the vicinity at present. Because this is the older gravel phase, it may date from a period of permafrost or related condition at the close of the Pleistocene Epoch. The mounds resemble features that have been attributed to permafrost in glaciated areas. It has been informally suggested that (1) the mounds were thrown up around animal burrows, or (2) they are composite fossil anthills. Whatever they are, the combination of features suggests that the age of this gravel is greater than that of phases one and two.

A still older(?) gravel (phase four) may be represented by a sparse scattering of small stream-worn pebbles at numerous places on low-lying basalt flows adjacent to the flood plain; the gravel extends to levels several feet above the flood plain. The pebbles are not a continuous deposit and are sufficiently sparse that at some places one must search to find them. Flood-plain deposition is improbable because it is unlikely that the river flood plain ever was built up as high as the levels on which the pebbles occur. A flood plain filled to that level would require subsequent erosion to its present level. Owing to lack of exterior drainage, redeposition would have been in the area of the playa basins to the north. Comminution of the gravel and redeposition of the material as the fine-grained lake beds to the north is an unlikely possibility. If the flood plain had once been filled to the higher level, remnants of high-level bedded gravel ought to be present, but such remnants have not been found. Possibly, during the rapid melting of alpine glaciers, the river flood plain was inundated with water at sufficient height for ice to float or to be thrust onto the basalt. Pebbles rafted in the glacial ice may have contributed the scattered material now observed.

MECHANICAL COMPOSITION

The mechanical composition of alluvium of the Big Lost River (samples 20–37) is illustrated in figure 4. From the latitude of State Butte southward, the material is largely gravel. About 70 percent of the average sample is pebbles and cobbles. Northward from State Butte, the proportion of gravel decreases rapidly, and the alluvium is largely sand and silt.

In the upper reach of the flood plain in T. 2 N., R. 28 E., coarse sandy gravel and gravelly sand are about equal in abundance. Sample 20 represents a substantial group of samples of the coarser gravel within half a mile of the present river channel. Sample 21 is representative of another substantial group of samples of somewhat finer gravel from the same general area. Sample 22, from the same vicinity, contains practically no gravel; it represents lenses that are common in the gravel. Sample 23 resembles sample 22 but is finer and well sorted; it represents a common type of sediment more than a mile from the river. Sample 24 seems to be a variation of sample 23.

All the samples 20–24 are from the general vicinity of the NRTS burial ground. Samples 20 and 21, which represent the most common material, illustrate the general coarseness of upstream gravel beds.

About 5 miles downstream from the burial ground, the average sample is somewhat less coarse and less well sorted. Samples 25–30 are from the flood plain in the vicinity of the MTR (Materials Testing Reactor) and ICPP (Idaho Chemical Processing Plant) areas, and these, of samples 25, 26 and 27 (sandy gravel) are representative of the majority of samples collected there. Samples 28, 29, and 30 represent variations of gravelly sand and sandy gravel. Beds of that type are relatively few in number in the reach of the flood plain from which they were taken.

The midreach of the gravel area of the flood plain, from the vicinity of the ICPP area downstream to the neighborhood of the STR (Submarine Test Reactor) plant of the Naval Reactors Facility, contains gravel beds little different from those near the ICPP area. The material here is somewhat more sandy with fewer coarse gravel beds. Sample 31, from about 2 miles downstream from the ICPP, represents the common sediment in that area. Sample 32 in the same figure represents materials in the vicinity of the STR plant. Sample 33 is representative of a large group of samples from the general area about 3 miles east of the STR. It shows a wide range of size grades and increased amounts of small grades down to silt size. The trend toward increased sandiness and inclusion of even finer material is shown by samples 34 and 35. They were taken from about 3 miles downstream from the latitude of the STR area and are representative of a large number of samples from that area. Sample 34 contains 3 percent clay, 7 percent silt, 73 percent sand, and only 17 percent fine gravel. Sample 35 contains less than 2 percent of fine gravel.

In the lower reach of the river, gravel is fine grained and rare, and the flood-plain deposits are largely sand and silt (samples 36 and 37, fig. 4). Sample 31 is typical of sediments about 5 miles east of the Big Lost River channel in T. 5 N. and R. 31 E., and sample 32 represents sediments from about a mile west of the river channel.

In summary: The coarser gravels are in the upstream reach of the flood plain, south of U.S. Highways 20 and 26. Downstream, toward MTR and ICPP, the amount of cobbles decreases. Farther downstream there is not much change as far as the latitude of the STR plant. Northward from there the decrease in coarse material is rapid. There is very little gravel north of T. 4 N.; this fact correlates with the decreased gradient of the river and flood plain. Tongues and sheets of fine gravel extending northward from T. 4 N. probably were transported by freshet runoff. Much of the finest material in the Big Lost River gravel probably is windblown.

CHEMICAL COMPOSITION OF SECONDARY CEMENT

Gross samples of the alluvium of the Big Lost River have not been analyzed, but the chemical composition undoubtedly varies within a substantial range. Analyses were made by the Pacific Testing Laboratories[3] of the composition of secondary mineral matter (cement) scraped from pebbles in gravel from the central part of the Big Lost River flood plain at a depth of 1.5 to 4.5 feet. The results follow:

Constituent	Samples (*percent by weight*) *261*	*281*
Moisture	0.42	0.50
Silica (SiO_2)	46.68	47.60
Iron oxide (Fe_2O_3)	4.90	5.32
Alumina (Al_2O_3)	4.84	4.26
Lime (CaO)	22.18	21.48
Magnesia (MgO)	3.18	2.11
Carbon dioxide	21.40	18.40

[3]Pacific Testing Laboratories certificate No. 6878, Jan. 13, 1950, to U.S. Atomic Energy Commission, Idaho Falls, Idaho.

PLAYA SEDIMENTS

Undrained depressions (playas) that contain ephemeral lakes and ponds are scattered throughout the NRTS. These depressions range in size from that of the Birch Creek playa, containing about 5 square miles, to that of small basins a few score feet in diameter. All the larger basins are in the northern third of the NRTS where four principal playas have an aggregate area of about 12 square miles. Playa No. 1 is south of Howe Point. From this basin a natural spillway, several feet higher than the floor of the basin, leads to playa No. 2 on the east. The aggregate area of these two basins is about 5 square miles. A spillway and channel leads eastward from playa No. 2 to No. 3, which covers about 2 square miles centered around sec. 33, T. 6 N., R. 31 E. Playa No. 4 (Birch Creek Playa), the largest of all, is the terminus of both the Big Lost River and Birch Creek; it lies west of the Test Area North administration area and largely north of Pole-Line road.

Most other playas on the NRTS are undrained depressions less than a square mile in extent on the Snake River basalt. A conspicuous example is Rye-Grass flat, just east of the junction of U.S. Highways 20 and 26. Many basins are too small to show on the scale of the map (pl. 1), but the aggregate area of all playas probably is about 25 square miles. Mapped playas cover about 22 square miles.

The playa sediments are mostly poorly sorted fine-grained light-gray to light-tan sand, silt, and clay; the nature and color are controlled by the type of material locally available. In the basalt area, the beds are largely reworked loessial sediment. In the Birch Creek playa, they are chiefly reworked Terreton Lake sediments. In Lost River playa No. 1, they are reworked fine alluvium (including fine gravel at places) and reworked dune sand and silt. Although locally derived, the sediments are readily distinguished from parent materials by their position, flat surfaces, closer compaction, and generally fine texture. The Birch Creek playa beds are not clearly distinguishable from Terreton Lake beds, but the playa beds have a harder surface crust, lighter color, more abundant mudcracks, and a sparser cover of vegetation. In most playa beds there is an appreciable amount of secondary calcite.

MECHANICAL COMPOSITION

The mechanical composition of the playa beds, illustrated in figure 4, show cumulative logarithmic curves for four samples (38–41). Numbers 38, 39 and 40 are common types, and curves for most samples that were analyzed are very close to these. The material is clayey, sandy silt with 14–40 percent clay, 5–20 percent sand, and 50–70 percent silt. The general similarity between sample 38 (from the Birch Creek playa) and sample 39 (from Rye Grass flat) is especially striking because of the long distance between their sources and their totally different depositional environments. Sample 39 is from a basalt basin where the only parent material is windblown (loessial) soil; sample 38 is from the environment of sample 40 is similar to that of 39. Sample 41 —which represents the only observed deviation from the other three types—is a clayey silt containing 6 percent sand, 62 percent silt, and 32 percent clay. It is from the Birch Creek playa near a silt bar.

SLOPEWASH SEDIMENTS

The slopewash sediments consist of miscellaneous materials that range widely in mechanical and lithologic composition and that came from a variety of sources. Talus, which occurs only in a very small area, is included with slopewash sediments on the geologic map. Talus on the flanks of the Twin Buttes consists of angular fragments of volcanic rock that are mechanically weathered from the bedrock and moved by gravity alone. There are no other sizable accumulations of talus in the NRTS.

Slopewash in lowland areas resembles the playa beds. The sediments are less well sorted and occur where rill and sheet runoff is the transporting agent. Most of the slopewash is poorly to moderately well sorted sandy silt, is locally derived, and contains appreciable amounts of secondary calcite. The grain-size distribution in some deposits is somewhat erratic, and at many places there is a considerable admixture of windblown sediment.

The principal areas that contain slopewash, including the talus around Twin Buttes, are in the southern and western parts of the NRTS where their total outcrop area is about 4 square miles. Single areas occupy about 20–300 acres. The slopewash areas in general are unimportant as construction sites, but areas covered by these sediments may be suitable for small or temporary structures or operations, especially if physical isolation is desired.

WINDBLOWN SEDIMENTS

Windblown sediments, nearly ubiquitous on the NRTS, mantle much of the basalt and some of the older sediments. Two principal types of windblown material are present: loess and wind-drifted sand and silt. These ordinarily are readily distinguishable, but at some places they are mixed and interfingered. On the geologic map (pl. 1) the two types are not distinguished but are grouped simply as windblown material (Qwb).

LOESS

Loess, windblown material that accumulated by the settling of atmospheric dust, is distinguished from dunes and other drifted deposits. Loess is characteristically fine grained, contains chiefly silt- and clay-size particles, and lacks definite stratification. Where deposits are thick, they tend to develop columnar structure. Throughout the Snake River Plain, loess forms a mantle of fine-grained buff to yellow and pinkish-brown sediments. It lacks the prismatic columnar structure seen in some loess deposits elsewhere, but its distribution and occurrence is such that it could have been formed only be settling from the atmosphere. Loess on the NRTS is characteristically light-buff to brown calcareous silt. The degree of size sorting is generally good, and there are only relatively small amounts of clay and sand.

Much of the loess material is sufficiently old that, even in the dry plains climate, weathering has reduced it to loessial soil. This soil supports a moderate stand of plains vegetation. The loess seemingly originated by deflation from distant areas containing unconsolidated sediments; hence, there is little locally derived material in the loess. At some places it probably contains some volcanic ash and decomposed pumice. Commonly the loess contains or is underlain by hardpan layers formed by precipitation of lime leached from the loess. Blocks of lava that rest on loess commonly are coated with lime on their lower surfaces. Lava underlying loess also ordinarily has a contact zone of lime deposits. At most places the loess is only a few inches or a few feet thick. On the plain in the station area, thicknesses of more than 10 feet are rare, although elsewhere on the plain as much as 60 feet of loess has been penetrated by drills.

By no means all the loess in the NRTS is shown on the map (pl. 1) because only the principal thicker deposits were mapped. At those places where the area covered is very small or the deposit is very thin over basalt, the loess was not mapped.

DRIFTED SAND AND SILT

Patches of windblown sand and silt occur throughout the NRTS, but they are conspicuous in the northeastern part where dunes, trains, and drifts mantle other materials and dominate the topography. These deposits are especially conspicuous on aerial photographs. Much of the sand and silt is locally derived, having been winnowed from other sediments. The sand in general is fine grained and well sorted although at some places there is a considerable admixture of clay and silt. The sand grains are rounded to subrounded, chiefly quartz, comminuted basalt, and other igneous and sedimentary rocks.

An exceptionally large, irregular sand drift is in sec. 4, T. 5 N., R. 31 E. South and southwest of Circular Butte, drifted sand forms rows of sand trains up to several feet high and hundreds to thousands of feet long. These trains have their long axes oriented parallel to the direction of the prevailing wind.

MECHANICAL COMPOSITION

The sand from drift trains characteristically is very well sorted, and most samples are similar to that represented by sample 42 in figure 4. The sample is chiefly fine sand with a little silt and practically no clay. Sample 43 probably is largely loess because most uncontaminated loess yields a curve very close to this one. Material like that in samples 44 and 45 also is very common in the loess.

Several samples of impure windblown material are represented by numbers 46–49 in figure 10. These are mixtures of loess and sand and possibly other materials. Samples 46 and 47 are from dune areas, but the size-grade curves resemble those for loess. Material resembling sample 48 is not rare. Sample 49 probably comes nearest to representing the "average" assortment in undifferentiated windblown materials.

MINERAL COMPOSITION OF SEDIMENTS

Minor information about the mineralogy of some sediments is contained in preceding pages. Detailed mineralogic study of gross material has not been made, but the composition of the silt and clay components in all sediments has been studied because these are of special importance in connection with waste-disposal problems. Specifically, natural decontamination of radioactive liquid waste released to the environment is largely by ion-exchange and related processes. The ion-exchange capacities of natural minerals range widely, and the kinds and amounts of these minerals in the sediment are important. Inasmuch as the fine-grained particles tend to be of minerals having the greater exchange capacities, only the silt and clay fractions of sediments were studied.

In geologic usage, clay is both a rock and a particle-size term. In this report, the unmodified word, clay, is a particle-size term. Clay minerals, on the other hand, are a specific group of minerals having well-defined physical, chemical, and optical properties. The rock, clay, is not precisely definable, because a great variety of materials, including nonclay minerals, has been called clay. In general, clay is a natural earthy, fine-grained material usually containing both clay and nonclay minerals; the whole is plastic when moist. The terminology is confusing at times but probably is too well entrenched to be modified.

Clay and silt fractions of more than 50 samples of all types of sediments on the NRTS were studied by John C. Hathaway of the Geological Survey. The component minerals were identified by X-ray diffraction patterns, and the results are shown in table 4. The table shows that most of the silt-size particles (median diameters of

TABLE 4.—*Mineral composition of clay and silt fractions of sediments from the NRTS and vicinity*

[Analyses by U.S. Geological Survey. Explanation: P, predominant in amount; S, subordinate in amount; Tr., trace amount]

Sample No.	Location	Type of material	Depth (ft below land surface)	Minerals present (approximate percent of each fraction): Clay fraction						Silt fraction						
				Montmorillonite	Hydrous mica	Kaolinite	Quartz	Calcite	Feldspar	Montmorillonite	Hydrous mica	Kaolinite	Quartz	Calcite	Feldspar	Dolomite
T. 7 N., R. 31 E:																
1	SE¼NW¼ sec. 34	Gravel, sandy	10	P	S	----	5	20	----	S	S	S	30	30	5	10
2	do	do	22	P	S	----	Tr.	10	----	S	S	S	40	15	Tr.	5
T. 6 N., R. 30 E:																
3	SE¼SE¼SE¼ sec. 12	do	1	15	30	10	5	35	5	----	----	----	50	30	10	10
T. 6 N., R. 31 E:																
4	NW¼NW¼NE¼ sec. 12	do	.7	25	25	20	5	25	Tr.	----	----	----	70	10	10	10
5	NE¼NW¼NE¼ sec. 13	Silt, sandy, with some clay.	5–5.5	45	15	5	15	10	Tr.	10	5	----	45	30	5	5
6	SW¼NE¼ sec. 13	do	15	35	25	15	15	10	----	----	Tr.	----	45	20	25	10
7	do	do	10	40	20	10	15	15	----	5	5	----	45	35	10	5
8	SE¼NE¼ sec. 13	do	21	P	P	S	S	----	----	----	----	----	----	----	----	----
9	NE¼SW¼ sec. 13	do	2–4	S	P	P	S	----	----	----	----	----	----	----	----	----
10	do	do	do	S	P	P	S	----	----	----	----	----	----	----	----	----
11	SW¼SW¼SW¼ sec. 13	Silt, clayey, sandy.	5	35	20	20	15	10	Tr.	----	----	----	55	25	10	10
12	SE¼SW¼ sec. 13	Silt, sandy, with some clay.	10	35	20	15	15	15	Tr.	----	----	----	60	25	5	10
13	NW¼NW¼SE¼ sec. 13	do	14.4	45	15	10	15	15	----	----	10	----	45	20	5	20
14	SE¼NE¼ sec. 14	Silt, clayey, sandy.	10	30	20	15	15	15	5	----	----	----	60	10	20	10
15	NW¼NE¼ sec. 14	do	5	30	25	10	20	15	Tr.	----	5	----	50	25	10	10
16	Center sec. 14	do	0	35	20	15	20	10	Tr.	----	----	----	60	25	5	5
17	do	do	5	30	20	15	20	15	Tr.	----	----	----	65	20	5	10
18	SW¼SW¼ sec. 23	do	5	40	20	10	15	15	Tr.	----	----	----	60	20	10	10
19	SE¼ sec. 23	Sand, silty	4.8–5.8	P	S	----	10	10	----	S	----	----	30	15	Tr.	5
20	NE¼NW¼SW¼ sec. 24	Silt, sandy, with some clay.	10	40	15	10	20	15	Tr.	10	10	----	40	30	5	5
21	NW¼NW¼NE¼ sec. 26	Silt and sand, windblown.	3.8–4.5	P	----	----	10	10	----	S	S	S	50	10	5	5
22	NW¼SW¼ sec. 26	Sand, silty	5.2–6	P	P	----	15	5	Tr.	S	----	S	50	10	5	15
23	SE¼SE¼SW¼ sec. 27	Sand, silty, clayey.	----	P	P	S	10	10	----	S	S	----	40	15	10	15
24	SE¼NE¼ sec. 34	do	5.2–6	P	P	S	15	10	----	S	S	S	45	25	Tr.	10
25	SW¼SW¼SW¼ sec. 34	Sand, silty	0.0–5	P	P	----	10	10	----	S	----	----	40	15	5	Tr.
26	do	Silt, sandy	0.5	P	P	S	15	5	----	S	----	----	50	10	10	10
27	do	Sand, silty, clayey.	1	P	P	----	15	Tr.	Tr.	S	----	----	45	5	10	5
T. 6 N., R. 32 E:																
28	Center sec. 22	Sand, clayey, silty.	0	P	P	S	10	10	Tr.	S	----	----	35	15	5	5
T. 6 N., R. 33 E:																
29	NE¼NE¼ sec. 21	Silt	1	P	P	S	S	----	----	----	----	----	----	----	----	----
T. 5 N., R. 31 E:																
30	NW¼ sec. 29	Sand, silty, clayey.	----	P	P	S	15	----	----	S	----	S	45	----	20	----
31	NW¼ sec. 31	Sand, silty	.5	S	P	S	15	----	----	S	S	S	40	----	15	----
32	Center sec. 31	Sand	.5	P	----	S	15	----	----	S	S	S	50	----	10	----
33	NW¼SE¼ sec. 33	Sand, silty	----	----	P	S	10	----	Tr.	----	S	----	50	----	5	----
T. 5 N., R. 33 E:																
34	SE¼SW¼ sec. 10	Silt	1–1.5	P	P	S	S	----	----	----	----	----	----	----	----	----
T. 5 N., R. 34 E:																
35	NE¼SE¼ sec. 18	Silt, clayey	0	P	P	Tr.	Tr.	----	----	----	----	----	----	----	----	----
T. 4 N., R. 30 E:																
36	NE¼NE¼NW¼ sec. 4	Sand, silty to gravelly.	3–3.4	P	----	S	15	5	----	S	----	S	50	5	5	10
37	NW¼NW¼ sec. 22	Silt, sandy	1	P	P	S	S	----	----	----	----	----	----	----	----	----
38	SE¼NW¼ sec. 22	do	1	P	P	S	Tr.	----	----	----	----	----	----	----	----	----
39	NE¼SW¼ sec. 23	Sand, fine	1.5	Tr.	P	P	S	----	----	----	----	----	----	----	----	----
40	SW¼SW¼NE¼ sec. 26	Silt, sandy	1	P	P	S	S	----	----	----	----	----	----	----	----	----
41	SW¼SW¼NE¼ sec. 27	do	1	P	P	S	S	----	----	----	----	----	----	----	----	----
42	SE¼SE¼SE¼ sec. 27	Sand	----	do	P	----	15	5	----	S	----	----	50	----	25	5
T. 2 N., R. 28 E:																
43	NE¼SW¼NE¼ sec. 12	Silt, sandy to gravelly.	19.7	do	do	S	10	10	----	S	----	----	60	Tr.	25	----
44	SE¼SE¼NW¼ sec. 12	Silt	----	do	S	----	5	15	----	----	----	----	60	5	25	10
45	do	Sand, silty	----	do	P	S	15	5	Tr.	S	S	----	55	5	15	20
T. 2 N., R. 29 E:																
46	SW¼NW¼ sec. 18	do	2.5	35	20	10	5	25	Tr.	5	Tr.	----	60	15	10	10
47	SE¼NE¼ sec. 18	Silt, sandy	3	35	25	5	10	20	Tr.	----	----	----	50	10	20	15
48	do	Silt, clayey	7	30	45	10	10	5	Tr.	10	15	----	50	5	15	5
49	do	Silt, sandy	11	10	60	5	Tr.	20	----	----	----	----	75	10	15	----
50	do	Silt	13	30	35	10	5	20	----	----	----	----	75	15	10	----
51	Center sec. 18	Sand, silty	3	70	15	5	5	5	Tr.	Tr.	----	----	70	10	10	10
52	NW¼ sec. 18	Sand, silty	3.9	P	S	----	S	----	----	----	----	----	----	----	----	----
53	SE¼NW¼ sec. 18	do	3	65	20	10	5	----	Tr.	10	----	----	75	----	15	----
54	NW¼SE¼ sec. 18	Sand, fine	5	35	20	15	15	10	5	----	----	----	60	15	15	10
55	do	Clay, silty	8	45	40	10	5	----	----	----	----	----	70	----	30	----
56	SE¼SW¼ sec. 18	Sand, silty	4	35	25	15	5	15	Tr.	10	----	----	55	15	10	10
57	do	Silt, sandy	13	40	45	10	5	----	----	----	----	----	90	----	10	----

2–62μm) are quartz; the rest are calcite, feldspar, dolomite, montmorillonite, and hydrous mica. The clay-size particles (median diameters less than 2 μm), in descending order of abundance, are montmorillonite, hydrous mica, kaolin, quartz, calcite, and feldspar. Minerals of the kaolin group are listed under kaolinite. In addition to the minerals shown, some samples contained small amounts of chlorite, vermiculite, and hornblende.

There is little or no mineralogically pure clay in the NRTS, and even the clay-size components in many samples are quite impure, containing only 15–75 percent of clay minerals. For those specimens in which numerical percentages were estimated, the average amounts of the several minerals are as follows (expressed in percent of fine-grained fractions of gross samples):

	Clay size	*Silt size*
Clay minerals:		
Montmorillonite	36	7
Hydrous mica	27	8
Kaolinite	11	+
Quartz	12	53
Calcite	13	17
Feldspar	<5	12
Dolomite	----	9

The columns do not add up to 100 percent because the averages are not weighted. They are simple averages of the results for differing numbers of determinations for each mineral.

The data indicate that little of the clay was formed in place and that most of it probably was transported into the area by wind and water from areas where clay was being produced by chemical weathering.

GEOLOGIC MATERIALS AND THEIR SUBSURFACE DISTRIBUTION

SUBSURFACE EXPLORATION

By R. L. Nace, J. R. Jones, and P. T. Voegeli

TEST DRILLING

Contractual test drilling by the Geological Survey (1949–56) was done primarily to obtain hydrogeologic information related to problems of water production and waste disposal for which purpose 42 deep[4] test holes were drilled. Since that early phase of exploration, an additional several hundred test holes were constructed by power and hand auger methods to obtain hydrogeologic data at several sites on the station in connection with construction and special hydrologic studies. Production-well drilling by the Atomic Energy Commission supplied additional information.

Exceptionally deep test drilling (depths greater than 1,000 ft) was done in several parts of the station to explore the possibilities for artesian water at reasonably accessible depths and to obtain information on the thickness of the zone of saturation. Test holes 6N–31E–27ba1 and 2N–27E–33ac2 were sunk to 1,200 feet to test the depth and continuity of the zone of saturation at their locations.

Samples of drill cuttings were obtained whenever possible from each test hole and production well constructed on the station. Results of examination of drill cuttings were used in preparation of descriptive lithologic logs. Drillers' and lithologic logs of test holes and production wells are on file in the office of the Water Resources Division, Geological Survey, Boise, Idaho. The principal immediate purposes of the sampling and logging of wells and test holes were (1) to classify the basalt and related volcanic rocks in terms of the range of their essential-mineral composition, texture, structure, hardness, and other physical characteristics; (2) to determine the areal distribution of the several rock types; (3) to classify the sedimentary interflow beds and to study their relations to the basalt; and (4) to study the relations of lithology to water-bearing properties of rocks. Most of the drilling was in basalt layers which differ but little from one another in their mineralogic composition. The principal differences are in the shade of color, texture, and structure of the rocks. These differences are highly localized and generally cannot be used for detailed correlations between wells or test holes (or even in outcrops). The physical differences between the rocks are significant chiefly in relation to their drilling characteristics and water-bearing properties.

[4]For the purpose of this report a deep hole is defined arbitrarily as one more than 100 feet deep.

ELECTRICAL-RESISTIVITY AND SEISMIC SURVEYING

Test boring by churn drill or hydraulic rotary drill to determine the thickness of overburden is expensive and time consuming. Experimental electrical-resistivity surveys were made in the burial-ground site and vicinity to test the usefulness of the resistivity method for determining the thickness of overburden and mapping the configuration of the upper surface of the basalt. Owing to the low conductivity of the generally dry bedrock and gravel mantle and to the seeming lack of strong differences in their resistivities, the resistivity method did not yield reliable results. Test borings made after the resistivity survey showed that the apparent surveyed thickness of the overburden was substantially greater than the actual thickness. The equipment may have been inadequate for dry-ground surveying, and a stronger electrical current might give more reliable results, especially if the data were interpreted on the basis of more experience in the area. On the whole, however, electrical-resistivity surveying does not seem to hold promise for general use on the NRTS. A pneumatic rotary drill used by the Commission was sufficiently rapid and economical to eliminate the need for resistivity surveying.

Early experimental seismic surveying by the refraction method did not yield conclusive results. Although usable results might have been obtained with elaborate equipment, the cost for the type of information desired, and the time consumed, probably would have exceeded those for pneumatic rotary test drilling. However, later use of the seismic refraction technique showed that it is generally suitable for locating the top of the basalt underlying playa sediments (Barraclough and others, 1967, p. 79).

RADIOACTIVITY LOGGING

The most successful geophysical technique used on the NRTS was gamma-ray logging of test holes and wells. No gamma-ray logging had been done previously on the Snake River Plain. Gamma-ray logging is feasible in cased or noncased holes and consists in measuring the gamma radiation of the rocks in place in the hole. The chief immediate purpose was to obtain a record of natural or background gamma-ray activity at various places and in the several types of subsurface materials. An additional purpose was to test the effectiveness of gamma-ray logging for distinguishing the several types of basalt and sediment.

The sequence and types of geologic materials in many wells on the Snake River Plain are not known, owing to lack of drilling records. If the geologic materials in the hole can be logged, even in general by interpreting gamma-ray logs, vital geologic data about wells for which little information is known may be obtained. Thus, the method not only provides information needed in the immediate study on the NRTS, but it also is a potential source of indirect evidence about subsurface geology in wells that have been logged inaccurately or not at all.

In all but about 10 percent of the logged holes, the interflow sediments had higher activity than the basalt. Generally, fine-grained sediments had greater activity than did coarse sediments. Below the water table the intensity of radiation from all materials was dampened by ground water. Changes in the diameter and thickness of the casing also affected the intensity of radiation. Generally, more accurate record was obtained from small-diameter casing because in the smaller holes the probe was closer to the rock. Gravel packing in wells dampened the effective radiation of the geologic unit being logged because of the variable thickness, size, and rocky type making up the pack and because the material in the pack has its own radiation properties.

SUBSURFACE GEOLOGY

By R. L. Nace

Study of the subsurface geology of the NRTS concerned only the rocks about which direct evidence is available (table 1). Drilling did not extend to the lower limit of the Snake River Group, and only inferential knowledge is available about underlying rocks. Data concerning the subsurface geology were obtained directly from test holes and wells, foundation-test borings at construction sites, test borings of the thickness of sediments overlying basalt in construction areas and potential construction areas, caisson holes and hand auger borings, roadcuts, test pits, gravel pits, and excavations for building and other facilities. A report by Walker (1964) gives some additional interpretation of the subsurface geologic units.

SNAKE RIVER GROUP

Neither the maximum nor the average thickness of the basalt of the Snake River Group beneath the NRTS is known. Test hole 2N–27E–33ac2 ended in basalt at a depth of 1,200 feet, and basalt was drilled to a depth as great as 1,480 feet in test hole 4N–30E–6ab1. Basalt older than the Snake River Group, called the Banbury Basalt, occurs elsewhere on the Snake River Plain, and some of the older rock is well exposed in the Snake River valley between Twin Falls and Bliss. Older basalt has not been identified from drill cuttings in the NRTS, however, and it is assumed that all the basalt drilled is in the Snake River Group. On that basis, the maximum thickness is not less than 1,500 feet. The basalt thins to a featheredge, of course, where it overlaps older rock.

Within the basalt of the Snake River Group that underlies the station area, there are wide differences in the thicknesses and attitudes of single flows, in the texture and internal structure of the rock, in the numbers and types of joints, crevices, and other voids, and in the nature and thickness of associated interflow sediments. There are correspondingly wide differences in the resistance to drilling and excavating. Not only does the basalt vary vertically from flow to flow, but many of the same kinds of variations occur laterally within a single flow. Thus, it is difficult or impossible to correlate single subsurface flows, even where drilled by holes only a short distance apart. For example, comparison of the logs of the upper 300 feet of wells 3N–30E–19bc1 and 3N–29E–24ad1 (fig. 5), which are 508 feet apart, discloses no obvious correlation between the units shown. Each of the thick basalt units shown in figure 10, however, undoubtedly consists of several or more successive flows which are not distinguished in the graphic log. At those places where good samples of cuttings are available, it is possible by careful study to differentiate single flows, and such differentiation is an aid to correlation.

At all places where the basalt was drilled, it displayed monotonous sameness within its range of variation. A few flows that are doleritic in texture have mineral grains sufficiently coarse to be seen with the naked eye, as in the depth interval from 307 to 328 feet in test hole 4N–30E–7ad1. Basaltic glass is a large percentage of some samples, such as those from the depth of about 606 feet in well 4N–30E–6ab1 and in the interval from 75 to 95 feet in well 4N–30E–7ad1. Secondary minerals in the basalt are rare; they occur chiefly as calcareous coatings on joint surfaces and as linings of vesicles.

ALLUVIUM OF BIG LOST RIVER

Alluvium of the Big Lost River was drilled in many

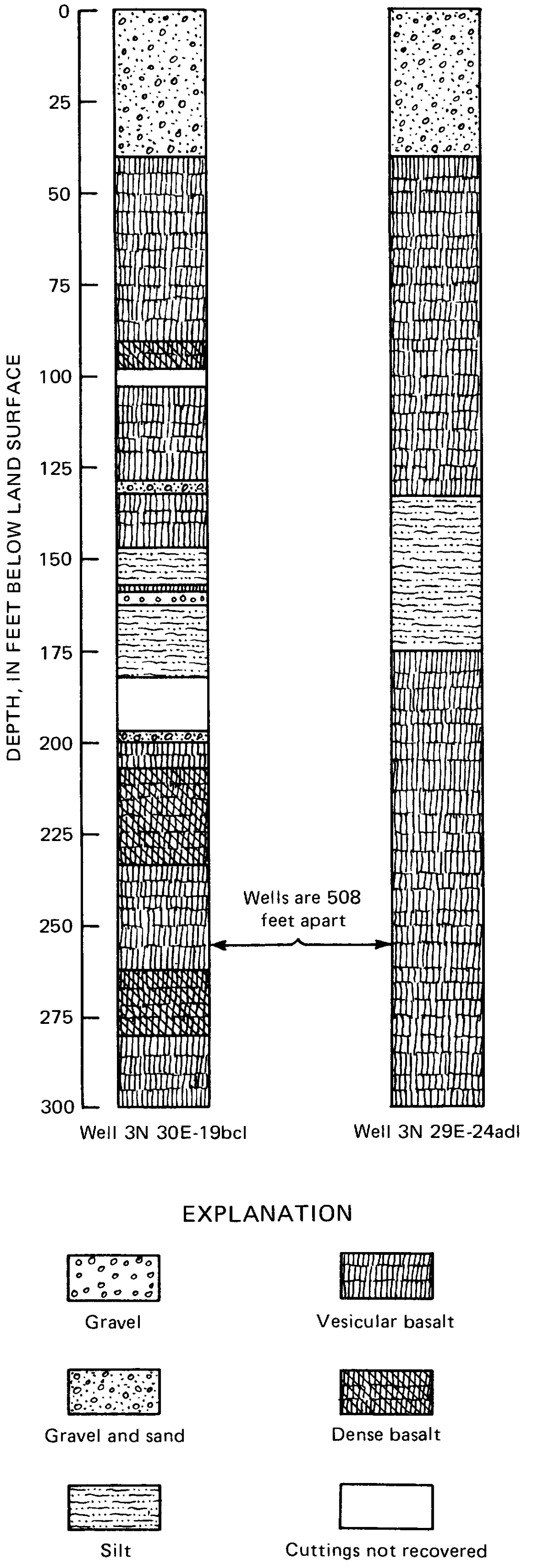


FIGURE 5.—Graphic logs of two wells showing extreme differences in subsurface geology through a short lateral distance.

test holes and borings. The greatest thickness found was 118 feet, in sec. 29, T. 5 N., R. 31 E., but greater thicknesses may occur at unexplored places. Some gravel interflow beds, such as those drilled in well 3N–30E–19bc1 and in numerous other wells and test holes, were deposited by ancestral streams, including the forerunner of the Big Lost River.

In most of the holes drilled on the alluvial plain of the Big Lost River, the alluvium is chiefly subangular to rounded sand and gravel in a silty-sand matrix. At some places, however, silt and gravelly silt predominate (well 3N–29E–14ac1, MTR area); elsewhere it is mostly gravelly, silty to sandy clay (test hole 4N–30E–7ad1).

UNDERLYING SILTY CLAY

Clayey silt, probably windblown, is interposed between the basalt and the alluvium of the Big Lost River at many places. Examples were encountered in test hole 3N–29E–14ad1 and numerous borings in the NTR area, in test hole 4N–30E–7ad1 (several miles north of STR area), and in wells and borings in the ICPP area. The material is buff colored and mostly calcareous and clayey, but at places it is silty to sandy and gravelly. The sediment undoubtedly is a windblown deposit that accumulated on the basalt before the alluvium was deposited; however, some of it had to be reworked by the river in order to explain the gravelly texture at some places.

In test hole 6N–31E–27ba1, near Big Lost River playa 3, a 6-foot bed of clay directly overlies the basalt beneath an alternating sequence of alluvial and lacustrine beds of clay, silt, sand, and gravel. The 6-foot clay bed may be lacustrine and unrelated to the silty clay farther south in the station.

ALLUVIUM OF BIRCH CREEK

Most of the area in which the alluvium of Birch Creek occurs has not been explored by borings or test holes. Local sections are exposed in gravel pits. At most of the few places where subsurface data are available, the alluvium rests on basalt. Neither the maximum nor the average thickness of the alluvium is known, but the observed range is 0–32 feet in test hole 7N–31E–34bd1. Greater thicknesses undoubtedly occur and, owing to the highly irregular configuration of the surface on which the material was deposited, there is great lateral variation in the thickness. Individual beds of the alluvium also are irregular in form, thickness, and lateral extent. At places the alluvium interfingers with deposits of ancient Terreton Lake.

TERRETON LAKE BEDS

The Terreton Lake beds generally overlie an irregular surface of basalt bedrock having considerable relief.

At some places gravelly material intervenes between the basalt and lake beds. The lake beds range widely in thickness as is shown by test holes 5N–34E–9bd1, 6N–32E–11ab1, and 6N–33E–26dd1 and by overburden test borings at the test site. The greatest observed thickness of lake beds is 137 feet (test hole 6N–33E–26dd1). However, not all the fine-grained subsurface sediments in the area occupied by Terreton Lake are deposits of that lake. The test pit at earth-crack locality 1 (fig. 6), for example, showed several beds of silt and sand that may be nonlacustrine. Moreover, the oxidized hard red zone between the depths of 43.2 and 44 feet and the fossil earth cracks there and in higher beds show that at several times during accumulation of the sediments they were exposed and dried subaerially. For example, the upper 3 feet of fine-grained sediment in the test pit is a playa sediment deposited after the last withdrawal of Terreton Lake. For these reasons the name, Terreton Lake beds, is applied to a distinctive local type of subsurface sediment and does not necessarily imply that all such sediments were deposited directly beneath ancient Terreton Lake.

FIGURE 6.—Fissure formed by slumping of walls. Near focus of earth cracks at locality 1, SW¼NE¼ sec. 13, T 6 N., R. 31 E.

The upper 126 feet of beds drilled in test hole 6N–31E–27ba1, all tan in color, undoubtedly is an alternation of alluvial, lacustrine, and playa deposits. Silt, the principal material, is interbedded with thin layers of clay, sand, and gravel. All the silt is calcareous, but most of the sand and gravel is not. A 6-foot basal bed of clay also is noncalcareous. Most of the beds are mutually gradational, but a 5 foot bed of sand and gravel at the depth interval of 45–50 feet contains little silt or clay and has sharp contacts.

Test hole 5N–34E–9bd1, near the southern boundary of the lake beds, penetrated only 24 feet of lake sediments. The upper 5 feet of material is clayey, sandy, light-tan silt which presumably was originally lacustrine but probably was reworked and redeposited by wind action. Beneath the silt is fine-grained silty, clayey, light-tan sand which coarsens downward in the depth interval from 18 to 24 feet. Both the silt and the sand are calcareous.

INTERFLOW SEDIMENTS

Interflow sediments were encountered in most of the test holes and wells on the NRTS. The sediments, like the basalt flows, differ widely among themselves in physical characteristics, thickness, and lateral extent. None of the interflow beds in any one well or test hole can be positively correlated, at present, with a bed in another well.

The relief on the bedrock surface controlled to some extent the thickness of the sediments; the accumulations generally are thickest in low areas. Hence, a thick section of sediments is not necessarily widespread (fig. 5), though it is apt to be more widespread than a thin one. Owing to the extreme irregularity of the basalt and sediment, it is not feasible to show detailed structural or stratigraphic correlations on cross sections of the NRTS. (See fig. 7.)

The history and mode of emplacement of the basalt and sediments explain the difficulty of correlating rocks from one hole to another and explain why materials drilled at one place are not necessarily the same geologic units as those drilled elsewhere at the same altitude or depth. The "lost rivers" of the modern Snake River Plain, for example, are not unique to modern time. Throughout the period of basaltic volcanic activity, streams discharged onto or across parts of the plain, but the basalt flows at times formed barriers to drainage off the mountains. Lakes, impounded between the volcanic rocks on the south and the foothills on the north, undoubtedly were common. Alluvial and lacustrine sediments accumulated on the basalt behind the barriers and later were covered by other basalt flows.

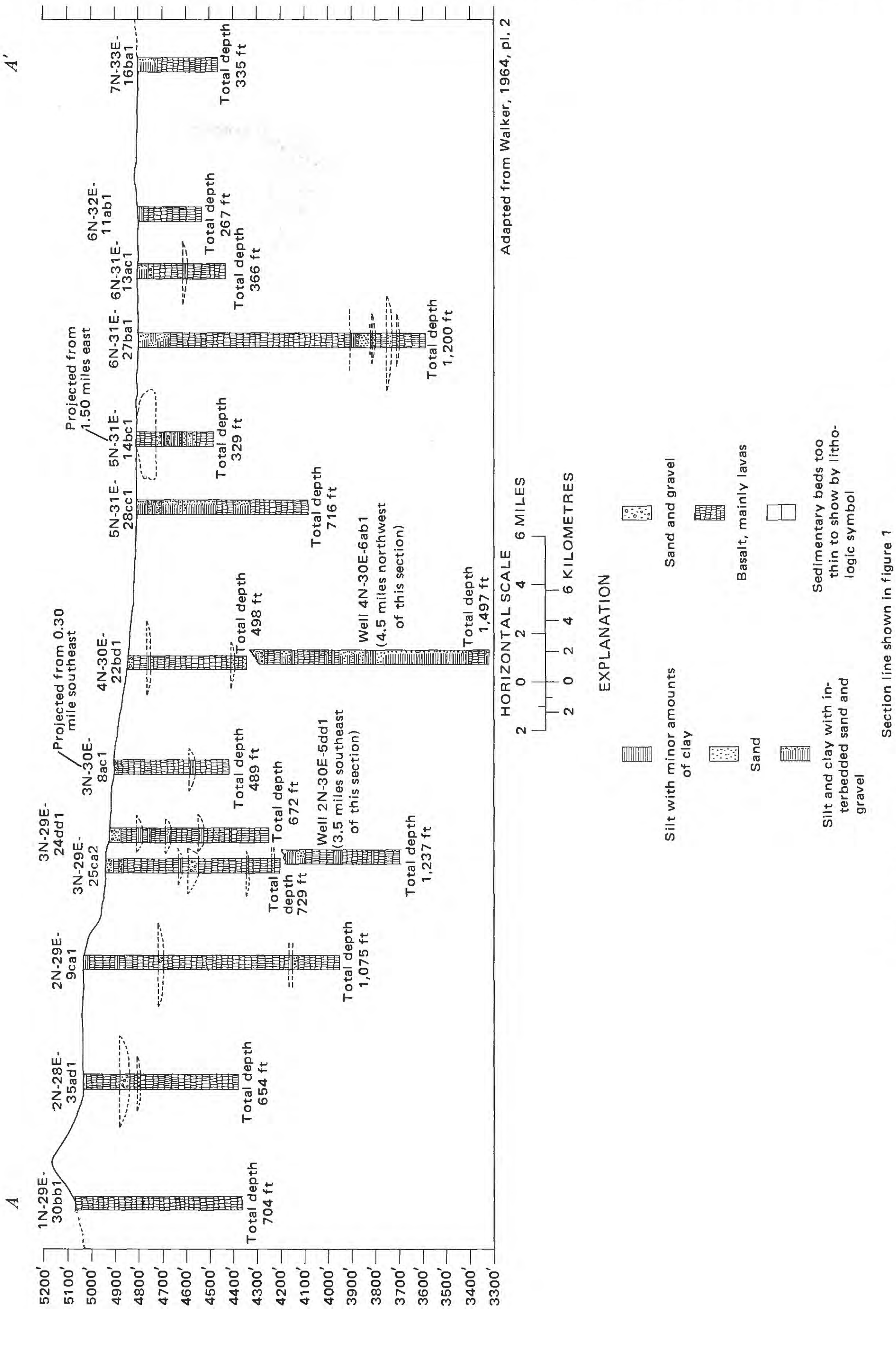


FIGURE 7.—Lithologic section A–A′, National Reactor Testing Station, Idaho.

In general the composition of the alluvial interbeds is quite similar to that of the surficial alluvium. Minor differences, however, were noted. Megascopic grains of mica are uncommon in surface sediments but are a conspicuous constituent of the sand from the depth of 735 to 744 and 760 to 765 feet in test hole 3N–29E–14ac2 and in a sandstone from the depth of 500 to 504 feet in test hole 4N–30E–7ad1.

The most common interflow sediments on the Snake River Plain as a whole are loess and windblown sand. Good examples of such material were found in test holes 6N–31E–27ba1, 4N–31E–16ad1, 4N–30E–7ad1, 3N–33E–3ab1, 2N–27E–33ac2, 2N–27E–2dd1, and 1N–29E–30bb1, and in wells 4N–30E–30aa1, 3N–30E–19ab1, 3N–34E–32bb1, and 2N–29E–9ca1. The thicknesses of the interflow units in those holes ranged from 0 to 532 feet. Other types of sediments, such as alluvial sand and gravel and lacustrine silt and clay, are common locally; on parts of the NRTS these seem to be more abundant than windblown materials. The sand and gravel particles are subangular to subround and range in size from very fine sand to pebbles. The most common coarse material is medium-grained sand and fine-grained gravel in which the fragments are of igneous, metamorphic, and sedimentary rocks derived from mountains on the northwest and west.

Unusually thick accumulations of fine-grained alluvial and lacustrine beds were drilled in test holes 4N–30E–6ab1, and –7ad1. About 75 percent of those beds are clay and silt, 20 percent are sand and friable sandstone, and 5 percent are gravel and gravelly sand. The beds represent about the full range of sediments exposed at the surface—alluvial, lacustrine, and eolian in origin; but no very coarse gravel beds were found. Most of the clay and silt are calcareous. The sand is chiefly tan in color, but some layers are pink, yellow, and orange brown.

The thick beds of sediments in test holes 4N–30E–6ab1, and –7ad1 were mostly unstable; therefore, they caused a great deal of trouble during drilling. In –7ad1 the top of a 77-foot bed of silt and intercalated fine sand and clay was struck at a depth of 538 feet. Interflow beds in –6ab1, predominantly clay, which were 121, 49, and 532 feet thick, were struck at depths of 419, 612, and 875 feet, respectively. The material from 419 to 540 feet was about 50 percent clay and 50 percent sand, gravel, and sandstone. More than 80 percent of the material from 612 to 661 feet was clay and silt, and the rest was fine sand. The thick mass of sediments from 875 to 1,407 feet, mostly clay and silt, probably was deposited in a lake. Gastropod and pelecypod shells and fragments were found in some of the cuttings from 1,060 to 1,230 feet in the lake beds and at various depths from 1,410 to 1,490 feet. Lake clay and silt were drilled from a depth of 1,480 feet to the bottom of the hole at 1,497 feet. These deep-lying sediments antedate the deposits of Terreton lake.

SPECIAL GEOLOGIC FACTORS IN EARTH MATERIALS

ION EXCHANGE

By R. L. Nace

All clay minerals, which are essentially hydrous aluminum silicates, can absorb and retain certain ions in an exchangeable state. Exchange of these for other ions may be accomplished by treatment with such ions, most commonly in an aqueous environment. "The exchange reaction is stoichiometric. The exchangeable ions are held around the outside of the silica-alumina clay-mineral structural unit, and the exchange reaction generally does not affect the structure of the silica-alumina packet" (Grim, 1953, p. 126).

Exchange capacity is not a property exclusively of clay minerals because all very finely divided inorganic material has some exchange capacity. The capacities of clay minerals, however, are large compared with those of most other minerals (table 5).

Both anion and cation exchange are included under the general term ion exchange. In the atomic-energy industry, natural ion exchange is especially important because it is a potential means of decontaminating liquid wastes released to the environment. Much remains to be learned about ion exchange, especially in regard to fission products and the possible conditions under which the exchange process may be reversed in natural sediments.

ION-EXCHANGE CAPACITY OF SEDIMENTS IN THE NRTS

Montmorillonite, one of the more efficient ion-exchange minerals (table 5), is the most abundant clay mineral on the NRTS. The next most abundant is hydrous mica, varieties of which have moderate to large capacities. Kaolinite, which is relatively much less abundant, has only small ion-exchange capacity. The clay- and silt-size material in all sediments on the NRTS has at least small to moderate exchange capacity. This ion-exchange capacity is well shown in laboratory

Table 5.—*Cation-exchange capacities of common clay minerals*

[After Grim, 1953, p. 129]

Mineral	Exchange capacity (meq/100 g at pH 7.0)
Kaolinite	3–15
Halloysite (2H_2O)	5–10
Halloysite (4H_2O)	40–50
Montmorillonite	80–150
Illite	10–40
Vermiculite (a hydrous mica)	100–150
Chlorite (a hydrous mica)	10–40
Sepiolite, attapulgite, palygorskite	20–30

tests of the clay- and silt-size fractions of gross samples that were made by Dorothy Carroll and Carol J. Parker of the Geological Survey. The results of tests of 160 samples are summarized in table 6. These data show that the fine-grained fractions from coarse sediments, such as gravel, have smaller exchange capacities than those from finer sediments. The reason is that the silt and clay fractions from fine sediments contain more clay minerals than do those from coarse sediments.

The clay minerals have higher exchange capacities than the nonclay minerals because in clay the exchange occurs both at the surface and within the crystalline lattice of the minerals. In the nonclay minerals, exchange occurs wholly or largely at the surface of the grain. The tests of the fine-grained fractions of sediments do not, of course, show the total exchange capacity of the gross samples from which the fine-grained fractions were extracted. The total capacity is somewhat greater than that shown by the tests, but it is not possible to set up rules for determining the total capacity by extrapolation or otherwise. In a silty clayey sand, most of the capacity is in the clay fraction, and little is in the silt. The sand portion has very low capacity. Even sand crushed to sizes less than 2 micrometres has an exchange capacity of only a few meq (milliequivalents) per 100 g (gram). Thus, the silt-clay fraction, even though it is only a very small fraction of the total sediment, has a very large percentage of the total exchange capacity. Accordingly it is believed that the exchange values reported in table 6 are in the correct order of magnitude for the total exchange capacity of the gross parent samples.

ION-EXCHANGE CAPACITY OF BASALT

The exchange capacity of basalt is relatively small. Determinations are difficult, and only a few preliminary tests have been made (table 7). The laboratory work was done by Dorothy Carroll and Hildreth Schultz of the Geological Survey. Broken rock was screened through sieves into nine size grades, and the exchange capacity was determined by an ammonium chloride method. One sample, composed of drill-hole cuttings of basalt, is quite fresh with no apparent alteration or formation of clay minerals. The second sample, pillow lava, also is quite fresh, but the glassy selvage differs from the rest of the rock. Clayey material associated with the pillow lava may be an alteration product.

The data are not sufficient for analytical comment. They show that the exchange capacity of the basalt is small except where alteration of the basalt has produced clay minerals.

DESICCATION AND EARTH CRACKS

By R. L. Nace and R. O. Smith

In July 1953 a set of unusual fractures developed in the Terreton Lake sediments in the SW¼NE¼ sec. 13, T. 6 N., R. 31 E. (here called locality No. 1). The geometric focus of the fractures was at the edge of a borrow pit adjacent to the newly graded, hard-surfaced Lincoln Boulevard. The main fracture was roughly S-shaped in plan, was about 350 feet long, and extended east-west. Another fracture, about 100 feet in length, extended southeastward from the focal point. The fractures extended through the pavement of Lincoln Boulevard at two places. Along most of the fractures, the horizontal separation of the walls at the surface intially was about 0.5– 1 inch. However water accumulated in the borrow pit following a heavy rain, and sediment from the walls was washed into the cracks. The wetted walls also slumped near the focus of the fractures and produced a fissure about 30 feet long, 3–4 feet wide, and about 3 feet deep (fig. 6). The fractures are here called earth cracks; the name is derived by analogy with common mud cracks. The writers believe that these are, in fact, giant mud cracks. The nature and cause of the cracks are of concern because their possible recurrence would influence engineering and construction plans for some types of structures.

The cause of ordinary mud cracks is desiccation, as is

Table 6.—*Summary of ion-exchange capacities of clay and silt fractions of sediments*

[Meq per 100 g of sediment. Analyses by Geological Survey]

Type of sediments[1]	Number of samples	Ion-exchange capacity: Range	Ion-exchange capacity: Average
Gravel:			
Coarse, clean	2	1.0– 2.9	2.0
Sandy	52	1.4–15.6	4.1
Sand:			
Clean	19	1.6–18.0	7.6
Silty	24	1.8–23.6	8.5
Silty and clayey	21	3.3–20.0	10.3
Silty, windblown	5	3.0– 7.5	5.2
Silt:			
Clean	4	6.2–34.8	20.4
Sandy	9	5.3–38.0	21.9
Sandy and clayey	17	7.1–30.4	13.5
Clayey	3	7.5–42.0	20.3
Clay, silty	1	--------	13.7
Soil mantle on acidic volcanic rock	1	--------	4.4
All sediments	158	1.0–38.0	8.8

[1]Terminology is based on size grades; mineralogic composition is not implied.

Table 7.—*Ion-exchange capacity of basalt*

[Meq per 100 g of rock. Analyses by Geological Survey]

Size grade	Sample 1[1]	Sample 2[2]: Rock	Sample 2[2]: Glassy selvage
>¼ inch			0.53
4 mm	0.98	0.42	.58
2 mm	.89	.58	.58
1 mm	.73	1.44	[3]1.33
.5 mm	.61	2.15	------
.25 mm	.86	3.78	------
.125 mm	1.32	7.71	------
.062 mm	2.80	12.23	------
<230 mesh	2.30	[4]22.64	------

[1]Fresh sample basalt of the Snake River Group; composite of cuttings from test hole on NRTS.
[2]Pillow lava adjacent to an interflow bed at Malad Springs in Snake River Valley. Exposed to weathering, but not much altered.
[3]All material that passed the 10-mesh sieve (<2 mm).
[4]Chiefly clayey material associated with the basalt; possibly an alteration product.

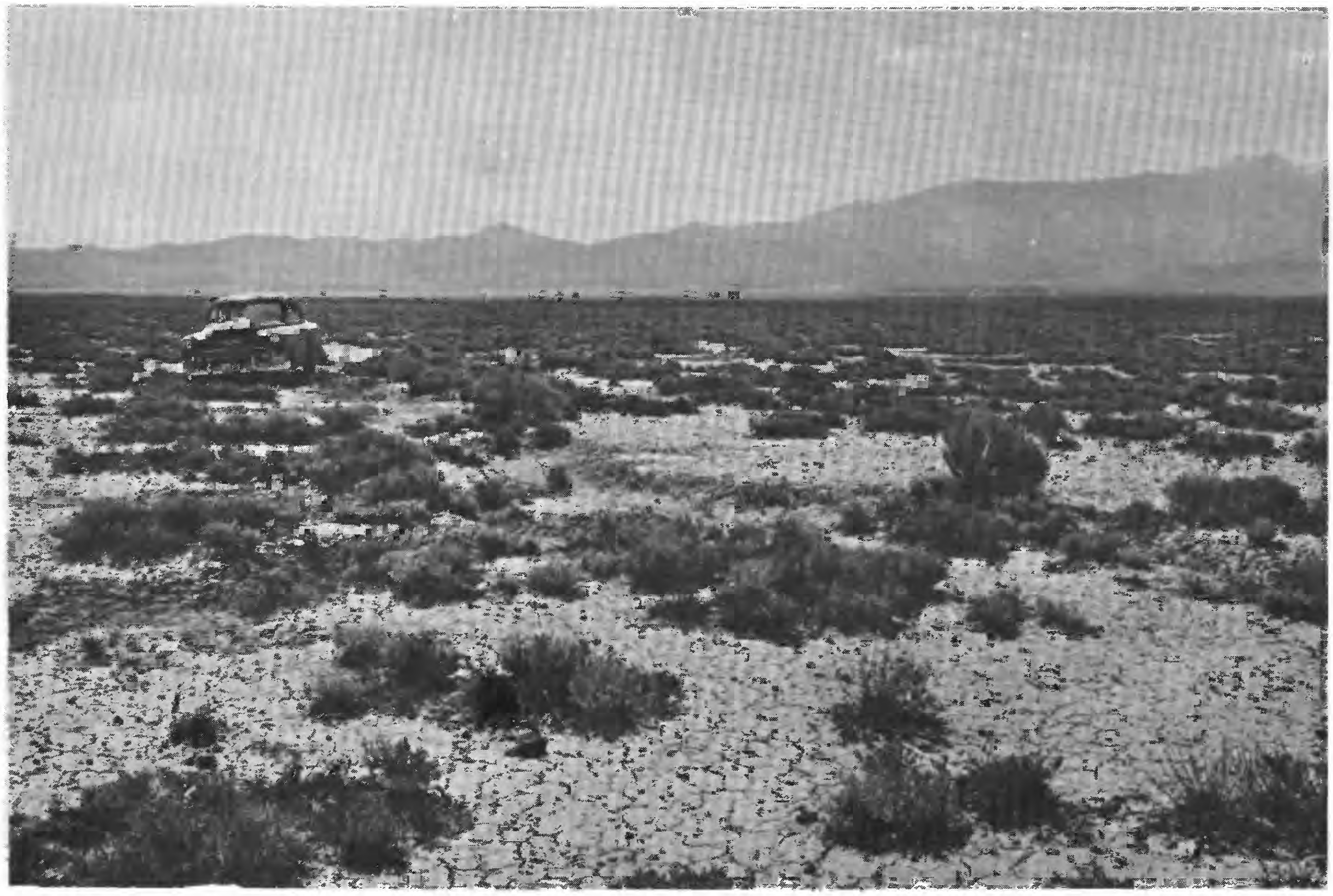


FIGURE 8.—Old earth crack in southern part of sec. 15, T. 6 N., R. 31 E.

well known. A similar cause for the earth cracks cannot be proved directly at this time, but various lines of circumstantial evidence point to desiccation as the principal agent.

DISTRIBUTION OF THE EARTH CRACKS

On the Birch Creek playa in the NW¼ sec. 23 and the SW¼SW¼ sec. 14, T. 6 N., R. 31 E. (locality 2), about a mile and three quarters southwest of locality 1, about 80 acres of land is marked by a system of shallow, linear depressions which make a plan pattern very much like that of ordinary mud cracks. These were discovered on aerial photographs in 1950 and were tentatively identified, after field examination, as "giant mud cracks." Subsequently, other old cracks were discovered at several places in the southern half of sec. 15, T. 6 N., R. 31 E. (fig. 8). These seem to represent cracks of all stages, from 1 or 2 years old to several to many years old. The linear depressions that mark the old cracks obviously were formed by slumping of the walls of the cracks. In this report, the "giant mud cracks" are called earth cracks, a term which is simple and implies a scale larger than that of mud cracks.

In the winter of 1953–54, a fresh earth crack that obviously had developed in 1953 was found near the east edge of locality 2, in the SW¼SW¼ sec. 14, T 6 N., R. 31 E. Subsequently, in the summer of 1954 several extensive sets of new earth cracks appeared on the floor of the Birch Creek playa in the SW¼SE¼ sec. 10 and the NE¼NE¼ sec. 22, T. 6 N., R. 31 E. (fig. 9). These cracks were similar in all respects to the new cracks at locality 1 and near locality 2; the similarity extends as far to include wide fissures where the walls of the cracks slumped. Earth cracks have not been found on the station area except in the Birch Creek playa and vicinity.

The earth cracks on the NRTS are not unique. Similar cracks on the floor of a playa in the Animas Valley, N. M. were described by Lang (1943), who attributed them to desiccation and shrinkage and called them "drying cracks." The climate, the topography, and the type of sediment in the Animas Valley are generally similar to those in the Birch Creek playa. The earth cracks in the Animas Valley are clearly shown on aerial photographs. Lang visited the site on several occasions during 1937–41. Because the year 1934 was one of extreme drought, Lang believed that the cracks may have

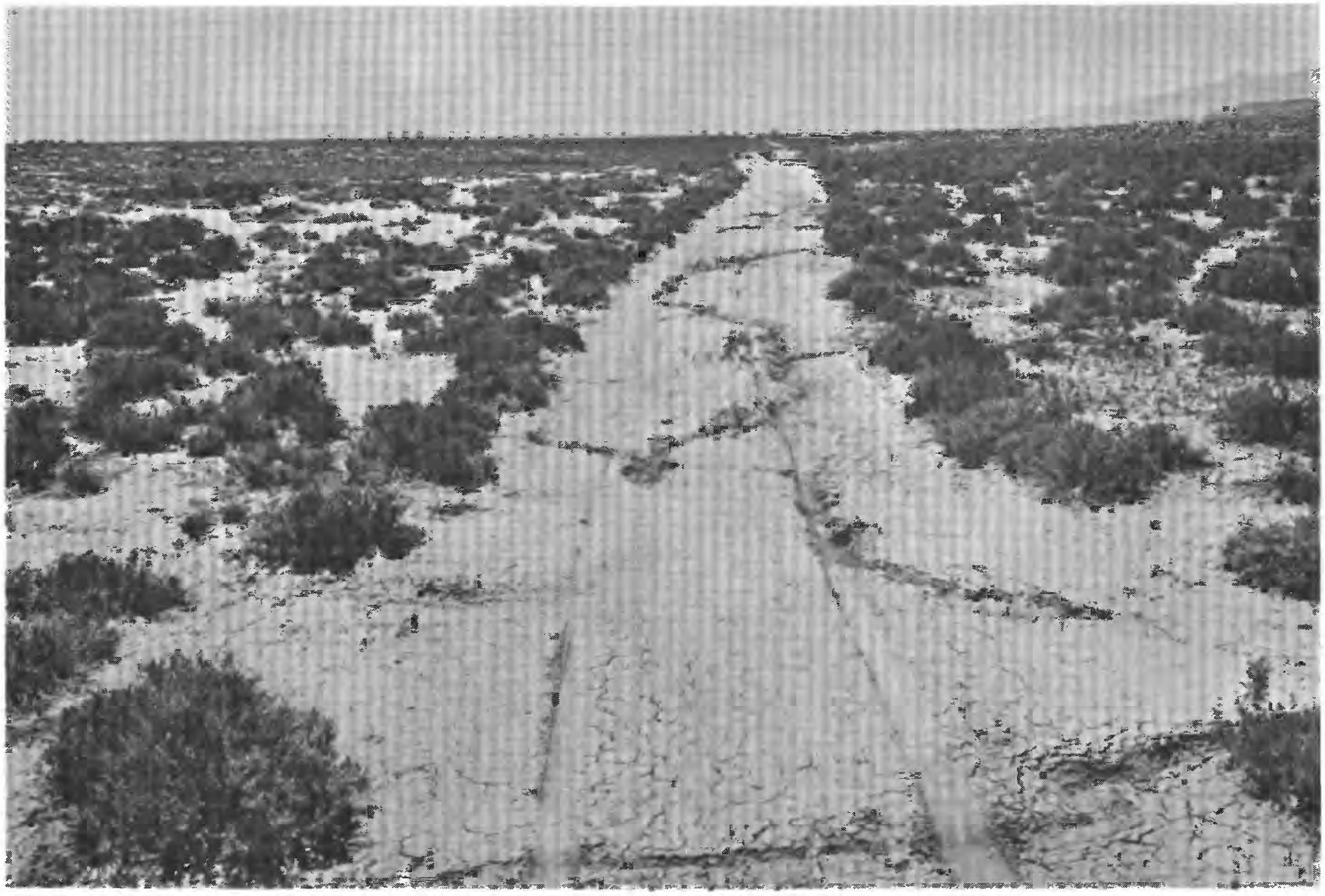


FIGURE 9.—Fresh earth cracks crossing road on floor of Birch Creek playa.

formed at that time. A resident of the valley recalled having seen in the playa floor open cracks that "were narrow but may have been two or three feet deep." The average width of the polygons bounded by the cracks was about 80 or 90 feet. The similarity to earth cracks in the Birch Creek playa is obvious. Seemingly, such features are unusual but not rare. Twenhofel (1932) noted that large cracks may develop to "depths of many feet on deltas and flood plains during long dry periods."

CHARACTERISTICS OF THE EARTH CRACKS

At locality 2 on the Birch Creek playa, the polygonal pattern of the earth cracks is made by elongated depressions 1–6 inches deep and 1–3 feet wide. The polygons are 50–100 feet across. Though the depressions and pattern are indistinct from the pedestrian perspective, they have been noted on aerial photographs. Because the depressions tend to collect moisture, they promote a more vigorous stand of vegetation than that growing in the interior of the polygons. The vegetation makes the depressions conscpicuous on aerial photos. Shrubs growing in the depressions indicate that the depressions are at least several years old. The depressions undoubtedly were formed when the walls of the earth cracks slumped, and sediment was washed downward to fill the cracks.

The fresh earth crack in the SW¼SW¼ sec. 14, T. 6 N., R. 31 E. closely resembles the earth cracks at locality 1. The crack is somewhat sinuous in plan, trends westward for about 60 feet, then turns abruptly southward for about 30 feet. The crack was still open when it was examined in 1954, and the horizontal separation of the walls ranged from 1 to 4 inches. Other fresh cracks that appeared in 1954 were similar in appearance, and at some places large fissures formed where the walls slumped. Owing to the dry climate, these remained open for many months and were still sharply defined in mid-1955.

Subsurface features of some of the cracks were exposed by excavating and were studied in detail. An excavation in sediments at the focus of the earth cracks at locality 1 reached basalt bedrock at a depth of about 51 feet (fig. 10). The three principal cracks were exposed in the northeast, southeast, and west walls of the excavation. To a depth of 4 feet, the cracks were open, and they ranged in width from 3 inches in the southeast

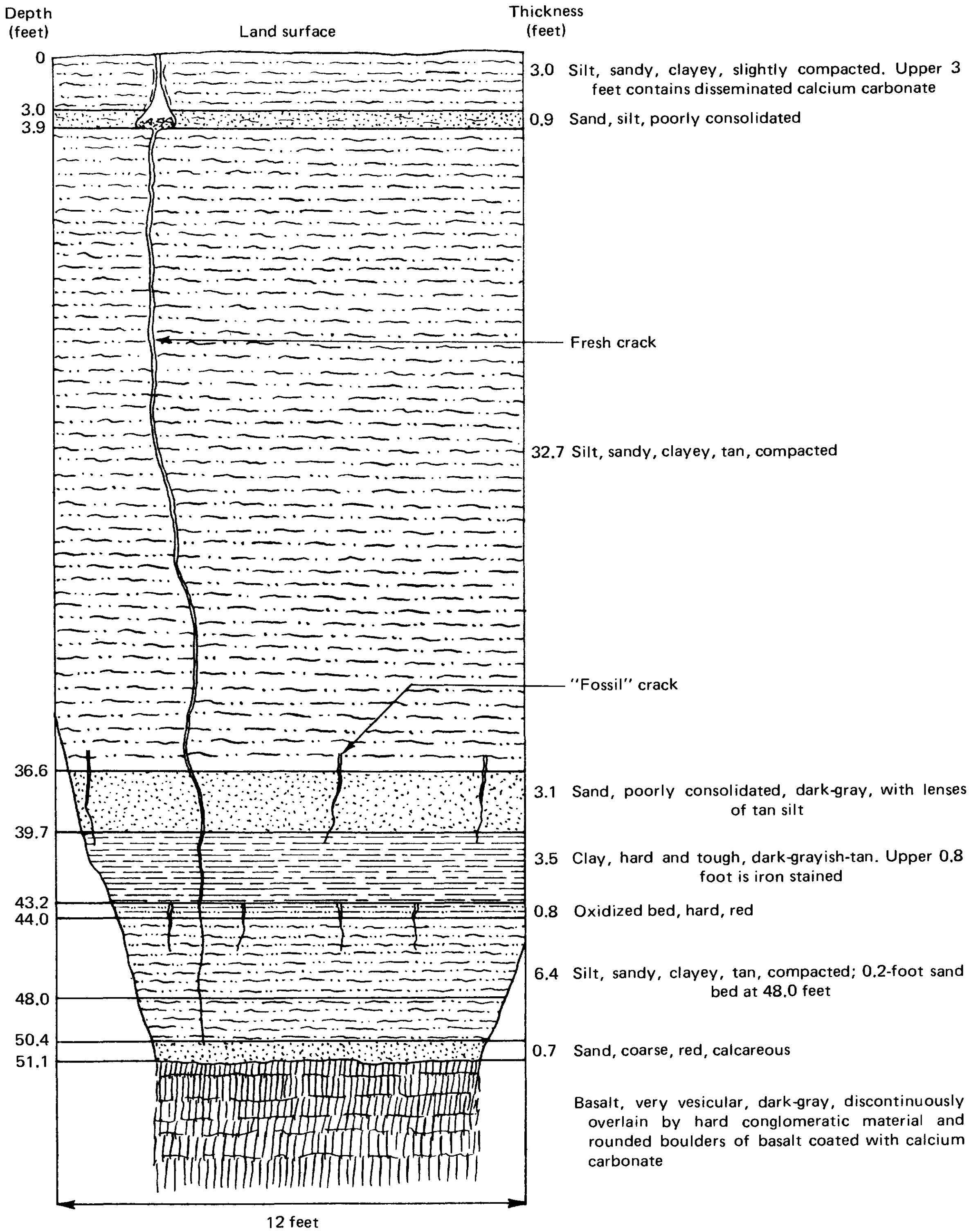


FIGURE 10.—Section exposed in west wall of excavation through earth cracks at locality 1, SW¼NE¼ sec. 13, T. 6N., R. 31 E.

crack to about 2.5 feet in the west and northeast cracks. The widened parts were partly filled with material that slumped from the walls. The maximum width of the cracks at the surface before slumping probably did not exceed 2 inches.

The width of the northeast crack is half an inch at a depth of 18 feet, three-sixteenths inch at 44 feet, and one-sixteenth inch at 49 feet. The crack does not extend below the depth of 49.7 feet, which is 4 inches above the bedrock surface.

The southeast crack is 3 inches wide at a depth of 4 feet and half an inch wide just above 42 feet. The crack disappears at a depth of 42 feet, about 9 feet above the bedrock surface, by breaking up into several parallel small cracks.

The west crack is one-eighth inch wide at a depth of 4 feet, half an inch wide at 39 feet, three-sixteenths inch wide at 44 feet and one-sixteenth inch wide at 50 feet. The crack disappears at a depth of 50.4 feet, which is 7 inches above the bedrock surface.

All the principal cracks are nearly vertical. They contain sedimentary dikes of light-colored sandy silt below a depth of 4 feet. The widths of the cracks diminish with increasing depth, and are confined to the sediments. The cracks do not extend into the underlying basalt. The basalt is intact except for ordinary joints and fractures which are original features. There was no evidence of new fracturing or other disturbances in the basalt. The original features of the basalt are readily recognizable and would be easily distinguishable from new features if these had been formed.

An interesting feature in the excavation at locality 1 is the presence of two systems of "fossil" cracks exposed in the walls at depth of 35.5 and 43.4 feet. Each system is independent of the other and of the new cracks. Aside from their small size, the "Fossil" cracks resemble the new ones. They are filled with sedimentary dikes, they involve the same geologic materials, they diminish in width with increasing depth, and they end within the sediments. The two systems of "fossil" cracks indicate that the earth cracked at this location at least two successive times during the past. The small size of the fossil cracks probably is an expression of the thinness of the blanket of sediment that covered the bedrock at the time the cracks formed. The blanket was only 7–15 feet thick, and the cracking probably was on a scale intermediate between ordinary mud cracks and "giant" earth cracks. The presence of the ancient cracks is evidence that the lake in which the sediments were deposited withdrew from the area at least twice before the final withdrawal and thus exposed its bottom deposits to desiccation.

In the Birch Creek playa, an excavation was made across the intersection of three older earth cracks in locality 2. The hole was 22 feet deep and did not reach bedrock. The cracks are nearly vertical, and above the depth of about 3 feet, they are filled with slumped material; below that depth they contain dikes of light-colored clayey silt. The cracks are filled now, but it is obvious that to depths of 3–3.5 feet the original shrinkage cracks were widened, as at locality 1, by slumping of the walls. Below the slumped zone the cracks are 1–2 inches wide at most, and they narrow downward to widths of 1 inch to one-fourth inch. The lower ends of the cracks were not reached by the excavation.

Near locality 2, in the SW¼SW¼ sec. 14, T. 6 N., R 31 E., a fresh earth crack was excavated to a depth of 11 feet. Above the depth of about 4 feet, the crack is partly filled with slumped material, and below 4 feet it contains a dike of loosely packed light-colored clayey silt. In the wall of the excavation, the crack has the following characteristics: is about 6 inches wide at a depth of 3–4 feet; widens rather abruptly to 2 feet at a depth of 5 feet; narrows gradually to about 2 inches at a depth of 10 feet. The erratic changes in the width of the crack obviously were caused by slumping.

CAUSE OF THE EARTH CRACKS

All the cracks excavated at the three localities have the following principal characteristics in common: They are in clayey silt, some of which is sandy, which encloses lenses of fine sand. The cracks extend nearly vertically downward and diminish in width with increasing depth; at shallow depth they are widened locally. The cracks are occupied by sedimentary dikes composed of transported material which is similar in composition to the enclosing beds.

Several possible causes for the fracturing have been considered, but only one cause, shrinkage of sediments undergoing mass desiccation during a term of years, is supported by geologic evidence. The evidence is conclusive that the cracking is a superficial phenomenon, restricted to the fine-grained lake and playa sediments overlying the basalt in the northern NRTS. The basalt neither causes nor participates in the cracking.

The "fossil" cracks exhumed at locality 1 and the occurrence of both old and new cracks in younger sediments show that the cracking is discontinuous and recurrent. The process probably is very slow, and sets of fractures completely surrounding vertical prisms of earth would not necessarily develop simultaneously. One or more sets of fractures may develop successively in a given area, perhaps during successive periods of desiccation months or years apart, and ultimately produce the well-developed earth-crack pattern exemplified at locality 2.

Construction activities in the vicinity of locality 1 caused saturation wetting of the soil at some places. At other places drying out of natural soil moisture may have been accelerated by construction work. Such factors may have triggered latent cracking but are not the primary cause because cracking has occurred where no such activities have taken place. On the other hand, the combination of a dry climatic interval in recent years and the cessation of surface runoff into the Birch Creek playa may have led to progressive desiccation of the playa area during a period of many years just past. The cracking is largely unrelated to construction work in the ANP area; therefore, further cracking may recur at specifically unpredictable locations and without discernible warning.

GEOLOGY IN RELATION TO CONSTRUCTION

By R. L. Nace and J. R. Jones

The rocks and sediments on the NRTS differ widely among themselves in the physical properties that directly affect the drilling of test holes and wells and the construction, maintenance, and operation of facilities. The behavior of materials during drilling, the availability and suitability of raw materials for construction, and the stability of materials in excavations, under load and under a range of moisture conditions, are some of the more important properties. Geologic factors that would directly influence engineering design, construction, and operations were studied chiefly at specific sites on the NRTS. The available engineering-geologic information is summarized herein; new data not previously available is included as well as some information furnished to the Atomic Energy Commission by consulting engineers and service laboratories.

TEST-HOLE AND WELL DRILLING

Shallow drilling for foundation testing and similar purposes offers no unusual problems. However, the drilling of each deep test hole or well is an individual problem, although past experience on the NRTS probably represents fairly well the range and diversity in drilling conditions and the problems that may be encountered.

METHODS OF DRILLING

The cable-tool (percussion) method of drilling seems to be the only method that is generally practical in the Snake River Plain. Light-weight rigs are generally unsuitable for drilling in the Snake River Group, even in small-bore holes. The basalt is tough and sufficiently elastic that light tools tend to bounce without cutting effectively. It is extremely difficult to get a straight hole with a light rig and tools because they are easily deflected from the vertical by joints and other irregularities in the rock. For small to medium-bore holes, a medium-weight rig that will swing a moderately heavy string of tools is very effective.

The hydraulic rotary method is generally unsuitable because drilling water would be lost in the many large natural voids in the basalt, and circulation of drilling fluid would be difficult or impossible to maintain. Also, open rock joints and abrupt changes in resistance to the drill would cause excessive wear of bits and breaking of tools.

If it is necessary to set casing before a hole is completed, the drill bore must be reduced to continue drilling. If it is desired to sink the large casing deeper, however, it sometimes can be done by underreaming in the small-bore hole, thereby allowing the larger casing to descend. In general, however, underreaming with a cable-tool drill is slow and laborious and most drillers try to avoid the practice. Nearly 700 feet of test hole 4N–30E–6ab1 were underreamed to lower 10- and 8-inch casing, but the work was extremely difficult, partly because the gummy mud formed by clayey sediments in the hole prevented proper hinging action of the cutting elements on the underreamer.

Drillers who have had experience in drilling volcanic rock other than the Snake River Group, as in the Columbia Plateau, commonly have difficulty in basalt of the Snake River Group and must acquire new or modified drilling techiniques. That is because of certain basic differences between the Columbia River Group of Oregon and Washington and and the Snake River Group of Idaho. Ordinary Columbia River basalt is relatively dense, hard, and brittle, with tight joints. The drilling rate is rather slow, and drill bits wear rapidly. Hole alinement, however, ordinarily is not unusually difficult to maintain. The basalt of the Snake River Group, on the other hand, is porous and tough, and its joints tend to be open or loose. The average drilling rate reportedly is more rapid than in Columbia River basalt and bit wear is not excessive, but hole alinement is difficult to maintain.

Well screens are not needed in wells tapping the basalt of the Snake River Group, but at those places where fine-grained interflow sediments or cinders occur below the water table, special measures may be required to case off or otherwise exclude or stabilize the sediment. Most production wells on the NRTS are very simple in design, they have a single size of casing extending from top to bottom. The casing is perforated in the interval from a few feet below the water table to a few feet above the bottom. Before a well is pumped the annular space between the casing and the wall of the drill hole is backfilled with graded coarse gravel from the bottom to a few feet above the water table. A seal of concrete covers the gravel, and most of the remainder of the space is backfilled with gravel or native earth. The upper part of the space is backfilled with puddled clay or other impervious material which serves as a seal.

Most wells that tap water in the basalt of the Snake River Group require little or no development, and many require little or no cleaning. In short, most wells are essentially ready for production as soon as construction is completed. The water usually clears up within a few minutes after the start of pumping.

A small percentage of wells is troublesome chiefly because of fine-grained interflow sediments in the zone of saturation. Gravel packing does not always prevent loose sediment from moving into the well and muddying the waters.

RAW MATERIALS

The alluvium of the Big Lost River is an abundant, widespread, and easily accessible source of road metal, earthfill, and concrete aggregate. The principal sources of coarse material are on the alluvial plain south of the latitude of State Butte bridge on Lincoln Boulevard. Northward from there, the alluvium is finergrained, it grades into silt and sand with a few beds of fine gravel. The Birch Creek alluvial fan is a convenient source of similar materials in the northern part of the NRTS, from several miles north of Pole-line road northward to the station boundary. The alluvium of the Big Lost River and that of Birch Creek is largely stream-channel and flood-plain deposits of subrounded to well-rounded fragments. Alluvial fans along the foothills of the Lemhi and Lost River Ranges are good sources of more angular gravel. All the gravel contains alkali-reactive minerals; the amount of these differs from place to place and may be excessive locally, especially for use with high-alkali cement. Opal, an outstanding alkali-reactive mineral, has not been found in the gravel, but its chemically related minerals, chert, chalcedony, and acid volcanic glass and rocks have been. Secondary mineral coatings on the gravel pebbles are largely calcium carbonate. Engineering tests reportedly show that the coastings do not materially lessen the strength of the concrete.

Abundant sand for fine aggregate is available in many parts of the station, especially north of State Butte and south of Pole-line road. Silt and clayey material, suitable as a binder for road metal, is abundant in the lake and playa floors of the northern NRTS and in the discontinuous mantle of loess in the basalt areas. The basalt is suitable for crushed road metal, ballast, and aggregate , but ordinarily it is not economical to quarry and process. Highly porous lava is unsatisfactory for aggregate because of its low strength, light weight, and high water absorption. Basaltic scoria and cinders, which occur in some of the volcanic cones in and near the NRTS, are suitable for roadbuilding, for which they are widely used throughout the Snake River Plain. The basalt is not economical to quarry and process. Highly porous lava is unsatisfactory for aggregate because of its low strength, light weight, and high water absorption. Basaltic scoria and cinders, which occur in some of the volcanic cones in and near the NRTS, are suitable for roadbuilding, for which they are widely used throughout the Snake River Plain. The basalt is not generally suitable for building stone because it is difficult to quarry and to hew.

Limestone and sandstone are available in foothill quarries near the NRTS in the complex of Paleozoic rocks. No nearby sources of shale are known.

EASE OF EXCAVATION

The sediments that occur on the Station are easily excavated by bulldozer, clamshell, dragline, or power shovel, usually without blasting. Some of the fine-grained compacted sediments in the northern NRTS require blasting. Little of the basalt bedrock is sufficiently loose to be removed without blasting or ripping. The major joint planes in the basalt are vertical, and therefore they are difficult to exploit in excavations. Planes of weakness other than joints and partings are uncommon in the basalt. Some highly vesicular layers are weak, and cinder beds ordinarily can be excavated as easily as sediments.

STABILITY OF MATERIALS IN EXCAVATIONS

Ordinary massive or tightly jointed basalt stands well in excavations, and wall support seldom is needed. Cinder beds and layers of loose blocky basalt in deep steep-walled excavations and tunnels, however, would require support. Basalt that is cut by extensive joint systems also tends to be unstable.

Excavations in foothill alluvial-fan materials are quite unstable because of the general lack of compaction and the absence of natural cementation. Walls of shallow excavations in the alluvial-plain gravels commonly stand well for short periods of time, and some walls have remained fairly stable for several years. Vertical walls, however, are unsafe because they tend to ravel and cave in excavations more than a few feet deep. The stability of the gravels is variable from place to place, owing to differences in the amount and texture of the matrix and in the degree of compaction and secondary cementation. Shorting of steep walls in deep excavations would be prudent if excavations are to be kept open for extended periods or are to be occupied by workmen. Sloping walls can be stabilized to some extent by spraying with a light coat of cement. The cement adds a little strength to the material and also excludes moisture, thereby preserving the natural stability of the dry material.

Excavated vertical walls in the Terreton Lake sediments and playa beds stand for long periods with very little slumping so long as they are dry. When wetted, the walls are prone to slough and cave, and they are unsafe in rainy or thawing weather.

STABILITY OF MATERIALS UNDER LOAD

The earth materials on the NRTS range widely in their response to structural loads. Basalt bedrock is the most suitable available foundation for heavy structures, especially for those applying concentrated or unevenly distributed loads. The unconsolidated sediments, especially the alluvial gravel, are a suitable support for many types of structures, especially for those applying well-distributed loads.

BASALT

Ordinary slightly vesicular to dense basalt of the Snake River Group has unconfined compressive strengths ranging from about 500 to 1,300 tons per sq. ft., whereas the strength of moderately vesicular to very vesicular basalt is in the range from 100 to 500 tons per sq. ft. The compressive strength of an "average" basalt probably is on the order of 500 tons per sq. ft. Tests were made[5] on 2⅛-in. drill-core samples of the Snake River Group from the SE¼NW¼ sec. 13, T 6 N., R. 31 E. Eight feet of core from basalt bedrock beneath the overburden was cut into lengths of about 0.4 foot. The end surfaces of each length to be tested were polished smooth, normal to the long axis. Tests of five of the sections yielded the following results:

Core No.	Depth below land surface (ft)	Total load strength (lbs)	Total load strength (tons per sq ft)	Nature of core
1	41.0–41.4	8,200	166	Very porous
2	43.7–44.1	15,400	311	Very porous
3	44.8–45.2	20,300	410	Medium porous
4	45.4–45.8	27,800	562	Fairly tight
5	48.0–48.4	15,800	320	Fairly tight on one end, extremely porous on other.[1]

[1]The strength determined, therefore, was that of the "extremely porous" part, not of the "fairly tight" part.

The conclusion was drawn that "Even the weakest rock encountered at this site can be subjected to a bearing capacity of 150 tons per sq ft without danger of shear failure***" (Porter and Company, 1952).

A second series of tests was made[6] on similar basalt cores from the NW¼NE¼ sec. 12, T. 6 N., R. 31 E., with the following results:

Core No.	Depth below surface of bedrock (in)	Total load strength (lbs)	Total load strength (tons per sq ft)
6	2–7	34,500	690
7	11–16	26,300	525
8	22–27	43,200	863
9	35–40	31,500	630
10	47–52	24,400	488

All the cores, numbers 6 to 10, were of "very tight" (nonvesicular) basalt. The conclusion was reached that "Even the weakest rock at this site can be subjected to a bearing capacity of 250 tons per square foot without danger of shear failure***" (Porter and Company, 1952).

Several series of compressive-strength tests were made by the Idaho State Highway Department[7] of basalt cores representative of the common bedrock at the MTR and EBR (Experimental Breeder Reactor) sites. Tests of cores having different diameters but of identical materials did not reveal significant differences in strength due to core diameter. The results of tests (table 8) are summarized below.

	Compressive strength (tons per sq ft) Range	Compressive strength (tons per sq ft) Average
Vesicular	153– 572	327
Slightly vesicular	444– 824	623
Minutely vesicular	263– 865	590
"Crystalline" [= densely crystallized?]	865–1,291	1,139

Four types of basalt were differentiated in the laboratory of the State Highway Department on the basis of vesicularity and crystallinity:

1. Vesicular; 10–25 percent voids, by volume.
2. Slightly vesicular; 1–10 percent voids, by volume.
3. Minutely vesicular; vesicles less than 1/32 inch in diameter, and ordinarily less than 5 percent visible voids, by volume.
4. Crystalline; less than 2 percent of volume is tiny intercrystalline voids.

The first three types were described as consisting of microscopic crystals and volcanic glass. The Idaho State Highway Department noted further that "The four types are normally present in successive order downwards in basalt flows of this area. Locally, very vesicular basalt with more than 25 percent vesicles caps the vesicular basalt [type 1]." Those observations of the cores agree with characteristics observed by geologists in the upper parts of ordinary basalt flows. The densely crystalline phase ordinarily is in the central interior of the flow, and downward from that phase the succession of types (phases) is repeated in inverse order and ends with a highly vesicular or granular glassy phase at the base. Seemingly, therefore, the cores represent the upper part of a single flow.

The "very vesicular" basalt was not tested, but it undoubtedly has substantially less compressive strength than the "vesicular basalt" (type 1). As would be expected, tests show that in the four types of basalt, the void volume and compressive strength are inversely related. Deviations from the general inversion undoubtedly are due to incipient fractures, random var-

[5]O.J. Porter and Company, Consulting Engineers, Sacramento, Calif., 1952, Report of tests conducted on cores taken of bedrock, test hole no. P–1: Typewritten memorandum to Atomic Energy Commission, Sept. 26.

[6]O. J. Porter and Company, 1952. Report of tests conducted on cores taken from bedrock at Test Hole No. P–3: Typewritten memorandum to Atomic Energy Commission, No. 6.

[7]Idaho State Highway Department, Materials Testing Laboratory, Boise, Idaho: Compressive strength of basalt cores from*** Reactor Testing Station, Idaho: Typewritten, not dated, 3 p. Tests made in August, November, and December 1949.

TABLE 8.—*Compressive strength of basalt cores from EBR and MTR sites*

[Tests by Idaho State Highway Materials Testing Laboratory, Boise, Idaho. V, vesicular; SV, slightly vesicular; MV, minutely vesicular; DC, densely crystalline]

Hole No.	Depth to bedrock surface (ft)	Depth of sample[1] (ft)	Type of basalt	Condition of core	Compressive strength (lb/in²)				
					Sample 1	Sample 2	Sample 3	Sample 4	Average
EBR site, sec. 9, T. 2 N., R. 29 E.									
BX (1⅝ in.) cores:									
P-1	8.5	18.4–20.6	SV	Short lengths	9,710	10,670	11,250	8,460	10,020
		29.2–32.0	MV	Few fractures	3,650	6,630	4,810	5,570	5,165
		88.8–90.6	DC	Long lengths	17,930	17,450	12,020	15,860	15,815
BX (1⅝ in.) cores:									
A-5	4.9	19	MV	Few fractures	8,980	6,300	8,100	8,500	7,970
A-7	3.0	19	SV	1–2-in. lengths	9,430	11,430	8,760	9,570	9,797
D-3	4.6	20	SV	1.5-in. lengths	6,160	8,540	7,770	7,160	7,407
D-5	15.5	26	MV	Few fractures	11,960	12,010	9,910	11,870	11,437
D-6	25.8	26	V	Close breaks	6,870	2,800	------	------	4,835
D-7	14.5	25	SV	2-in. lengths	6,450	6,640	7,960	7,390	7,110
G-5	8.8	10	V	Some fractures	4,530	4,490	4,390	------	4,470
MTR site, sec. 14, T. 3 N., R. 29 E.									
BX (1⅝ in.) cores:									
CD-4	41.3	42.2–42.4	V	0.2–0.4-ft lengths	2,870	------	------	------	------
		44.5–44.8	V	0.2–0.4-ft lengths	------	4,630	------	------	------
		46.0–46.4	SV	0.5–1.0-ft lengths	------	------	6,610	(¼-in. vesicle in break)	
NX (2⅛ in.) cores:									
S-1	54.1	56.6–57.5	V	0.3–0.8-ft lengths	7,940	------	------	------	------
		57.5–58.0	V	do	------	5,650	------	------	------
		60.0–60.6	SV	do	------	------	10,820	------	------
S-2	52.7	53.7–54.1	V	Fractured	3,300	------	------	------	------
		60.2–60.7	SV	do	------	9,550	------	------	------
R-12	42.3	42.3–43.0	V	Short lengths	4,500	------	------	------	------
		44.5–45.3	V	do	------	2,120	------	------	------
R-13	44.5	44.5–45.0	V	0.2-ft lengths, fractured	3,780	------	------	------	------
		47.0–47.5	V	do	------	5,650	------	------	------

[1]Depth of sample represents depth increment submitted for testing.

iations in the arrangement of the vesicles, and variations in the size and arrangement of mineral grains in the body of the rock.

The basalt in place underground may differ materially in overall compressive strength from the small core samples whose unconfined strength was tested. Most of the undisturbed rock probably is stronger. However, weak vesicular basalt underlying dense basalt may yield under load added to the dense basalt. Some extremely porous and "spongy" basalt can support only a few pounds of load per square foot; however, such material is relatively rare. If it is at the surface of the basalt, of course, it can be removed. So far as is known, no buried lava tubes have been found during subsurface exploration and testing on the NRTS. Several breached tubes are exposed on the station area and environs, however, and there is always an outside chance that a construction site may overlie a tube. Inasmuch as the geologic conditions vary unpredictably from place to place, exploratory boring and foundation testing ordinarily is necessary at construction sites, especially for heavy structures or those that may be potentially dangerous from the standpoint of nuclear safety.

LAKE AND PLAYA BEDS

The fine-grained lake and playa beds on the NRTS are relatively poor materials on which to support heavy loads, especially those materials that are concentrated or unevenly distributed. When wetted the materials are somewhat plastic. Tests have been made[8] of samples from four 2-inch test holes 25–51 feet deep. The holes were sunk by churn drill, and the samples were collected at intervals with a Porter 2-inch power-driven soil sampler. The testing-laboratory conclusions from the results of triaxial-compression and consolidation tests are summarized in table 9. The material to a depth of at least 13 feet was very dry and a fairly firm clayey silt and sandy silt. At some places a 10-foot bed of firm medium-plastic clay was found beneath the surface. Reportedly this material was somewhat oxidized and had mottled coloring. "Decomposed soapstone" reportedly was found beneath the clay in one hole overlying silty brown clay. The real identity of the "soapstone" is not known because true soapstone does not occur in the NRTS.

The laboratory tests were made on water-saturated core samples, but the materials were saturated only after being placed under confining pressure equal to the pressure of overburden in the natural state. The purpose of saturation was to simulate the least favorable condition that may arise at the construction site. The natural moisture content of samples ranged from 6 to 33 percent of the dry weight. The clay in two test holes, at a depth of about 30 feet, reportedly was saturated. The soil density ranged from 87 to 109 pounds per cubic foot.

[8]O. J. Porter and Co., Foundation Report, ANP area, National Reactor Testing Station, Sept. 22, 1952, 6 p., 13 pl.

TABLE 9.—*Allowable bearing capacities for footings at depth beneath the land surface in Terreton Lake beds*

[From report of laboratory tests by O. J. Porter and Co., consulting engineers]

Test-hole No. and location	Depth below land surface (ft)	Allowable bearing capacity (pounds per sq ft)	Material
P-1 and P-2	3	3,000	Clayey silt
SE¼NW¼ sec. 13	5	3,000	Clayey silt
T. 6 N., R. 31 E.	7–20	6,000	Sandy silt and silt
	20–24	[1]11,000	Sand
	28–40	14,000	Medium-plastic clay
	Below 40	2,600×D	Sand and gravel
P-3	3	3,500	Sandy silt
SW¼NE¼ sec. 12	5	3,500	Sandy silt
T. 6 N., R. 31 E.	7–42	[2]6,000–12,000	Sandy silt and silt
	Below 42	2,600×D	Sand and gravel
P-4	3	4,000	Sandy silt
NE¼SW¼ sec. 11	5	4,000	Sandy silt
T. 6 N., R. 31 E.	7–18	6,000	Sandy silt
	18–25	2,600×D	Sand and gravel

[1]Applicable only if sand is confined by 20 feet of overlying material.
[2]If confined by full weight of overburden, 6,000 pounds per sq ft at 7-foot depth and 12,000 pounds per sq ft at 42-foot depth. Where overburden is removed, allowable capacity is 6,000 pounds per sq ft.

The materials sampled with the drive corer differed markedly in their resistance to the drive-core sampler. Using a 1,200-pound hammer and 24-inch fall, the number of blows per foot of drive ranged from about 15 (sandy silt) to about 150 (firm silt).

GRAVEL

The gravel in the NRTS is generally high in bearing strength and thus presents no unusual problems for ordinary heavy loads, especially if the loads are well distributed. If fine-grained sediments are interbedded with the gravel, the material is less satisfactory as a base for structures. In many parts of the gravel-covered area, a layer of clayey to sandy silt is interposed between the gravel and underlying basalt bedrock. The material is somewhat plastic when moist. The depth through gravel to the basal layer of fine sediment ranges from a few feet to 50 feet or more. If the clayey material is at substantial depth, it may have little relation to shallow foundation problems. For deeper foundations, test borings commonly are put down through the gravel and silt to determined local conditions. For some heavy structures, the foundation includes caissons sunk through the sediments to a solid seat in the basalt; for others, the gravel is stripped off and the structures are supported directly on the bedrock.

A field test[9] was made on gravel in place in sec. 14, T. 3 N., R. 29 E. Under natural dry conditions, under a total load of 26,560 pounds (26,000 pounds added weight plus weight of bearing plate and accessories), and applied to a circular bearing plate having an area of 1 square foot, the total settling of the loaded gravel was 0.065 foot at the end of 10 days (table 10). In the first few days, under loads increasing from 560 to 8,560 pounds,

[9]Test by contract engineering services at the NRTS, Idaho: Report on soil-bearing test at CD-4, site 2A (MTR), Lost River Reactor Testing Station, Idaho, 1 p., Nov. 10, 1949.

TABLE 10.—*Compaction of gravel under load, sec. 14, T. 3 N., R. 29 E.*

[From records of the Atomic Energy Commission]

Date	Load (lbs per sq ft)	Total settlement (ft)	Remarks
Nov. 1949			
1	560	------	Started test 11:00 a.m.
1	4,560	0.010	At noon
2	4,560	.101	8:30 am
2	8,560	.012	11:00 am
3	8,560	.012	8:30 am
3	12,560	.014	11:00 am
4	12,560	.016	8:30 am
4	14,560	.020	11:00 am
5	14,560	.022	8:30 am
5	18,560	.038	11:00 am
5	18,560	.039	4:30 pm
7	18,560	.043	8:30 am
7	22,560	.043	11:00 am
8	22,560	.049	8:30 am
8	26,560	.053	3:30 pm
9	26,560	.055	8:30 am
10	26,560	.065	[1]8:30 am

[1]Ground wetted by application of 1,000 gallons of water during final 24 hours of test.

settling was at rates of about 0.0 to 0.002 foot per day. As the load was increased, the settling rate ranged up to about 0.016 foot per day. The final load of 26,560 pounds was applied during the last 41 hours, during which the amount of settling was 0.016 foot.

Three tests were made[10] on materials at the ICPP site—on undisturbed gravel, on a 2-foot cushion of gravel on basalt, and on gravel spoil excavated from a building site. Settling under loads of 9,000–12,000 pounds was on the order of a few sixteenths of an inch in periods of 3–4 days. Rebound after removal of the load ranged from 0 to about $^{1}/_{16}$ inch at the end of 2 days. Presumably, the tests were made with a standard-bearing plate having an area of 1 square foot.

Gravel in the alluvial fans spreading out from the foothills west of the NRTS is less compact and less stable than the flood-plain gravel and doubtless has a somewhat higher compaction factor.

LOESSIAL SOIL

"Soil" from a depth of 3–4 feet at the EBR site was tested for shearing strength and other properties at the University of Idaho.[11] The sample was of windblown silty sand. Shearing tests showed a coefficient of cohesion of 3.5 (lbs per sq in.) and an angle of internal friction of 30°00′. Consolidation tests showed a coefficient of consolidation of 0.915 $cm^2\ min^{-1}$ (sq cm per min) (Gilboy method; see Plummer and Dore, 1940) and of 0.0455 $cm^2\ sec^{-1}$ (Taylor method; see Taylor, 1938). Various tests of an "undisturbed" sample of the silty sand yielded the following results.

[10]Foster Wheeler Corp., letter, R. W. Hudson to H. N. LaCrois, Nov. 16, 1950.

[11]Bennett, G. B., University of Idaho. College of Engineering, Materials Testing Laboratory: report no. 3794, lab. No. M 2803, Nov. 2, 1949; report no. 3542, lab. No. M 2803, Oct. 25, 1949; report no. 4558, lab. No. M 2084, Nov. 12, 1949.

Atterberg limits

	Percent
Liquid limit	31.6
Plastic limit	19.9
Plasticity index	11.7
Shrinkage limit	16.0
Shrinkage ratio	1.78
Field moisture equivalent	21.5
Volume change (at FME)	9.8
Lineal shrinkage	3.0
Specific gravity	2.72

The sample had the following size-grade characteristics:

	Percent
Gravel (retained on 10-mesh screen)	5
Coarse sand (passed 10-mesh, retained on 40-mesh)	2
Fine sand (passed 40-mesh, retained on 270-mesh)	59
Silt (0.05–0.005 mm)	25
Clay (less than 0.005 mm)	9
Colloids (less than 0.001 mm)	1

Other tests of the same sample gave the following results:

Shear tests:	
Coefficient of cohesion (C)	11.0 lb/in^2
Angle of internal friction	25°50′
Consolidation test:	
Coefficient of consolidation:	
Gilboy method	1.31 cm^2 min^{-1}
Taylor method	.0775 cm^2 sec^{-1}

DRAINAGE, WEATHER, AND ACCESSIBILITY

Much of the NRTS is mantled by windblown silt. The deposits of Terreton Lake are fine sand, silt, and clay. Similar materials occur in various playas and in the northern part of the alluvial plain of the Big Lost River. The fine sediments have good moisture-retention capacity, but they absorb water rather slowly and are generally low in permeability. Light rains ordinarily yield little runoff, but occasionally heavy rains yield substantial runoff into local depressions, especially from steeper land surfaces. After heavy rains and during rapid thawing of snow and ground ice in the spring, many of the low-lying areas contain ponds or quagmires.

At times water from the Big Lost River, from ephemeral streams, and from local slopewash inundates low flats and playas. Big Lost River playas 1 and 2 were inundated for prolonged periods in 1951 and 1952 by runoff in the river. Rye-Grass flat and several other playas in the lava field were under several feet of water in February 1950. During times of heavy rain or rapid thawing, cross-country travel by wheeled vehicles is impossible, and most of the unimproved desert trails are impassable.

In ordinary years winter snow cover on the NRTS is light, but in exceptional years snow accumulates to depths exceeding 2 feet on open flats and up to 4–5 feet in some low areas. Snowdrifts form readily, and roads that trend across the direction of the prevailing strong winds often are blocked by large drifts. The ground commonly is frozen continuously from early December to late February. Frost heave in the soil and rock is strong, especially in late winter and early spring when there is frequent alternation of freezing and thawing. The depth of the frost zone is not known, but in severe winters it probably ranges from 3 to 6 feet. Frost heave causes considerable road damage and is a threat to shallowly buried pipelines and shallow building foundations.

The difficulty of vehicular traffic over the native terrain varies greatly with the local surface materials, the amount of soil moisture, the weather, and the type of vehicle. Flood plains, lake bottoms, and parts of alluvial fans are easily crossed when dry. Parts of the playas are flat, smooth, and nearly devoid of vegetation, and on these the chief dry-weather hazard to vehicles is scattered boulders. On the other hand, flood plains and lake bottoms are treacherous because of mud, even after light rainfall or during mild thawing. After heavy rain or deep thawing these areas commonly are passable only by tracklaying vehicles. Conventional vehicles can traverse most of the "desert" trails in dry weather, but trails crossing sand dunes or bare basalt are difficult. Dry windblown sand is a trap for two-wheel drive vehicles but commonly is passable when wet. Much of the native basalt area is too broken and rugged for cross-country passage by wheeled vehicles. When the snow cover is thick, only snow planes, tracklayers, and similar vehicles can traverse native basalt terrain.

DUST AND DRIFTING SAND

Wind erosion and transportation are conspicuously active only in the northern part of the NRTS where there are active sand dunes. Elsewhere on the Station, however, wind erosion becomes active wherever the native soil cover and vegetation are disturbed. In most of the area the soil is rather effectively stabilized by native vegetation. Some bare flats covered by fine soil have little or no vegetation, but these ordinarily are stabilized by a dried-mud crust. The native conditions thus favor low dust hazard, but wherever these conditions are disturbed, the dust becomes a problem owing to the strong prevailing winds and the ready susceptibility of all the fine sediments to wind action. New sand dunes can form and serious dust clouds orginate wherever the vegetation or other natural wind protection is disturbed, therefore, native vegetation should be protected and should be removed only where necessary. Wind action can be abated also by landscaping and drift fences, by developing artificial vegetative cover, and by avoiding unnecessary cross-country driving, that breaks the soil crust and kills vegetation.

Active sand dunes are not widespread on the NRTS; they are most numerous in the northern part south of Pole Line road. In that area small sand dunes tend to form locally and commonly drift across the desert roads (so-called sand shadows). The active large dunes in the vicinity of sec. 4, T. 5 N., R. 31 E. have migrated an appreciable distance during the period of development on the station. Visual evidence suggests that the front of the active dunes may have moved northeastward some hundreds of feet since 1949. Aerial photographs, taken now and compared to older photographs, would give an approximate measure of the amount of movement. The dune movement is potentially important because the direction of movement is toward the ANP area, including access roads thereto.

CONTROL OF DRIFTING SAND

Removal of drifted sand from roads or other places where it is not wanted ordinarily is a short-term expedient. Solid, fixed barriers to drifting sand also are expedients, because the barriers eventually become buried. Effective control of drifting sand depends upon careful study of the factors that govern the origin, growth, and migration of the sand in a specified area. The best results are achieved by artificially immobilizing the sand, by inducing destruction of the drifts, or by causing the wind to work toward a given objective, rather than by directly opposing the wind. In the latter alternative, the methods of protecting a stretch of road, for example, are not necessarily the same as those for protecting a building or group of buildings.

Detailed analysis of methods of controlling drifting sand is beyond the scope of this report. The physics of sand movement is discussed thoroughly by Bagnold (1941). Excellent descriptions of drifted-sand formations in Arabia are given by Kerr and Nigra (1952), who describe the experiences and successful methods of sand control of the Arabian American Oil Co.

EARTHQUAKE HAZARD

The Snake River Plain, including the NRTS, like other areas in the Northwest , is subject to occasional seismic tremors. The seismic record for the area is short—the oldest recorded shock occurred in 1884. There is no record of significant quakes originating within the plain, though disturbances have been felt in Pocatello and Arco. Sixteen quakes were recorded in Idaho during 1894–1945, and of these, the chief epicenters were more than 100 miles distant. The seismic data for the area are summarized in a special report (Anonymous, 1949, p. 63–65). The NRTS is in earthquake zone 3 (U.S. Dept. of Commerce, Coast and Geodetic Survey, 1969). Zone 3 denotes an area where major destructive earthquakes may occur.

Seismic tremors during earthquake activity are caused by rock-block movement on fault scarps producing vertical-ground and surface-ground displacement. The extent of occurrence, distribution, and magnitude of such displacement in the prehistoric and historic geologic record is significant for evaluating the potential occurrence of future displacement by seismic activity.

A preliminary review of seismic wave effects in the Station area was begun in 1965 as a result of the interest of the Health and Safety Division of the Idaho Operations Office, ACE in the seismological aspects of reactor safety (Barraclough and others, 1967, p. 103). Inasmuch as general seismic responses are observed on some water-stage recorder charts, available records showing seismic fluctuations were studied in relation to geologic factors such as lithology and structure. Although a seismic wave effect can be delineated on a water-stage recorder chart, the timing mechanisms on these recorders are not sufficiently precise for quantitative interpretation.

The potential for faulting and strong earthquake activity near the NRTS was investigated by M. G. Bonilla and G. H. Chase of the U.S. Geological Survey in 1967. Their work resulted in identifying various sites near the Station at which several kinds of geologic features indicated faults. These features consisted particularly of the Arco, Howe, and Mud Lake scarps and lineaments. The Arco and Howe Scarps were interpreted to be the consequences of geologically young faulting, and the Mud Lake scarp, which had been previously attributed to faulting , (Stearns and others, 1939, pl. 3, p.43), was believed to suggest an active fault zone because of seismic tremors felt nearby in 1911. An examination of lineaments several miles long on the lava plain and especially of a lineament extending about 17 miles northward from East Butte suggested that the lineaments were formed during emplacement of lava rather than caused by faulting. As the examination was based on a brief field reconnaissance, additional geologic and seismologic study is needed.

Further studies, including geologic and seismologic investigations, were authorized by the Division of Reactor Development and Technology, AEC, to obtain detailed information on only the conspicuous scarps and lineaments found by Bonilla and Chase. Detailed information was needed to evaluate whether the scarps were formed by faulting and, if so, whether data were also needed on the ages and displacements of particular faults. Detailed studies of lineaments would include their possible relation to faulting. Thus, areas selected for detail study consisted of the scarps north and south of Arco and Howe and the scarp and Mud Lake because "They were the most obvious potential sources for large earthquakes near the NRTS" (Malde, 1971, p. 3a).

In order to detect small and moderate earthquakes that might occur in the area and to locate their epicenters with respect to geologic structure, a network of six portable seismometers was established around the Station. This network was operated from December 1968 to September 1969 by the U.S. Geological Survey's National Center for Earthquake Research. Results of this investigation are discussed by A. M. Pitt and J. P. Eaton (in Malde, 1971, p. 159–163). The following conclusions by Malde (1971, p. 8–10) summarize the results of these geologic and seismologic studies near the NRTS.

Well-defined high-angle faults were exposed by trenching across scarps in alluvial fans along mountain ranges north of Arco and Howe, Idaho, a few miles from the NRTS boundary.

The Arco scarp coincides with a zone of closely spaced faults in alluvial fans along the western foot of the Lost River Range. It extends northward about 10 miles from Arco. The southern end of the scarp has been eroded by the Big Lost River, and the northern end merges into an unstudied scarp in bedrock. As a topographic feature, this range-front fault zone has a length of more than 20 miles, of which the Arco scarp is the southern part. As determined by trenching in alluvial fan deposits at one place on the Arco scarp, multiple movements in the fault zone have resulted in an aggregate vertical displacement of at least 40 feet. Measured offsets of stratigraphic units within the fault zone indicate at least two episodes of vertical movement on individual faults. One episode of movement caused a minimum vertical offset of 15–20 feet, and another offset was more than 10 feet.

The Howe scarp coincides with a zone of closely spaced faults in alluvial fans along the western foot of the Lemhi Range. A southern segment of the scarp follows the southern part of the range a distance of 9 miles, and a northern segment is at least 4 miles long. These segments are separated by a bedrock ridge 2 miles wide in which the scarp in indistinct. As determined by trenching in alluvial fan deposits at one place on the southern segment, multiple movements in the fault zone have resulted in an aggregate vertical displacement of at least 50 feet. Measured offsets of stratigraphic units in the fault zone indicate four or more episodes of vertical movement on individual faults, ranging from 1 foot to more than 10 feet.

The hazard represented by the fault displacements measured at the Arco and Howe scarps can be appreciated from records of historic earthquakes caused by movement on fault scarps in the Rocky Mountains and the Basin-and-Range province.*** For example, the 1959 Hebgen Lake earthquake in Montana (Richter magnitude 7.1) was accompanied by vertical ground-surface displacements of as much as 20 feet along prehistoric scarps. Surface displacement on the main fault occurred along a length of 15 miles. In Nevada, the 1954 Fairview Peak and Dixie Valley earthquakes (Richter magnitudes 7.1 and 6.8, respectively) were accompanied by vertical ground-surface displacements of from 7 to 12 feet along prehistoric scarps. The surface displacements on these faults were 36 and 38 miles long, respectively. Also, during the 1934 Hansel Valley earthquake in northern Utah (Richter magnitude 6.6.; Eppley, 1965, p. 58), ground-surface displacements of nearly 2 feet were observed on a fault segment about 5 miles long.

For the Arco and Howe scarps, although the total length of particular faults cannot be readily determined, the overall lengths of the scarps and the measured amounts of individual displacements are comparable to such features seen at places of historic faulting in Montana, Nevada, and Utah, as explained above. By this analogy, the faulting that accounts for the Arco and Howe scarps must have been accompanied by large earthquakes.

Faulting in the alluvial fans near Arco and Howe is geologically young. However, the total displacements of underlying bedrock caused by vertical movement on the range-front faults amounts to thousands of feet, and the ages of the displaced bedrock show that the first movements began millions of years in the geologic past. Thus, the observed faults in the alluvial fans are merely a result of the latest of many episodes of movement. To avoid underestimating the geologic hazards shown by these faults, the time of latest faulting is assumed in this report to be possibly as young as allowed by the available field evidence. Thus, at both the Arco and Howe scarps, the evidence indicates faulting in the last 30,000 years, possibly more recently than 10,000 years ago, and movement within even the last 4,000 years cannot be ruled out. Because the probability of renewed faulting along the Arco and Howe scarps is directly related to the decreasing age of the visible faults, this evidence of geologically recent movements implies a greater risk for future earthquakes than do the older displacements.

In summary, the lengths and displacements on the Arco and Howe scarps, together with the evidence for geologically recent movements, indicate that large earthquakes related to renewed faulting along these scarps might recur at any time in the future.

The scarp that overlooks the north shore of Mud Lake consists of fine-grained sedimentary deposits on the east (Clay Butte) and two layers of basaltic lava on the west, separated by detrital deposits. Drilling shows that the lower lava is concealed in Clay Butte, and talus from this lava is buried by sedimentary deposits near the shore of Mud Lake. The various deposits and lava penetrated by drilling fail to show that any geologic unit has been demonstrably displaced by a fault along this scarp. However, because the geologic history of Mud Lake is still inadequately known, the possibility of faulting cannot be completely ignored, even though remote. Thus, if sensitive installations are planned for construction near Mud Lake, further geologic investigation would be prudent.

The lineaments examined on the lava plain at the NRTS present no identifiable geologic hazards. The principal lineament that trends northward from East Butte is marked by a surficial streak of sand that crosses numerous undisturbed irregularities that formed during eruptions of the lava. Excavation across the streak shows an unbroken lava surface. Another trench across a shorter but analogous lineament that passes through the site of Experimental Breeder Reactor II also shows undisturbed lava. Excavation in surficial deposits at one of the lineaments that trend northeast from Middle Butte reached the underlying basalt at two places, neither of which displays any disruption of the intial lava surface.

The NRTS network of seismographs, during its 9 months of operation, did not locate a single earthquake within a distance of 70 km. Moderate activity, however, was detected in a zone about 100 km north of the NRTS and in a zone about 150 km northeast that includes the locus of the Hebgen Lake earthquake of 1959 in Montana (Richter magnitude 7.1). Large earthquakes might occur anywhere in these active zones. The absence of detected earthquakes at the NRTS does not disprove the possibility that strain in the earth's crust could produce slippage on a nearby fault and thus generate a large earthquake.

VOLCANIC ACTIVITY HAZARD

Relatively recent volcanism has occurred in Craters of the Moon National Monument and in at least one place adjacent to the southwestern part of the NRTS. Recent activity has occurred at several other places on the Snake River Plain, as at Hells Half Acre to the east. Some of the small volcanic cones within the station may be comparatively recent in origin. Volcanic areas characteristically have alternate periods of activity and quiescence. A logical question, therefore, is whether resumption of volcanic activity within or near the NRTS is likely. No categorical answer to that question can be given because there is no assurance that the present is a period of cessation of activity rather than of mere quiescence. The inactivity has endured for some hundreds of years at least—longer than is ordinary for areas of active volcanism—and renewed activity seems unlikely. Moreover, if activity recurred, the place of eruption in an area such as the Snake River Plain would be completely random, so far as is known. Inasmuch as only "dying" phases of volcanism are even remotely likely, the chance of a hazardous eruption in or near the NRTS is remote.

REFERENCES CITED

Anonymous, 1949, Survey report, Fort Peck, Montana-Pocatello, Idaho sites; Prepared for the United States Atomic Energy Commission by Smith, Hynchman, and Grylls, Inc.: Detroit, Mich., 149 p.

Bagnold, R. A., 1941, The physics of blown sand and desert dunes: New York, William Morrow and Co., 265 p.

Barraclough, J. T., Teasdale, W. E., and Jensen, R. G., 1967, Hydrology of the National Reactor Testing Station, Idaho; Annual progress report 1965: U.S. Geol. Survey open-file report, 107 p.

Barraclough, J. T., Teasdale, W. E., Robertson, J. B., and Jensen, R. G., 1967, Hydrology of the National Reactor Testing Station, Idaho, 1966: U.S. Geol. Survey open-file report, 95 p.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., 508 p.

Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill Book Co., *384* p.

Kerr, R. C., and Nigra, J. O., 1952, Eolian sand control: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 8, p. 1541–1573.

Kirkham, V.R.D., 1931, Snake River downwarp: Jour. Geology, v. 39, p. 473–479.

Lang, W. B., 1943, Gigantic drying cracks in the Animas Valley, New Mexico: Science, v. 98, no. 2557, p. 583–584.

Malde, H. E., 1971, Geologic investigation of faulting near the National Reactor Testing Station, Idaho, *with a section on* Microearthquake studies by A. M. Pitt and J. P. Eaton: U.S. Geol. Survey open-file report, 167 p., 26 figs.

Malde, H. E., and Powers, H. A., 1962, Upper Cenozoic stratigraphy of Western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 73 no. 10, p. 1197–1220.

Nace, Raymond L., Deutsch, Morris, and Voegeli, Paul, Subitzky, Seymour, ed., 1972, Physical Environment of the National Reactor Testing Station, Idaho—A Summary: U.S. Geol. Survey Professional Paper 725–A, 38 p.

Plummer, J. L., and Dore, S. N., 1940, Soil mechanics and foundations: New York, Pittman Publishing Corp., 126 p.

Stearns, H. T., Crandall, Lynn, and Steward, W. G., 1938, Geology and ground-water resources of the Snake River Plain in southeastern Idaho: U.S. Geol. Survey Water-Supply Paper 774, 268 p.

Stearns, H. T., Bryan, L. L., and Crandall, Lynn, 1939, Geology and water resources of the Mud Lake Region, Idaho, including the Island Park area: U.S. Geol. Survey Water-Supply Paper 818, 125 p.

Taylor, D. W., 1938, Fundamentals of soil mechanics: New York, John Wiley and Sons, Inc., 240 p.

Turner, F. J., and Verhoogen, Jean, 1951, Igneous and metamorphic petrology: New York, McGraw-Hill Book Co., 602 p.

Twenhofel, W. H., 1932, Treatise on sedimentation, 2d ed.: Baltimore, Williams and Wilkins Co., 926 p.

U.S. Department of Commerce, Coast and Geodetic Survey, 1969, Seismic probability map of the United States.

Walker, E. H., 1964, Subsurface geology of the National Reactor Testing Station, Idaho: U.S. Geol. Survey Bull. 1133–E, 22 p.

Washington, H. S., 1917, Chemical analyses of igneous rocks, published from 1884 to 1913, inclusive: U.S. Geol. Survey Prof. Paper 99, 1201 p.

U.S. GOVERNMENT PRINTING OFFICE: 1975-0-689-907/25