UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geologic Factors Pertinent To The Proposed A. J. Wiley Hydroelectric Project, No. 2845, Bliss, Idaho

By

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This report has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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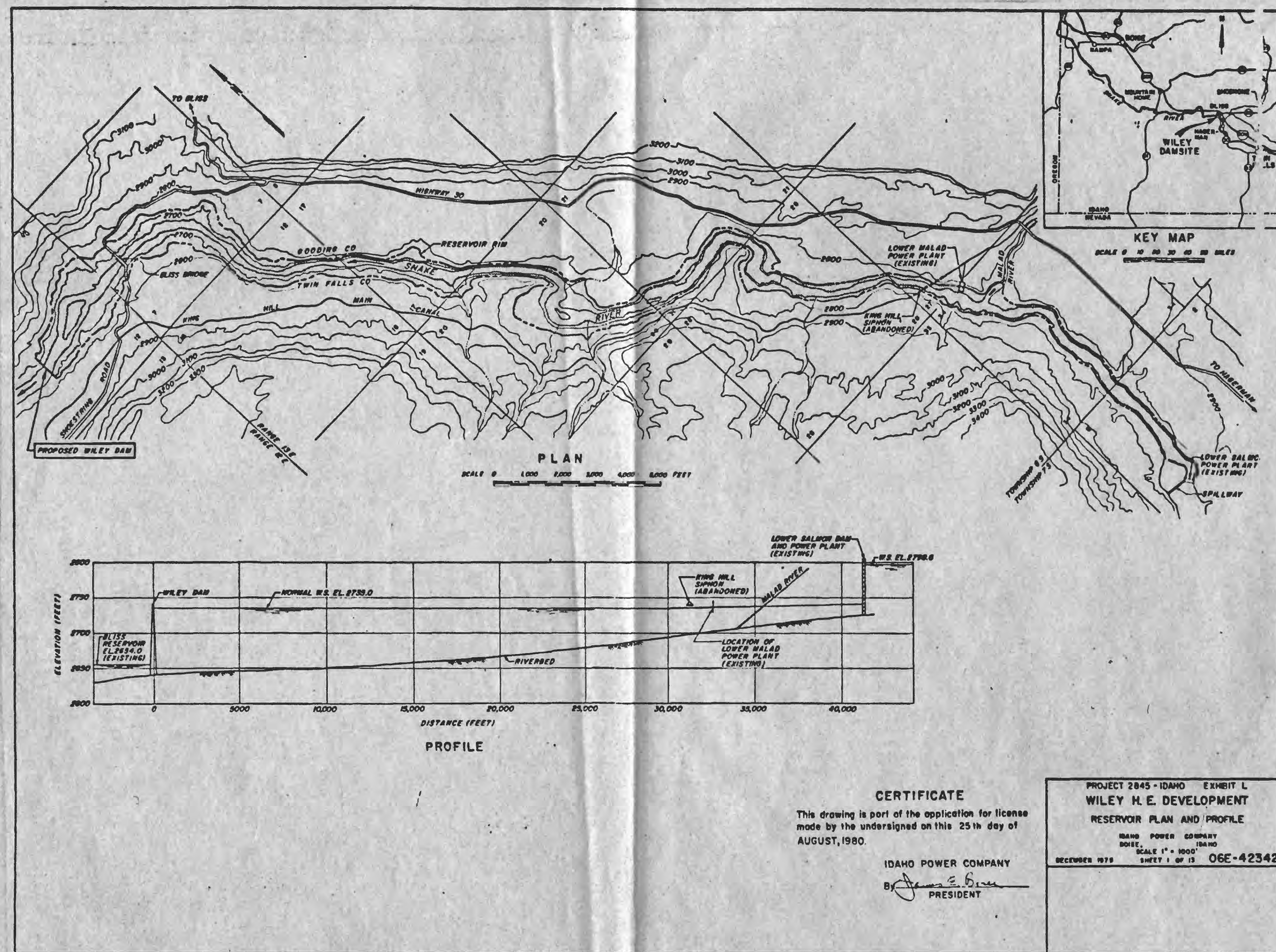

Figure 1.--Map showing the location of the proposed Wiley Dam and its reservoir (from Exhibit L submitted by the applicant).

PART 1

INTRODUCTION

1.1 Nature and Status of the A. J. Wiley Hydroelectric Project

The A. J. Wiley Hydroelectric Project is a proposal by the Idaho Power Company to develop hydroelectricty near Bliss, Idaho, by building a dam on the Snake River (fig. 1). The proposed dam would impound a narrow reservoir as deep as 85 feet in a free-flowing reach of the river that extends from the upper reach of water impounded by the Bliss Dam to the foot of the Lower Salmon Falls Dam, nearly 8 miles farther upstream. The proposed dam would be built in three sections: a spillway section and a powerhouse (intake) section to be constructed of concrete in the right-hand part, and an embankment section to be constructed as a zoned-fill of selected earth materials in the left-hand part. (Right and left are to be understood in the sense of looking downstream.)

In August, 1979, the Idaho Power Company was granted a 3-year permit (Project No. 2845) by the Federal Energy Regulatory Commission (FERC) to make site investigations and environmental studies in the project area. A year later, on August 26, 1980, the company applied to FERC for a license to construct the project. On October 8, 1980, as explained in a letter by William W. Lindsay, Director of the Office of Electric Power Regulation, the company was given 90 days to correct certain deficiencies in the application. Because several of the deficiencies identified by Mr. Lindsay pertain to geologic aspects of the project, his letter is attached to this report as Appendix A. Hereafter in this report, the deficiencies listed by Mr. Lindsay are identified by the numerical entries in his letter. The Idaho Power Company is referred to as the applicant.

1.2 Focus of This Report

Any proposal to dam a river, particularly a major stream such as the Snake River, provokes a complex range of questions that ultimately must be resolved when considering whether or not construction of the dam is in the public interest, and--if so--what features must be incorporated in its design. This report focuses only on the geologic aspects of the proposal. It deals with factors that are believed to be significant in considering the technical and economic feasibility of the proposed project, factors that bear on matters of design intended to ensure a safe structure, and factors pertinent for evaluating geologic hazards that might be aggravated in the project area.

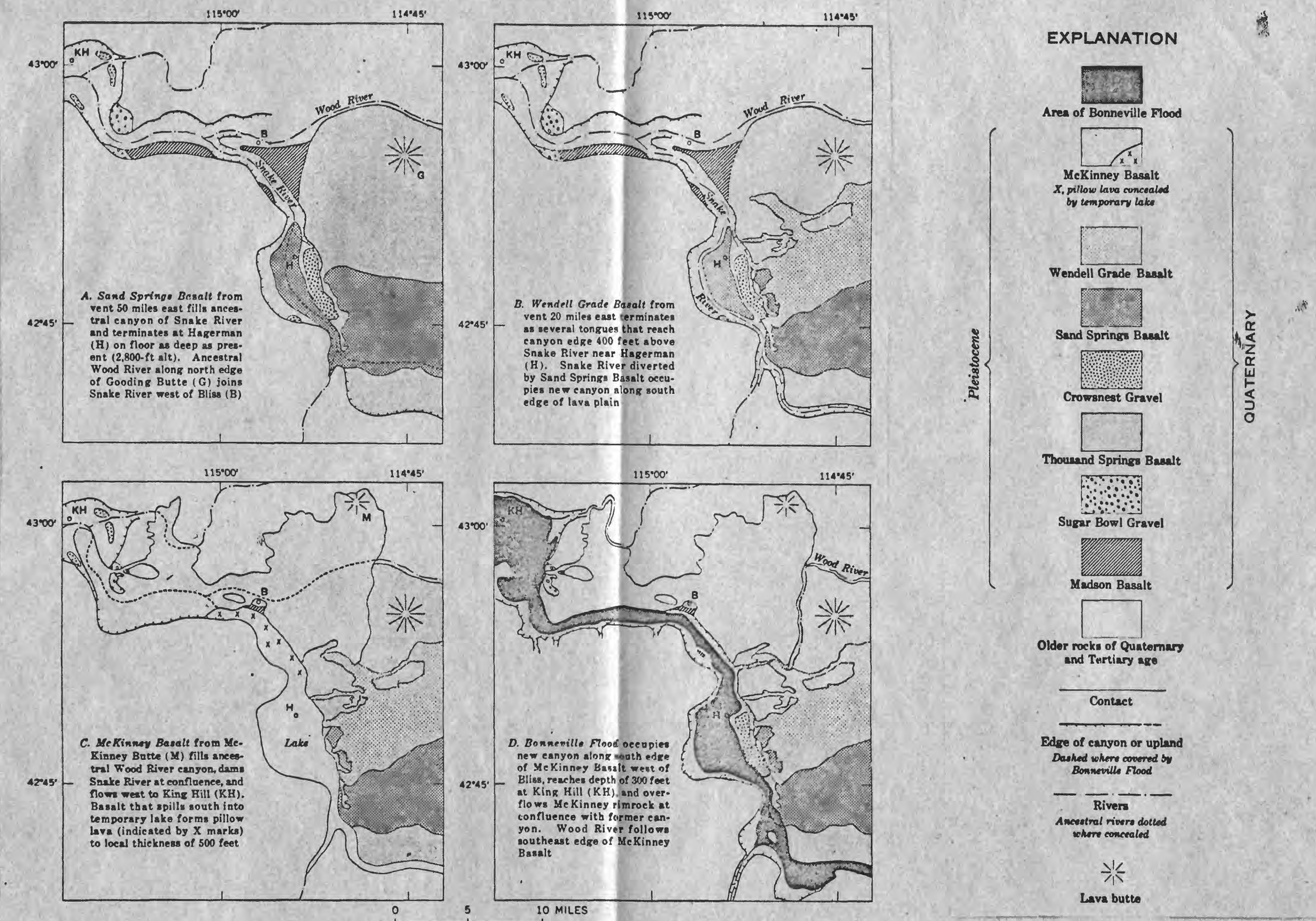

Figure 2.--Maps of area between Hagerman and King Hill showing late Pleistocene drainage changes caused by local lava flows (from Malde, 1971). (As shown in table 1, the Crowsnest Gravel is now recognized as being younger than the McKinney Basalt.)

Compared to the geology of many projects of this kind, the geology of the A. J. Wiley Hydroelectric Project is varied and complex. Highly contrasting geologic materials are found at the left and right abutments of the proposed dam site and under its central floor. Moreover, the proposed reservoir would impinge on materials as varied as basalt, pillow lava, lacustrine clay, and flood gravel. The distribution and the physical properties of these materials are significant factors for evaluating geologic hazards and the feasibility of the project.

In discussing the geology of the A. J. Wiley Hydroelectric Project, I am mindful of the advice given long ago by Kirk Bryan (1929, p. 29-33) that the geologist "should be scrupulously frank in laying before the engineer the nature of the evidence and the basis on which a conclusion has been reached." When adverse geologic conditions have been identified or predicted, Professor Bryan said that the engineer then has the responsibility to explore and overcome the difficulties of construction.

In order that the geologic conditions of the project area can be better understood, a sketch of the geologic setting is given below. This is followed by a summary of the principal geologic problems, based on the more detailed discussion in the main body of the report.

1.3 Geologic Setting of the A. J. Wiley Hydroelectric Project

The A. J. Wiley Hydroelectric Project is in an area distinguished by the overlap of late Pleistocene basaltic lava flows on thick, older formations of basalt and poorly consolidated stream and lake deposits (Malde, 1965). The boundary between these two major geologic divisions is steep and is broadly traced by the canyon of the Snake River, such that the older deposits form a dissected canyon wall 700 feet high to the left of the river, and the younger lava flows form cliffs that reach more than 500 feet above the river on the right. The canyon floor, including the banks of the proposed reservoir, is variously composed of both the older and younger geologic units, depending on vagaries of past deposition and erosion.

When the geologic units are subdivided and mapped in greater detail, the Snake River is seen to have become entrenched in its present canyon in the project area by downcutting that was impeded from time to time by eruption and spread of the late Pleistocene lava flows. The river thus was forced to cut a series of ancestral canyons progressively farther south and west along the margins of successive canyon-filling lava flows (fig. 2). In the late stages of downcutting in the project area, the canyon acquired a two-story configuration, with a narrow bottom trench 200 feet deep cut in the relatively resistant Banbury Basalt, and a wider upper story cut either in clays and silts of the Glenns Ferry Formation or--along the right side--in remnants of the Glenns Ferry that are capped by one or more of the late Pleistocene lava flows. (See Part 3 for descriptions and ages of stratigraphic units.) The physiography of the trench cut in the Banbury is important for the control of reservoir leakage and for the design of the proposed impoundment. These topics are dicussed in Parts 4 and 5. Certain details about the occurrence of the Glenns Ferry Formation in the project area, together with the underlying Banbury Basalt, pertain to the hazard of increased landslide activity at Bliss. This topic is discussed in Part 6.

From the perspective of the proposed dam and reservoir, the most significant geologic event was the eruption of the canyon-filling McKinney Basalt. The basalt dammed the ancestral Snake River at a place still concealed a mile or two northwest of the proposed dam, thus forming a temporary lake. Where the basalt spilled into the lake, copious amounts of pillow lava were deposited. Pillow lava is a peculiar open-textured volcanic deposit that forms in water. It is one of nature's most porous materials. Because the pillow lava makes up the right abutment of the proposed dam, and because it occupies much of the reach of the proposed reservoir, its distribution has important consequences with respect to reservoir leakage and the design of the dam.

Immediately after deposition of the pillow lava, lacustrine clay began to accumulate in the lake and ultimately grew to a height nearly equal to the level of the McKinney lava dam. Eventually, the lake overflowed, and the lava dam was breached along its southern margin by downcutting in poorly consolidated silt and clay of the Glenns Ferry Formation. The Snake River thus began to cut its present canyon west of Bliss, and the lake was correspondingly lowered and drained.

When the Snake River canyon had achieved substantially its present form in the project area, flood debris from catastrophic overflow of Pleistocene Lake Bonneville was heaped in large piles along the canyon floor, reaching heights of more than 200 feet. Because the flood debris consists of unconsolidated gravel and sand, its open texture would provide unimpeded passages for migration of reservoir water.

1.4 Synopsis of Geologic Problems, or Potential Problems, Raised by the A. J. Wiley Hydroelectric Project

The geologic factors discussed in this report pertain to three general problems: reservoir leakage, foundation conditions, and the hazard of landslides. The existence and magnitude of some aspects of these problems can be demonstrated from features of the geologic deposits and their origin, whereas an assessment of the potential hazard of others depends on acquiring further geologic information about the distributiuon of concealed deposits and on making suitable tests of geologic materials. This difference between recognizable and potential geologic problems can be better appreciated from the following summaries of the problems themselves.

Substantial leakage from the proposed reservoir is predicated on the porosity of pillow lava in the right abutment (Part 4.1) and on the history of the ancestral Snake River (see Deficiency W-3, Appendix A). The presence of the pillow lava as a leaky conduit (Part 4.2), together with leakage through its associated lava dam, accounts for a thick body of lacustrine clay in the area upstream, which accumulated virtually to the full height of the lava dam. The lake in which the clay was deposited could not have overflowed while the clay was accumulating, for overflow necessarily would have initiated downcutting of an outlet and would have prevented buildup of the clay to its observed height. Thus, all the water carried by the river when the clay was being deposited must have been discharged downstream solely by leakage. Because construction of a man-made dam would recreate the former conditions, although at a much smaller scale, the geologic record suggests that leakage from the resulting reservoir would be substantial (Part 4.3). A possible way to overcome this problem, depending on measurements of the hydrologic properties of the pillow lava (Part 4.4) and the results of field tests, might be to install a grout curtain across the full remaining width of pillow lava at the dam site (Part 4.5).

Foundation conditions at the proposed dam are complicated by the existence of several kinds of geologic materials, and by the incomplete knowledge of their response to conditions that would be created by the impoundment. Three of the most significant complications are briefly explained below.

First, the presence of permeable pillow lava at the proposed dam site indicates the need to isolate the earth-fill embankment from excessive seepage (Part 5.1). Water that reaches the embankment could endanger its impermeable core or exceed the designed tailwater hydrostatic conditions within its downstream section (see Deficiences L/N-1 and 2).

Also, the embankment is underlain by a unit of sand that grades upward to silt (bed 4). Substantial seepage through the permeable lower part of bed 4 could cause piping (internal erosion) of the upper part and lead to failure of the overlying earth-fill structure. Seepage might be prevented by installing effective seals at suitable places within the full thickness of the pillow lava, or by removing all pillow lava from the area below the intake and spillway sections.

Second, the original physical properties of Banbury Basalt in the left abutment at the proposed site have been altered by former geologic conditions, perhaps in a way that would make the basalt subject to rapid weathering. The Banbury has proved to be adequate as a foundation for the Bliss Dam a short distance downstream, but an outcrop near the proposed dam disintegrates to clay and sand when exposed to weathering (Part 5.2). Circumstances about this process and procedures to test the engineering properties of the basalt are discussed in the text (see Deficiency L/N-2).

A third complication under much of the proposed dam site is the presence of debris that probably reached its present position by viscous flow (Part 5.3). Because of physical features of the debris, and because specimens from an outcrop of the debris disintegrate in water, its stability under conditions that can be expected under the proposed dam should be determined (see Deficiency L/N-2).

The hazard of landslides pertains chiefly to an active landslide immediately southwest of Bliss, for which the exposed materials consist of bodies of lacustrine clay, sediments of the Glenns Ferry Formation, and blocks from lava flows that form the canyon rim. The landslide occupies half a square mile and extends from river level nearly to the canyon rim 500 feet higher. Submergence of the toe of the landslide by the proposed reservoir would weaken the landslide debris and aggravate the risk of landsliding. This problem is discussed in the text in terms of several degrees of risk: calving of the lower reach of the landslide; failure of the upper reach; and catastrophic displacement of reservoir water by sudden large-scale collapse of the landslide area (Part 6.1). An assessment of these risks depends on subsurface information, on measurements of physical properties, and on other data needed in order to analyze the stability of the area (see Deficiency W-2).

Landslides in the project area are also a possible hazard in reducing the capacity of the proposed reservoir. The report describes three sites of active or potential landslides that could reduce reservoir capacity (Part 6.2).

PART 2

BACKGROUND OF THIS REPORT

I first became aware of the A. J. Wiley Hydroelectric Project in 1976, when I received a telephone call about it from the Walla Walla District of the Corps of Engineers. Then, late in 1979, I learned that the Idaho Power Company intended to apply to the Federal Energy Regulatory Commission (FERC) for a license to build the project. Through a telephone conversation with Ronald A. Corso of FERC, I learned that a letter to the company explaining my concern about geologic problems raised by the project would be appropriate and timely. A copy of my letter of January 30, 1980, which briefly explains my concerns at that time, is attached as Appendix B. Acting upon the advice of Mr. Corso, copies of the letter were sent to the Idaho Public Utilities Commission, and to Vincent D. Sullivan, Office of Environmental Review, U.S. Department of the Interior.

My letter of January 30 was based partly on geologic studies by Howard A. Powers in 1954-1955 and by Mr. Powers and me in 1959 (Malde and Powers, 1972). The letter was also based on my understanding of geologic events that led to the formation of the present Snake River canyon (Malde, 1971).

Several telephone conversations with Peter Leitzke of FERC later in 1980 led to my receiving from him on September 5 excerpts from Exhibits L and W and other items of geologic interest from the company's Application for License. Mr. Leitzke also arranged for an informal field conference that was held in the project area on October 20-21 with him and Jack Duckworth of the FERC Environmental Review Staff and with Douglas E. Sprenger and Donald E. Westcott representing the applicant.

To prepare for the field conference, I studied the excerpts from the application and then made further investigations of the project area on September 12-15 and on October 13 and 15. As a matter of record, I would have made these investigations as part of my current research in the area, irrespective of the application, because the stratigraphic position assigned by the applicant to a body of lacustrine clay differed from my current understanding, and I had a scientific interest in resolving the discrepancy. Some features of the project area were also examined on October 19 with Robert L. Schuster, formerly chief of the U.S. Geological Survey's Branch of Engineering Geology, who had participated in the investigation of the failure of Teton Dam (U.S. Department of the Interior, 1980), and who is a noted authority on landslides (Schuster and Krizek, 1978).

Immediately after the field conference, on October 22-24, I again reviewed certain geologic aspects of the project area with Harry R. Covington, a colleague in the U.S. Geological Survey who is knowledgable about the geology of the region, and with Richard L. Whitehead, a geologist in the Survey's Boise office who has a wide knowledge of ground-water conditions in the Snake River Plain.

Since my recent field work in the project area, I have benefited from the expert knowledge of several professional colleagues, as noted at appropriate places in this report.

PART 3

STRATIGRAPHY

3.1 General Stratigraphic Relations

The succession of geologic units in the project area is significant because of its bearing on the origin, distribution, and (in some instances) the physical properties of the geologic materials. The applicant's description of the stratigraphy is considered by FERC to be deficient (see Deficiency W-4, Appendix A).

From the concensus reached during the field conference on October 20-21, I am confident that the stratigraphy of the project area is now reasonably well understood, although intricacies in the stratigraphy and distribution of certain units that are important to foundation conditions at the proposed dam site (Deficiencies L/N-1 and 2) and to the problem of reservoir leakage (Deficiency W-3) are still incompletely determined. Also, the geology of one unit found by the applicant, namely the "older alluvium," is not yet sufficiently understood, and this deficiency can be expected to be important in further consideration of its physical properties and distribution (Part 5.3). Pertinent features of the principal geologic units in the project area, or in adjoining areas significant to the proposed project, are briefly described in table 1.

Table 1.--General Stratigraphic Sequence in the Area of the A. J. Wiley Hydroelectric Project (modified from Malde and Powers, 1972).

Stratigraphic Unit	Description of Pertinent Features
PLEISTOCENE:	
Melon Gravel	Boulder gravel deposited by the Bonneville Flood from river level to a height of 225 feet.
Crowsnest Gravel	Pebble and cobble gravel 25-50 feet thick that forms a terrace on lacustrine clay 250 feet above river level in Hagerman Valley. New evidence indicates that the underlying clay is younger than the McKinney Basalt.
Root Lake clay (an informal term)	Laminated lacustrine clay distributed in scattered large and small bodies from river level to places 530 feet higher (altitude 3,180 feet).

Table 1.--Continued.

McKinney Basalt	Lava flows of porphyritic plagioclase-olivine basalt from McKinney Butte 9 miles northeast of Bliss. Pillow lava facies occupies a former canyon reaching from 100 feet below present river level at the proposed dam site (altitude 2,550 feet in drill hole DH-69) to just below lava of the canyon rim (altitude 3,175-3,200 feet).
Older alluvium	Applicant's term for unsorted debris of highly altered basalt and chunks of clay, silt, and sand in a matrix of clay and silt, locally more than 50 feet thick, which underlies McKinney pillow lava in the environs of the proposed dam. Rests on steep topography eroded in Banbury Basalt. Exposed only 0.6 mile downstream from the proposed dam site on the right bank where the debris is overlain conformably or gradationally by the pillow lava. Depositional features in the outcrop suggest viscous flow.
Wendell Grade Basalt	Upland lava flow of olivine basalt from Notch Butte east of Hagerman. Terminus spills over the canyon rim 1.7 miles east of Hagerman and overlaps old talus and landslide debris.
Sand Springs Basalt	Lava flow of olivine basalt from a vent east of Hagerman. Fills a former canyon exposed in cross section as a canyon fill at least 210 feet thick at the mouth of Sand Springs Creek. Terminates near the present canyon floor 1 mile downstream from Lower Salmon Falls.
Thousand Springs Basalt	Lava flow of porphyritic plagioclase-olivine basalt from a vent east of Hagerman. Terminates 200 feet above river level (altitude 3,000 feet) at the U.S. Fish Hatchery southeast of Hagerman as a canyon-filling lava flow less than 50 feet thick.
Malad Member of Thousand Springs Basalt	Porphyritic plagioclase-olivine basalt as much as 200 feet thick from Gooding Butte. Fills a canyon 300 feet above present river level near the mouth of Malad Canyon (altitude 3,025 feet).

Table 1.--Continued.

Madson Basalt	Lava flow of olivine basalt from a vent east of Bliss. Fills a canyon discontinuously exposed in cross section from Tuttle to a place on the northern canyon rim 10 miles west of Bliss. Lowest outcrops are about 350 feet above present river level (altitude 3,000 feet) in the project area.
Tuana Gravel	Pebble and cobble gravel interbedded with sand and silt. In the project area forms a veneer 25-50 feet thick on an eroded surface cut on the Glenns Ferry Formation 600 feet above present river level (altitude 3,250 feet).
PLEISTOCENE(?) AND PLIOCENE:	
Glenns Ferry Formation	In the project area consists of poorly consolidated, thinly bedded silt, clay, carbonaceous shale, and some sand and basaltic lava in floodplain deposits several hundred feet thick. Forms the western canyon wall to a height 600 feet above present river level. Exposed at the head of a landslide area at Bliss where it is locally overlain unconformably by Madson Basalt.
MIOCENE:	
Banbury Basalt	Lava flows of olivine basalt interbedded locally with minor amounts of stream and lake deposits. Basalt commonly altered by development of clay and other secondary minerals. Basalt of upper part is 150 feet thick at the proposed dam (altitude of base 2,675 feet, or 25 feet above river level). Underlying stream and lake deposits extend downward to 2,550 feet at the proposed dam site, according to drilling records provided by the applicant.

3.2 Revised Understanding of Lacustrine Clay Associated with the McKinney Basalt

As mentioned in Part 1.3, pillow lava contemporaneous with eruption of the McKinney Basalt is overlain by a thick section of lacustrine clay. This stratigraphic relationship is described in the information submitted by the applicant, and its discovery prompted my recent field work in the project area. My previous understanding was that the lacustrine clay is correlative with clay of the Bruneau Formation, and, hence, is older than the McKinney Basalt. Thus, when I wrote to the applicant in January, 1980, I was concerned that the presence of the Bruneau Formation in a landslide area at Bliss could be hazardous (Appendix B).

To my chagrin, but to my satisfaction in the search for accurate geologic knowledge, the investigations by the applicant, together with my own observations, establish that the Bruneau Formation does not exist in the project area, nor indeed in the present canyon area upstream. Rather, the lacustrine clay is a unique geologic unit that accumulated behind the lava dam formed by the McKinney Basalt. Some details about the stratigraphic relations are explained in Part 3.3. In this report, the lacustrine clay is referred to as the Root Lake clay, a name based on informal terminology adopted by the applicant. Similarly, the ancient lake formed by the lava dam of McKinney Basalt is referred to as Root Lake.

In light of the confusion that has been caused by my error in this matter, I am mindful of a remark attributed to the pioneer engineering geologist, C. P. Berkey (Burwell and Roberts, 1950, p. 3):

> It is occasionally possible for a single little insignificant looking fact to render a whole series of enormously interesting explanations impossible. This is not at all peculiar to experienced geologists, but it still remains that practical work in the field of geology presents just such situations often because one necessarily works with an imperfect record of fact, and is obliged to cultivate a lively imagination.

The finding that the Root Lake clay overlies McKinney pillow lava does not lessen the concern about aggravating the risk of landslides at Bliss through effects produced by the proposed reservoir (Part 6.1). Furthermore, the finding that the clay accumulated in a lake impounded by the McKinney Basalt bears importantly on the ability of the reservoir to hold water (Part 4.3) and, hence, upon design considerations for the proposed dam itself (Part 5.1).

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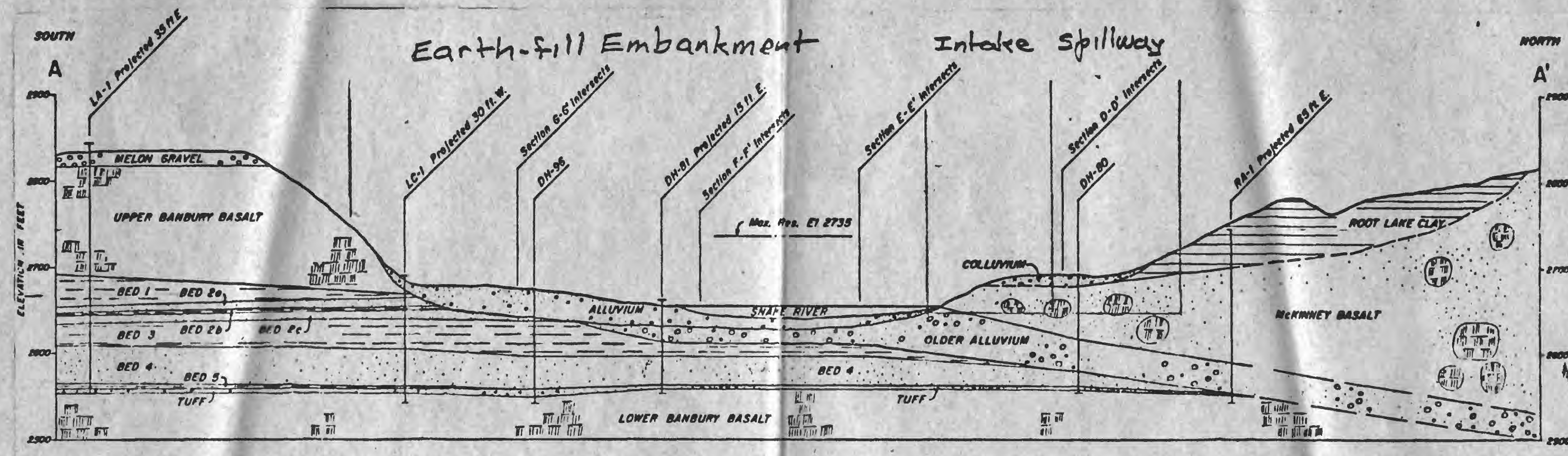

Figure 3.--Cross section between the left and right abutments of the proposed dam (from Exhibit L submitted by the applicant).

3.3 Relation of Root Lake Clay to Pillow Lava of the McKinney Basalt and to Older Geologic Units

Drilling records and outcrops at the proposed dam site, as well as outcrops at several places in the canyon upstream, demonstrate that the Root Lake clay overlies pillow lava of the McKinney Basalt, in addition to various older geologic units.

The contact of the clay on the McKinney pillow lava is not widely exposed, but certain outcrops that are described below show that the clay was deposited directly on the pillow lava. In one particularly instructive outcrop, layers of glassy basaltic fragments that were produced during formation of the pillow lava grade upward into laminated clay (outcrop no. 2 described below). This relationship suggests that the Root Lake clay began to accumulate immediately after the pillow lava was deposited, at least in its initial deposits at low altitudes in the canyon of that time.

Other outcrops of the Root Lake clay, although now scattered because of erosion during entrenchment of the present canyon, define the original distribution of the clay and, accordingly, closely define the character of the ancestral canyon when the clay was being deposited. Such outcrops show that the clay accumulated from present river level to an altitude of 3,180 feet, filling a canyon upstream from the McKinney lava dam much like the present canyon in its dimensions and character--although, of course, then occupied by ancient Root Lake. The clay is preserved in some continuous sections as much as 280 feet and 400 feet thick, as described below (outcrops no. 11 and no. 5, respectively).

These general stratigraphic and physiographic relations can be better understood by considering the outcrops described below, preferably by examining them in the field, or by noting the described features on available topopgraphic maps and on U.S. Geological Survey Miscellaneous Investigations Map I-696 by Malde and Powers (1972), keeping in mind that the Bruneau Formation on Sheet 2 of the map is now identified as Root Lake clay.

1. The farthest downstream outcrop of Root Lake clay is in the right abutment of the proposed dam, where it is preserved as a remnant at altitudes between 2,675 and 2,800 feet on a southward dipping surface of McKinney pillow lava (fig. 3). Contiguous outcrops extend half a mile upstream and rise to 2,900 feet.

2. At the south end of the Shoestring Road Bridge (2,150 ft. N., 800 ft. E., SW cor., sec. 7, T. 6 S., R. 13 E., Bliss quad.) and at an altitude of 2,675 feet, Root Lake clay overlies rubble composed of unsorted angular blocks of Madson Basalt mingled with fragments of glassy McKinney lava (a kind of material typical of the pillow lava facies) and with some McKinney pillows. The rubble gradationally gives way upward to as much as 5 feet of bedded glassy fragments and then to lacustrine clay (fig. 4). The transition to clay is within an interval 8 inches thick marked by alternating laminae of clay, silt, and basaltic fragmental material. The relations suggest an uninterrupted transition from deposition of material representative of the pillow lava to deposition of clay.

3. Above and below old U.S. Highway 30 1 mile south of Bliss, along an east-west nose in the canyon wall, Root Lake clay overlies a steep, westward-plunging slope of McKinney pillow lava, which rises from an altitude of 2,925 feet to about 3,050 feet (the contact on the highway is exposed at 1,750 ft. N., 500 ft. W., SE cor., sec. 7, T. 6 S., R. 13 E., Bliss quad.).

4. Root Lake clay makes up much of the exposed material of the large landslide previously mentioned at Bliss (Part 1.4). The highest outcrop (1,600 ft. S., 200 ft. E., NW cor., sec. 8, T. 6 S., R. 13 E., Bliss quad.) reaches an altitude between 3,150 and 3,175 feet, adjacent to a cliff of Madson Basalt at the head of the landslide, and contiguous to an outcrop of the Glenns Ferry Formation at the same altitude. As discussed in Part 6.1, this outcrop of Root Lake clay is significant in comprehending the origin and nature of the landslide.

5. A recent excavation made for the King Hill Canal (1,250 ft. N., 2,500 ft. E., SW cor., sec. 20, T. 6 S., R. 13 E., Bliss quad.) exposes Root Lake clay on as much as 6 feet of steeply dipping colluvium, which in turn rests on eroded beds of the Glenns Ferry Formation. The colluvium contains abundant angular blocks from the Madson Basalt (which is preserved as a remnant 1/4 mile southeast and 125 feet higher) as well as rounded pieces of the Shoestring Road lava flow and pebbles of the kind found in Tuana Gravel higher in the canyon wall. Good exposures in this area make the Root Lake clay continuously recognizable from river level to an altitude of 3,175 feet in the canyon wall to the west.

Figure 4.--Outcrop at the south end of the Shoestring Road Bridge showing layers composed dominantly of glassy fragments typical of the McKinney pillow lava overlain by laminated Root Lake clay. The upward change from fragmental basalt to clay takes place in an interval about 8 inches thick, which is characterized by alternating laminae of these materials.

Landsliding and gully erosion in Root Lake clay at the west end of the former siphon for the King Hill Canal (750 ft. N., 150 ft. E., SW cor., sec. 27, T. 6 S., R. 13 E., Hagerman quad.) has exposed the base of the clay at an altitude of about 2,800 feet, resting on rubble that has some of the characteristics of rubble at the Shoestring Road Bridge (outcrop no. 2 described above). The rubble incorporates substantial amounts of fragmental glassy McKinney lava as well as scattered McKinney pillows. The rubble may have originated as colluvium (for example, as a former talus deposit), but it locally contains sorted layers in the upper part. Irregularities at the upper surface of the rubble, which dips steeply toward the river, are engulfed by laminae of the overlying Root Lake clay (fig. 5). Like the outcrop at the Shoestring Road Bridge, these features suggest the lack of a hiatus between deposition of material that includes McKinney pillow lava and deposition of the Root Lake clay.

7. Along a road known as the Tupper Grade, on the east side of Billingsley Creek, which here forms the eastern wall of the Snake River canyon, Root Lake clay overlies Wendell Grade Basalt at an altitude of 3,090 feet (800 ft. S., 1,400 ft. E., NW cor., sec. 19, T. 7 S., R. 14 E., Tuttle quad.). The clay is continuously recognizable at least as high as 3,120 feet. The Wendell Grade Basalt at this place forms a small cascade that spilled from the canyon rim onto talus and landslide debris along the ancestral canyon wall. Much of this old debris is still in place, having been exhumed by erosion of the Root Lake clay.

8. Recent excavation of a ditch to collect spring water from the base of Sand Springs Basalt at a place about 30 feet above the Snake River downstream from Lower Salmon Falls (550 ft. S., 2,050 ft. E., NW cor., sec. 2, T. 7 S., R. 13 E., Hagerman quad.) has exposed Root Lake clay lying against a cliff formed by the basalt and on talus derived from the basalt. (The stratigraphic relations are found at a place mapped as being a basalt in the Glenns Ferry Formation, but the new exposure indicates that all the basalt at this locality represents the Sand Springs.)

9. At an altitude of 3,050 feet along the Brailsford Ditch southeast of Hagerman, the terminus of the Thousand Springs Basalt is overlain by Root Lake clay (the outcrop extends half a mile southeast from 700 ft. S., 1,500 ft. E., NW cor., sec. 6, T. 8 S., R. 14 E., Tuttle quad.). The clay is capped at an altitude of 3,100 feet by a terrace deposit of Crowsnest Gravel.

Figure 5.--Outcrop at the west end of the former siphon for the King Hill Canal showing laminae of Root Lake clay that engulf irregularities at the upper boundary of blocky rubble. The rubble contains substantial amounts of glassy fragments typical of the McKinney pillow lava. The glassy fragments are seen in the photograph as darker areas of granules and small pebbles, which occur as interstitial material between blocks in the rubble and as larger masses surrounded by blocky constituents.

10. The canyon stretching upstream from Thousand Springs to Melon Valley, which was formed by canyon-cutting in Banbury Basalt at the margin of the Thousand Springs Basalt (Malde, 1971), has many scattered remnants of Root Lake clay. The highest outcrops of the clay reach an altitude of 3,180 feet, where the clay provides the base level for an upland erosion surface, now considerably dissected.

11. The canyon wall south and west of Hagerman, like the canyon upstream from Thousand Springs, has several remnants of Root Lake clay. The largest remnant overlies a steep slope eroded in the Glenns Ferry Formation in an area now dissected by Yahoo Creek. The abrupt contact is well exposed where crossed by the Crowsnest Road (3,600 ft. N., 2,000 ft. E., SW cor., sec. 10, T. 8 S., R. 13 E., Yahoo Creek quad.). This deposit of Root Lake clay rises continuously from its base at an altitude of 2,900 feet near the mouth of Yahoo Creek to an altitude of 3,180 feet. Its upper surface exhibits a weathering profile as much as 5 feet thick, which provides the base level for an upland erosion surface equal to the surface found in Melon Valley.

In addition to the outcrops of Root Lake clay described above, the distribution of the clay in the reach of the proposed reservoir provides further evidence of its relation to the McKinney pillow lava. The distribution supports the conclusion that the clay began to accumulate immediately after deposition of the pillow lava, while the lake impounded by the lava dam of McKinney Basalt (Root Lake) continued to exist.

In particular, the principal outcrops of Root Lake clay in the reach of the proposed reservoir lie on the left side of the present canyon, in places reaching the canyon floor. The McKinney pillow lava, on the other hand, occupies the right side of the canyon. This distribution of the clay and the pillow lava takes on added significance when it is realized that the existing canyon in this reach closely matches the course of the ancestral canyon when the pillow lava was deposited. It appears that the contact between the pillow lava and the clay was steep, with pillow lava being deposited first on one side of the ancestral canyon, and clay being then deposited on the other.

Some signs of the steepness of the contact are preserved in the right abutment and in contiguous outcrops that climb 100 feet higher a short distance upstream (outcrop no. 1 described above). A steep contact of clay on pillow lava is also evident a mile south of Bliss (outcrop no. 3 described above).

The existence of discrete depositional areas for the pillow lava and the clay, and the evidence of a steep contact between them, are understandable from the origin and mode of deposition of the pillow lava. As explained in Part 3.4, the pillow lava accumulated as a deltaic front that advanced into the deep water of Root Lake from the right side of the ancestral canyon. The Root Lake clay then filled the remaining area of the lake.

3.4 Stratigraphy and Distribution of McKinney Basalt

The McKinney Basalt in the area of the proposed project occurs as two facies: upland lava flows that form the canyon rim, and pillow lava that fills part of the ancestral canyon (fig. 6). The facies coincide in the sense that the pillow lava is found only where McKinney lava flows are present along the canyon rim. Both facies are largely confined to the right side of the canyon. The McKinney lava flows, like other late Pleistocene lava flows in the area, are comparatively resistant to erosion, and their distribution is pertinent when considering the hazard of landsliding at Bliss (Part 6.1). The pillow lava, on the other hand, is a highly porous material whose distribution is important to the problem of reservoir leakage (Part 4).

From outcrops of older rocks in the project area, it is clear that the ancestral McKinney canyon was approximately the size of the present canyon, although deeper, and was nearly in the same location. The left side as far downstream as the place where the ancestral canyon disappears into the northern wall of the present canyon, from 2 to 3 miles west of Bliss, was composed of Banbury Basalt and the overlying Glenns Ferry Formation. Some sinuosity is suggested by a projecting spur, capped by a remnant of Madson Basalt (NE1/4 sec. 29, T. 6 S., R. 13 E., Bliss quad.), and by adjacent embayments that preserve remnants of Root Lake clay. The right side of the former canyon in the project area was mostly outlined by a rim of Madson Basalt. The continuity of the Madson may have been interrupted in the landslide area at Bliss, although tangible evidence for this conjecture has not been found. Also, the Madson may be missing along a short stretch extending from 1 to 2 miles southeast of Bliss, which is covered by McKinney lava flows. It is unlikely that this gap in the Madson (if it exists) represents part of a former canyon of the Snake River around the east and north sides of Bliss. Such a canyon is physiographically improbable, and it does not account for the canyon-filling McKinney pillow lava found at the proposed dam site and from there downstream. Finally, the eastern canyon rim in the upper reach of the project area was formed by the Malad Member of

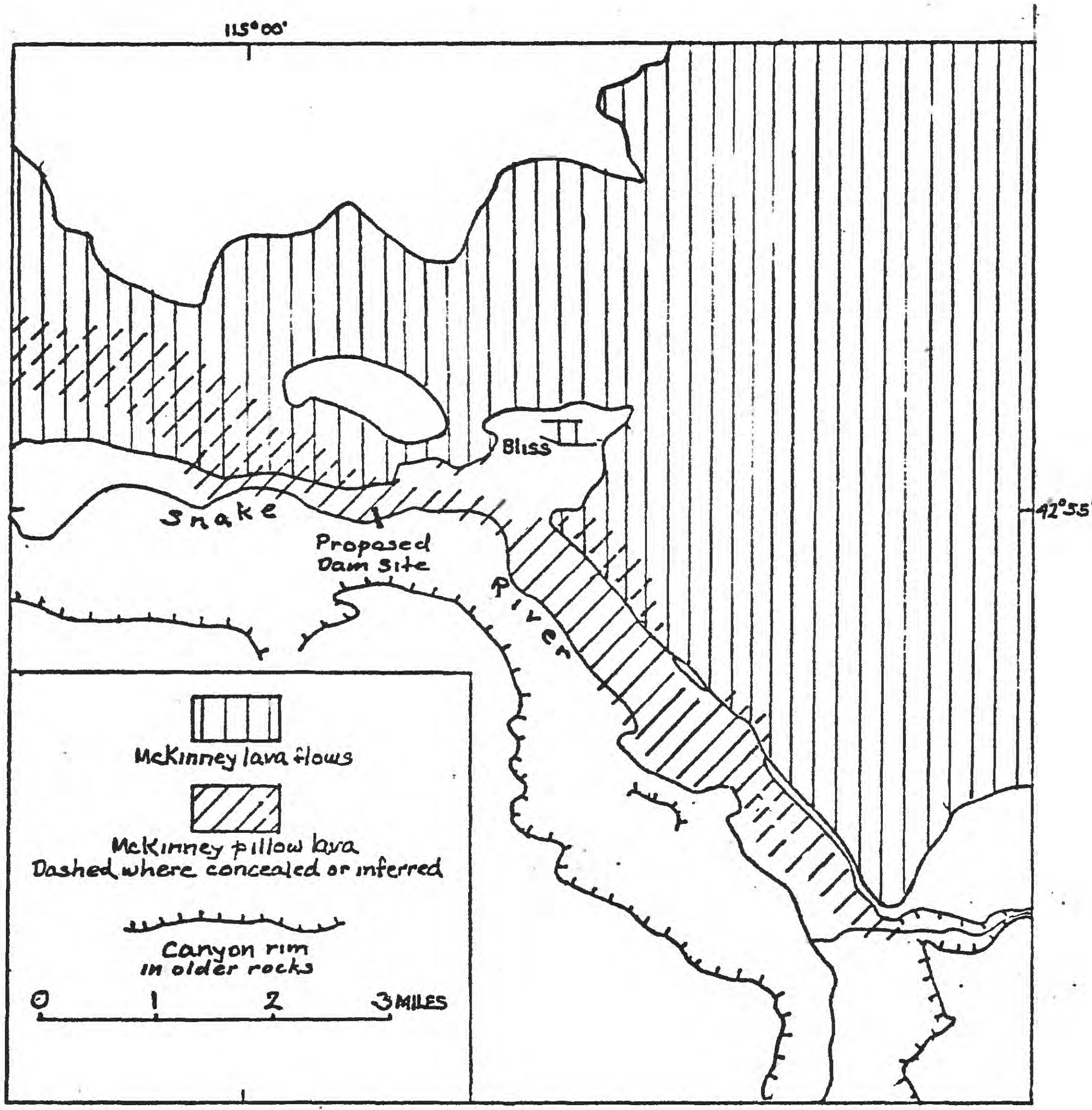

Figure 6.--Sketch map showing the distribution of McKinney Basalt near Bliss, Idaho. This geologic unit consists of pillow lava that occupies a former canyon of the Snake River and lava flows that rest on the pillow lava as well as on the surrounding upland. Edges of the lava flows are exposed as rimrock by erosion along the right side of the present canyon.

the Thousand Springs Basalt, a lava flow physiographically similar to the Madson.

Root Lake, which was formed when McKinney Basalt blocked the Snake River west of Bliss, had a decisive influence on the nature and distribution of basalt that was deposited in the canyon upstream. Outcrops described below show that McKinney lava spilled southward and westward into the lake, building steeply inclined beds of pillow lava that advanced into the canyon until the supply of lava ceased. Lava flows meanwhile advanced over the subaqueous pillow lava much like the advance of topset beds over the foreset beds of a delta. The result was a rim of lava flows along the right side of the canyon from which a face of pillow lava plunged steeply to the canyon floor. If the lava flows of the canyon rim are subaerial, as seems likely, their contact on the pillow lava marks the level of Root Lake when these lavas were deposited. On this basis, lake level was at times as high as about 3,175 feet, virtually the same as the altitude of the highest deposits of Root Lake clay. With respect to the upper reach of the clay, it is significant that the top of the McKinney where downcutting of the present canyon eventually took place (N1/2 sec. 11, T. 6 S., R. 12 E., Bliss quad.) is at an altitude of 3,200 feet.

Immediately downstream from the proposed dam site, the ancestral canyon was completely filled with pillow lava, as shown by outcrops that reach from the river to the rim of the northern canyon wall, capped continuously by McKinney lava flows. Drilling by the applicant shows that the pillow lava in places extends downward at least 100 feet below river level (outcrop no. 9 described below). From the dam site upstream, pillow lava was deposited continuously along the right side of the ancestral canyon, except possibly in the landslide area at Bliss. Much of this pillow lava, and practically all of it up to the level of the proposed reservoir, is still preserved.

Further understanding of the distribution of the pillow lava facies of McKinney Basalt can be gained from the following outcrops.

1. A roadcut on U.S. Highway 30 at the canyon rim 3 1/2 miles southeast of Bliss exposes inclined beds of McKinney pillow lava that plunge toward the river over a steep face of Madson Basalt (fig. 7). About 100 feet of pillow lava is exposed. At the top, approximately at an altitude of 3,175 feet, the pillow lava grades upward more or less abruptly into a lava flow. The field relations indicate deposition of the pillow lava in foreset beds that advanced into the canyon when the water level of Root Lake was at an altitude of at least 3,175 feet. The advance of pillow lava was accompanied

Figure 7.--Deltaic foreset beds of McKinney pillow lava plunging to the left (southwest) over Madson Basalt, seen here at the lower right, which formed the canyon rim. The pillow lava terminates upward more or less abruptly at an altitude of 3,175 feet by the transition to a capping lava flow of McKinney Basalt, which forms the present canyon rim. The outcrop is a roadcut on U.S. Highway 30 (2,000 ft. N., 1,100 ft. W., SE cor., sec. 21, T. 6 S., R. 13 E., Bliss quad.).

by a superimposed lava flow that may have been above the level of the lake.

2. Roadcuts on U.S. Highway 30, extending from 400 feet to 1,400 feet north of Malad Canyon (Big Wood River), also expose steeply inclined beds of McKinney pillow lava. The field relations indicate that the pillow lava spilled westward over a cliff of basalt, which is assigned to the Malad Member of the Thousand Springs.

3. Large, dikelike masses of McKinney lava, some of them more than 100 feet in length, stand as monuments in several groups at the foot of the canyon wall southeast of Bliss. (The principal outcrop is crossed by old U.S. Highway 30, 1,800 ft. N., 2,400 ft. W., SE cor., sec. 21, T. 6 S., R. 13 E., Bliss quad. Other outcrops are found along the highway, 500 ft. S., 1,400 ft. E., NW cor., sec. 17, and 600 ft. N., 200 ft. E., SW cor., sec. 8, T. 6 S., R. 13 E.) These bodies of lava are the kind that sometimes forms in pillow lava when the volume of lava is large. That is, the exposed dikelike masses were once engulfed by pillow lava, probably like the material found at the first two outcrops listed above.

4. Where the Big Wood River is crossed by U.S. Highway 30 (350 ft. S., 1,400 ft. W., NE cor., sec. 34, T. 6 S., R. 13 E., Hagerman quad.), McKinney pillow lava occupies a trench in Banbury Basalt about 1,500 feet wide and at least 125 feet deep. The trench clearly marks the axis of the canyon at this place when the McKinney was deposited.

5. About 25 feet of pillow lava is exposed at river level approximately midway between outcrops of Madson Basalt that define a former canyon not more than 0.9 mile wide (800 ft. N., 2,600 ft. W, SE cor., sec. 21, T. 6 S., R. 13 E., Bliss quad.). The pillow lava is overlain by Melon Gravel that reaches a level substantially above the proposed reservoir (altitude 2,825 ft.).

6. Beginning a mile downstream from the outcrop described above, McKinney pillow lava is nearly continuously exposed to the right of the river from river level to altitudes of about 2,775 feet. In the upper half mile of this stretch the pillow lava also forms the left bank. (The exposures extend from 2,200 ft. S., 1,300 ft. W., NE cor., sec. 20, to 900 ft. N., 1,900 ft. W., SE cor., sec. 7, T. 6 S., R. 13 E., Bliss quad.) The pillow lava is overlain by Melon Gravel.

7. McKinney pillow lava is exposed north and south of the Shoestring Road Bridge, extending several hundred feet upstream along both banks. The outcrop on the right resembles the pillow lava just described along the river upstream. Pillow lava on the left is mingled with rubble of Madson Basalt, as mentioned in describing outcrop no. 2 of Root Lake clay (Part 3.3).

8. One mile west of Bliss, pillow lava is found between McKinney rimrock and an underlying remnant of Madson Basalt, extending from 3,125 to 3,150 feet in altitude (NE1/4NE1/4 sec. 12, T. 6 S., R. 12 E., Bliss quad.).

9. McKinney pillow lava is exposed in the right bank at the proposed dam site and has been found as deep as an altitude of 2,550 feet by drilling in the right abutment (drill hole DH-69, 2,550 ft. S., 1,950 ft. E., NW cor., sec. 12., T. 6 S., R. 12 E., Bliss quad.). The pillow lava is also more or less continuously recognizable in the canyon wall above the right abutment, except where covered by Root Lake clay, reaching to McKinney lava flows at the canyon rim.

10. Beginning 0.6 mile downstream from the proposed dam site, and continuing another 0.8 mile downstream, the right wall of the present canyon consists entirely of pillow lava. This is the place where the ancestral McKinney canyon trends northwesterly away from the present canyon and beneath the McKinney rimrock. The pillow lava preserved here is continuous with the canyon-filling pillow lava at the proposed dam site (outcrop no. 9 described above).

PART 4

PROBLEM OF RESERVOIR LEAKAGE

The application for the A. J. Wiley Hydroelectric Project is considered by FERC to be deficient in evaluating potential leakage from the proposed reservoir, and in describing the feasibility and cost of measures intended to mitigate leakage (see Deficiency W-3, Appendix A). The location and extent of the ancestral canyon and the nature of material within it are pointed out as matters of particular interest. These considerations provide the focus for the discussion that follows.

The ability of the proposed reservoir to hold water is evaluated here by considering the properties of McKinney pillow lava in the reservoir area, the continuity of the pillow lava as a hydraulic conduit, and the evidence of past leakage as inferred from the history of Root Lake. Procedures for testing the transmissivity of the pillow lava are then briefly discussed. Finally, the possible use of a grout curtain across the full width of pillow lava in the right abutment of the proposed dam is explained.

Unless an effective way is found to provide an impermeable barrier between the proposed reservoir and the canyon-filling McKinney pillow lava downstream, geologic conditions indicate that the reservoir will surely leak. There are no grounds for uncertainty about this forecast. The only question is the amount of leakage. My understanding of the geology leads me to believe that leakage from the proposed reservoir would be substantial, perhaps to the extent that the reservoir may not hold appreciable water.

4.1 Physical Properties of McKinney Pillow Lava

Pillow lava forms by the spilling of hot, fluid lava into more or less deep water. Some of the lava may break up into globular masses ranging from several inches to several feet across, which solidify in rounded, pillowlike forms. Also, some of the lava may be fragmented by explosions of steam, or simply by the stresses associated with the chilling effect of water, such that particles of glassy lava ranging in size from coarse sand to pebbles are produced. Such fragments may be mingled with the pillows, or they may be sorted into bedded layers that resemble sedimentary deposits. Accordingly, the resulting volcanic material can take various forms, depending on the nature of a particular volcanic event and the features of the lake basin in which the pillow lava is deposited. There also may be abrupt and seemingly random lateral and vertical changes in the physical features of a given body of pillow lava.

With respect to the McKinney pillow lava, outcrops scattered from the canyon rim to the Snake River suggest considerable uniformity through a broad range in depth. Deposits at the canyon floor resemble those near the rim. Pillows are a conspicuous constituent, but they are commonly surrounded or interbedded with finer fragments of glassy lava. The pillows have glassy skins and may be glassy to the core if not much larger than about a foot in diameter. The finer fragments are highly irregular in shape. Many of them are angular or lumpy, or have projecting corners. In contrast with particles in ordinary sedimentary deposits, such fragments lack any signs of abrasion and have surfaces that are noticably rough. Fragments finer than very coarse sand are rare. These irregularities in the constituents cause the pillow lava to be poorly packed and highly porous. Probably, the porosity is equal to that of coarse sand--about 40 percent. Further, because the pores are large, are interconnected, and are not at all filled with secondary mineral matter, the pillow lava can be expected to be highly permeable. That is, the pillow lava is likely to be capable of passing a substantial volume of water in a given time.

Outcrops of the pillow lava exhibit various degrees of mechanical strength, as expressed by differences in angle of repose. It is of interest that the constituents of the pillow lava quickly solidified when they were chilled by the lake water, such that the end product is a loose, uncemented, unconsolidated mass. Nonetheless, perhaps because of interlocking angular particles, the pillow lava is capable of standing in steep slopes--even nearly vertical cliffs in some places. The roadcuts on U.S. Highway 30 mentioned in Part 3.4 have some areas that are vertical, although the slopes of the roadcuts are more generally about 30 degrees.

Vertical cliffs of pillow lava are especially common along the Snake River. The applicant has attributed the cliffs to case-hardening, meaning some lithologic change by which the exposed face of pillow lava has been made comparatively resistant to disaggregation and slumping. Cliffs of pillow lava are found near the mouth of the Big Wood River (outcrop no. 4 described in Part 3.4), along the Snake River from 1.8 to 3.2 miles above the proposed dam site (outcrop no. 6), and where the ancestral canyon is filled with pillow lava downstream from the dam site (outcrop no. 10).

The cliffs of pillow lava may express some local difference in lithology that could make the pillow lava along some reaches of the proposed reservoir less permeable to water than at other places. However, these outcrops crumble easily when struck by a geologic hammer, and they do not differ noticeably in porosity from the pillow lava elsewhere. Also, their existence does not necessarily require a lithologic change in the character of the pillow lava. For example, the cliffs of pillow lava may indicate nothing more than the lack of fine-grained interstitial material, which could cause slumping of the pillow lava (if it were present) by promoting the capillary rise of river water. Many sandstones also form cliffs, even though most of them are highly permeable. Thus, without further investigation, the presence of cliffs in the pillow lava should not be construed as signifying a lithologic change that may promote reduced permeability. Nonetheless, local differences in the permeability of the pillow lava should be investigated, particularly in the environs of the proposed dam site. Testing procedures are discussed in Part 4.4.

4.2 Continuity of McKinney Pillow Lava as a Hydraulic Conduit

The applicant considers that Root Lake clay would be an effective barrier to leakage, where it is present on McKinney pillow lava in the proposed reservoir, but recognizes that the clay has been removed by erosion in some areas. Thus, the applicant anticipates that "some artificial blanketing will be required upstream from the dam to assure against unexpectedly high reservoir loss" (letter from Carter B. King to Ralph I. Clements, March 17, 1980). A blanket, in this context, is understood to be a sealant that would be applied to pillow lava in the reservoir area where Root Lake clay is missing. The applicant's concept is that an impervious blanket might be needed along the right bank for a distance 1,500 feet upstream from the dam site--this being the distance along which pillow lava in the buried canyon of the ancestral Snake River is thought to be connected with pillow lava in the right abutment of the proposed site.

The applicant's suggested method for sealing the reservoir is based on a misunderstanding of the extent of the canyon-filling McKinney pillow lava upstream from the proposed dam and its continuity as a hydraulic conduit. The discussion that follows describes hydraulic connections of increasing length that would drain the proposed reservoir by leakage through the right abutment. Such hydraulic connections are evaluated solely in terms of the continuity of the McKinney pillow lava because this is the only geologic unit in the area of the proposed reservoir that could have significant permeability.

Outcrops of the pillow lava, together with outcrops of older rocks that define the route of the ancestral canyon, provide the available evidence on the continuity of pillow lava upstream from the proposed dam. Outcrops of Banbury Basalt are especially pertinent for tracing the canyon-filling pillow lava because the Banbury makes up the bottom 200 feet of the ancestral canyon, measured from present river level. In this regard, it is of interest that Banbury Basalt is continuously exposed immediately to the left of the river throughout the length of the proposed reservoir--except for a few intermittent deposits of pillow lava, Root Lake clay, and Melon Gravel. Obviously, this wall of basalt approximately defines the left side of the former canyon. In contrast, as explained further below, Banbury Basalt is exposed on the right side of the river only at two places. However, the Banbury is undoubtedly continuously present to the right of the river, concealed by younger deposits, because it must have also defined the right side of the former canyon. The trench between these walls of Banbury Basalt is still filled with McKinney pillow lava, except where the pillow lava has been excavated by the present Snake River. It is this concealed canyon fill of pillow lava and its inferred continuity as a hydraulic conduit that is of interest here (fig. 8).

Based on the geology described in Part 3.4, McKinney pillow lava is thought to be continuous along the right side of the river from the right abutment of the proposed dam to the foot of the landslide at Bliss, a distance of about a mile. If the pillow lava is also present under the toe of the landslide, then a continuous hydraulic conduit extends at least 4 1/2 miles upstream via pillow lava in the concealed canyon to the right of the river, and possibly as far as 6 miles. Root Lake clay is virtually absent to the right of the river upstream from the Bliss landslide, and water of the reservoir would undoubtedly infiltrate the pillow lava and be discharged by leakage through the right abutment of the proposed site--assuming a connection through the landslide area--unless seepage from the proposed reservoir can be artifically impeded. An impervious blanket might be difficult and costly to install and maintain along this reach, not only because of its length, but also because long stretches consist of Melon Gravel, which forms unstable slopes.

From the proposed dam site to the Bliss landslide, McKinney pillow lava is continuously exposed except for a covered interval from 0.3 to 0.7 of a mile above the dam. The covered interval is at the foot of a segment of the canyon wall that closely corresponds with the right wall of the former canyon, judging from a remnant of Madson Basalt below the canyon rim. Because Banbury Basalt along the left wall is exposed 500 feet south of the river, the floor of the former canyon must lie approximately beneath the river. The depth of the former canyon in the right abutment of the proposed dam (altitude 2,550 feet) indicates that the canyon floor can be expected to be about 100 feet below the

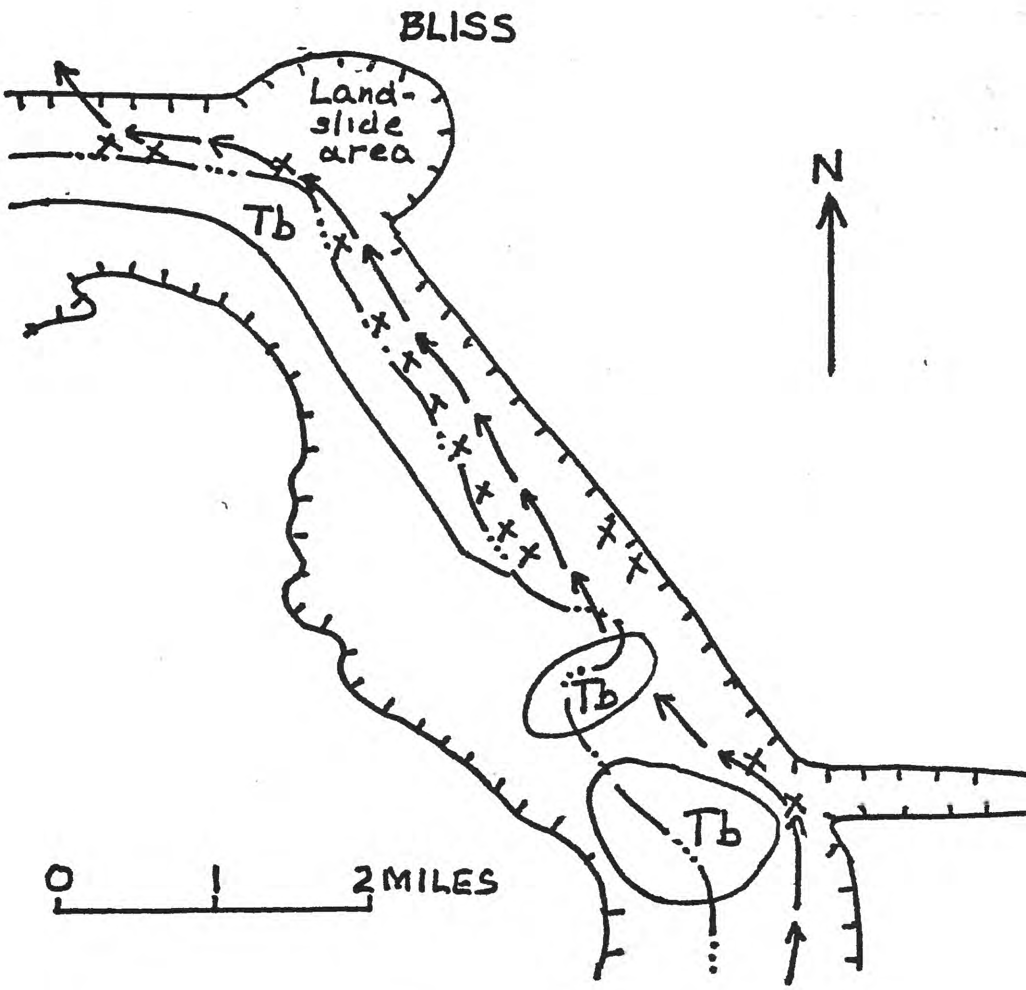

Figure 8.--Sketch map showing inferred continuity of McKinney pillow lava (crosses) in a concealed trench (arrows) to the right of the present Snake River near Bliss, Idaho. The trench is cut in Banbury Basalt (Tb). Seepage from the proposed reservoir would follow pillow lava in the trench and would be discharged around the right abutment of the proposed dam. The present canyon rim is shown by hachures.

river at this place, covered by a substantial thickness of pillow lava. Drilling to test this inference would be desirable because of the connection that might be thereby confirmed with pillow lava farther upstream. Such a connection would augment the length of the reservoir where water could be carried to the right abutment via the concealed canyon fill of pillow lava. Also, if such a connection is confirmed, the task of installing an impervious blanket to prevent leakage from the proposed reservoir into the pillow lava--assuming that no other remedy is more practial--would be greatly increased. The length to be sealed would reach at least a mile upstream, and an undetermined amount of river gravel might have to be removed from the reservoir floor before a sealant could be effectively applied.

Whatever is learned about the continuity of pillow lava in the first mile of the reservoir, the applicant has recognized the need to determine criteria for installing an impervious blanket along the first 1,500 feet. In order to be effective, such a blanket would have to be connected to the curtain or other impermeable structure that will be needed in pillow lava at the right abutment (Parts 4.5 and 5.1).

The area occupied by the Bliss landslide apparently represents a part of the former canyon wall where little, if any, McKinney pillow lava was deposited (Part 6.1). However, pillow lava is exposed in places at the toe of the landslide, as well as immediately upstream. Further, as in the downstream area just described, Banbury Basalt is exposed to the left of the river a short distance from the toe. Thus, the former canyon is probably concealed beneath the toe of the landslide, filled in part by pillow lava. The likelihood of a continuous channel of pillow lava in this area is enhanced by the presence of a steep front of pillow lava on the south side of the landslide, dipping toward the toe (outcrop no. 3 described in Part 3.3). Also, a McKinney lava flow forms the northern canyon rim, probably underlain by pillow lava, opposite the toe of the landslide. Drilling to test the inferred presence of pillow lava beneath the toe of the landslide would be desirable. Such drilling should be designed to determine the location and depth of the former canyon and to identifiy the nature of the canyon-filling deposits. A finding that pillow lava is continuous through the area of the landslide would have considerable significance to the problem of reservoir leakage because a hydraulic connection would thus be established with a long stretch of pillow lava upstream. The results of drilling would also be of interest in analyzing the hazard of augmented landslide activity, as discussed in Part 6.1.

Upstream from the Bliss landslide, Banbury Basalt is first exposed on the right side of the river at a point 4 1/2 miles above the proposed dam (SE1/4SW1/4SE1/4 sec. 21, T. 6 S., R. 13 E., Bliss quad.). McKinney pillow lava is exposed in the right bank for most of this reach, and practically all the remainder is Melon Gravel. (A small outcrop of Root Lake clay is found near the SE corner of sec. 21.) As explained above, the central trench of the former canyon is concealed to the right of the river along this reach. Further, outcrops of McKinney pillow lava along this part of the canyon provide convincing evidence that the concealed trench is filled primarily, or entirely, with pillow lava (see Part 3.4). Finally, because of the visible porosity of the pillow lava and the open texture of the Melon Gravel, water of the proposed reservoir would readily permeate any buried deposits of pillow lava. In short, seepage from the reservoir would be carried downstream through a natural hydraulic conduit. If, as seems likely, pillow lava is continuous through the area of the Bliss landslide and thence downstream to the proposed dam, the hydraulic conduit would drain water from the reservoir by leakage through the right abutment--assuming that a suitable barrier cannot be installed.

In the above discussion, the Banbury outcrop 4 1/2 miles upstream from the dam site is considered to be part of the right wall of the former canyon. If, instead, the outcrop is part of the former left wall, the central trench of the former canyon must lie somewhere to the right, but short of an outcrop of Madson Basalt that is found below the canyon rim at this place (see fig. 7). In this circumstance, a concealed conduit of pillow lava would exist upstream to the Big Wood River, 6 miles above the dam site (see outcrop no. 4 described in Part 3.4). Along this part of the proposed reservoir, water would seep into the pillow lava through covering deposits of Melon Gravel.

4.3 Potential Leakage as Indicated by the History of Root Lake

The applicant emphasizes that Root Lake clay has infiltrated openings in the upper surface of McKinney pillow lava at the proposed dam site and can be expected to form an impervious blanket where the clay is preserved. Because the clay once filled all the area occupied by ancestral Root Lake, presumably covering all the pillow lava that was then exposed, its former extent suggests that it would have prevented leakage from the lake. Curiously, the geologic record indicates that Root Lake leaked throughout its lifetime, and that it leaked voluminously. The path of leakage could only have been via the canyon fill of McKinney pillow lava and thence through the lava dam of McKinney

Basalt farther downstream. Construction of the proposed dam would restore part of the former route by which the water of Root Lake was lost by leakage through the pillow lava, namely the route around the right abutment to the canyon immediately downstream. It is also evident that reservoir water could percolate through the pillow lava still farther to the concealed lava dam, where it might then migrate downstream along the buried ancestral canyon of the Snake River (fig. 2). Thus, it is of interest to consider the geologic evidence of leakage from Root Lake.

The conclusion that Root Lake leaked voluminously is based on the inference that the lake could not have overflowed for any substantial period of time while the Root Lake clay was being deposited. As explained in Part 3.3, the clay accumulated throughout the area of Root Lake to an altitude of 3,180 feet, a height only slightly below the highest McKinney lava flow in the area of the lava dam. Clearly, the lake surface was virtually at the level of the lava dam when the last of the clay was being deposited. It is also clear that the lake did not overflow until sometime after the clay had reached its full height. Overflow, if it had occurred, would have brought running water in contact with clays and silts of the Glenns Ferry Formation at the southern margin of the lava dam, and rapid erosion of these poorly consolidated sediments would have lowered the lake level, thus preventing buildup of the clay to its observed height. Eventually, of course, Root Lake did overflow, downcutting in the Glenns Ferry Formation was thereby initiated, and the lake was progressively lowered. The process of downcutting ultimately formed the present canyon of the Snake River west of Bliss (fig. 2).

The conclusion is inescapable that water was discharged from Root Lake not by overflow but by leakage through the canyon-filling McKinney Basalt. Evaporation from Root Lake, which was probably about the same as the present annual average of 37 inches (Meyers, 1962, pl. 3), obviously would have been insufficient to prevent overflow, given the large discharge of the Snake River. (The discharge is discussed below.) Further, the geologic evidence indicates that the lake leaked at a more or less controlled rate, thus maintaining a high stand of lake water, not only when the last of the Root Lake clay was accumulating, but also when the McKinney pillow lava was being deposited. A condition of equilibrium is implied. The water level was probably achieved and maintained by some relationship between hydrostatic pressure, rate of leakage, and the cross-sectional area of the canyon-filling McKinney Basalt at a given depth of lake water.

The volume discharged from Root Lake by leakage through the McKinney pillow lava must have been substantial, and this loss must have been maintained continuously while the

Root Lake clay was being deposited. The present discharge of the Snake River at this place averages 10,720 cubic feet per second and amounts to about 8 million acre-feet annually (U.S. Geological Survey, 1974, streamflow data for Snake River at King Hill). To this must be added the amount of water depleted for irrigation, which is typically 2.5 million acre-feet annually (Simons, 1953). A rough estimate of the time that elapsed before significant overflow took place is that the Root Lake clay took 25,000 years to accumulate, assuming that the clay was deposited at the rate of 1/4 inch per year--or 50 years per foot--and that the total deposit is 500 feet thick.

The finding that Root Lake lost water by seepage must be considered in light of the evidence for present-day leakage through the McKinney Basalt. The concealed lava dam formed by the basalt now leaks only a small amount, although the Snake River flows on McKinney pillow lava along most of the length of the proposed project, as well as in the upper reach of the Bliss Reservoir immediately downstream. The leakage is thought to be represented by a discharge of somewhat more than 200 cubic feet per second that rises in the bed of the Snake River at Bancroft Springs, 9 miles downstream, where the canyon-filling McKinney Basalt is intercepted by the present canyon (data credited to Carl Tappan, _in_ Idaho Power Company interim report, "A J Wiley Hydro Electric Development," June 5, 1953). The above-river flow from Bancroft Springs is only 17 cubic feet per second (Decker and others, 1970). Probably, the explanation for this amount of leakage under existing conditions lies in the characteristics of the concealed canyon-filling deposits between Bliss and Bancroft Springs, which are still to be investigated by drilling. Until more information has been obtained, the characteristics of the canyon-filling deposits, and their ability to hold water under the higher hydrostatic head that would be formed by the proposed reservoir, are unknown. In any case, as pointed out above, loss of water through the lava dam is not necessarily the primary concern. Rather, leakage through pillow lava that connects the proposed reservoir with the canyon immediately downstream may be the problem of greater interest.

A final matter worthy of consideration is the means by which the water in Root Lake was channeled to the leaky lava dam. Conclusions about the path of leakage are necessarily speculative, but geologic relations suggest that the lake leaked primarily by underflow through the McKinney pillow lava. For one thing, as pointed out above, direct leakage from the lake was almost surely impeded by deposition of the Root Lake clay. For another, leakage from the upper few feet of the lake when it became nearly filled with clay cannot be assumed to have been sufficient to discharge the full flow of the Snake River--although some leakage at this level presumably took place until leakage was reduced by buildup of the clay. In short, substantial flow through pillow lava under the Root Lake clay is indicated. These considerations provide further reason to believe that the pillow lava is continuous in the project area and that significant leakage around the right abutment of the proposed dam can be expected.

4.4 Hydraulic Properties of McKinney Pillow Lava

The geologic evidence that the McKinney pillow lava is a leaky conduit indicates that the design of the proposed impoundment will require measurements of the hydrologic properties of the pillow lava, as determined by suitable testing procedures. Because these measurements would directly pertain to a field test of the feasibility of grouting (Part 4.5), information about the hydrologic properties is especially needed across the full width of pillow lava in the right abutment (where grouting may be necessary).

The pertinent hydrologic variable to be determined is the transmissivity of the pillow lava, which is defined as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient (Lohman, 1972, p. 6). Transmissivity is equal to the thickness of the saturated interval multiplied by the hydraulic conductivity, which in turn is expressed in terms of the volume of ground water that is transmitted in a given time through a given cross-sectional area, measured at right angles to the direction of flow. The thickness of concern is the interval from the top of the proposed reservoir to the base of the pillow lava.

Transmissivity in thin unconfined aquifers has long been measured by the Thiem method (Lohman, 1972, p. 11-13), whereby the effect of pumping water from a well is observed in other wells that are spaced at designated radial distances from the pumped well. In a typical test, the distances between the observation wells and the pumped well are twice and four times the thickness of the aquifer. For the A. J. Wiley Hydroelectric Project, the McKinney pillow lava in the environs of the proposed dam is presumably saturated from river level to its base, a depth of 100 feet. Thus, the observation wells would be located at distances of 200 feet and 400 feet on opposite sides of the pumped well.

A possible pitfall in measuring the transmissivity of the McKinney pillow lava is the variation that can be expected from lithologic inhomogeneities. For example, dense bodies of lava might be encountered that would differ in hydraulic conductivity from that of nearby masses of fragmented pillow lava (see outcrop no. 3 described in Part

3.4, for example). Thus, the design of the well system might be advantageously based on the experience that has been gained in drilling exploratory borings in the project area, provided that the borings were not drilled by using mud. Borings in which circulation of water was lost can be expected to be sites with high hydraulic conductivity.

Transmissivity can also be calculated by measuring the hydraulic conductivity in a sufficient number of boreholes. Two variants of a procedure are described in "Field Permeability Tests in Boreholes, Designation E-18" (U.S. Water and Power Resources Service, 1974, p. 573-578), which is attached here as Appendix C. The factor of permeability that is determined by the procedure is synonymous with hydraulic conductivity. The procedure requires that clear water be pumped down the borehole, using a pump with a capacity considerably greater than the loss of water that can be anticipated. Erroneous determinations of the amount of water accepted by the ground will result if the boring is made with drilling mud and if the pump is too small. Under typical conditions, measurements of the rate of flow into the hole are made at successive 10-foot increments of depth (Peter P. Aberle, U.S. Water and Power Resources Service, oral communication, Nov. 21, 1980). The procedure can be used both above and below the water table, although with some differences in accuracy. Thus, this method of measuring hydraulic conductivity could be advantageous at the A. J. Wiley site, where the pillow lava to be tested occurs both above and below river level. It appears that detailed advice from users of the procedure would be helpful.

The applicant reports that "field water pressure test data" for McKinney Basalt indicate permeability (hydraulic conductivity) of about 10^{-4} cm/s, or 0.3 ft/day. Figuring that the saturated interval is 100 feet thick, the calculated transmissivity of the pillow lava would be 30 ft^2/day. The transmissivity of other basalts in the region ranges from 550,000 to 15 million gallons per day per foot, or from 74,000 to 2 million ft^2/day (Mundorff and others, 1964, Table 9). The range in values reflects differences in hydraulic conductivity between dense lava flows and basalt that has some zones with an open texture. Because of the high porosity of McKinney pillow lava, it can be expected to have values for hydrologic conductivity at least as great as the upper end of the range. Thus, the hydraulic conductivity reported by the applicant appears to be from at least 2,000 to perhaps more than 60,000 times too small. Detailed information about the testing procedure used by the applicant might clarify the apparent discrepancy. In particular, if the test wells were drilled using mud as part of the drilling fluid, the reported values for permeability can be expected to be inaccurate.

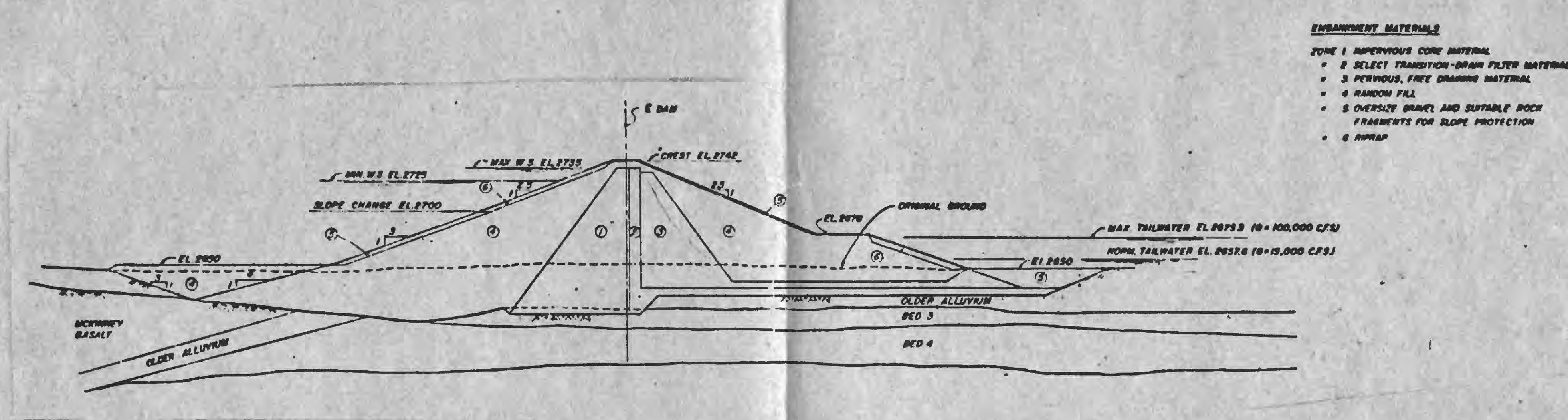

Figure 9.--Section through the proposed earth-fill embankment (from Exhibit L submitted by the applicant).

4.5 Grouting of McKinney Pillow Lava

Measurements of the hydrologic properties of the McKinney pillow lava may suggest that grouting would be an effective and relatively economical method of installing a barrier between the proposed reservoir and the canyon downstream. Almost surely, some barrier will be needed. Indeed, as mentioned in Part 4.2, the applicant anticipates providing a barrier by installing a blanket of impervious material on pillow lava in the reservoir area. A blanket, however, might be shown to be a difficult and costly device to impede leakage, depending on findings about the continuity of the pillow lava and its transmissivity. For instance, the length to be sealed might prove to be as long as 6 miles, some of the distance being in unstable deposits of Melon Gravel. Thus, the feasibility and cost of installing a grout curtain in the pillow lava at the right abutment of the proposed dam may be found to be worthy of investigation.

The dimensions of the required grout curtain can be estimated from existing results of drilling by the applicant and from geologic features near the proposed dam site. The curtain would extend in pillow lava from the intake structure northeasterly to Banbury Basalt concealed in the present canyon wall. The position of the nearest part of the concealed Banbury is not yet determined, but the geologic relations suggest to me that the curtain might be about 2,300 feet long, measured at the height of the proposed reservoir. Its maximum depth would be about 185 feet, if carried no lower than the base of the pillow lava.

A judgment about whether grouting should be investigated depends on the hydrologic properties of the pillow lava, as mentioned above. Moreover, a determination on whether grouting is technically feasible, and whether its cost would be reasonable, requires a field test at the site itself. From conversation with Mr. Aberle, who was in charge of grouting at the Teton Dam, I understand that the grouting characteristics can be determined empirically by following a suitable testing program. Contractors are available to make the proper tests. Obviously, information about the grouting characteristics would be needed throughout the full thickness of the interval to be grouted.

PART 5

FOUNDATION AND CONSTRUCTION PROBLEMS

5.1 Protecting the Earth-Fill Embankment from Excessive Seepage

The design criteria for the earth-fill embankment focus on the control of seepage in the section downstream from the core. Thus, the applicant mentions that joints and fractures in Banbury Basalt at the left abutment will be sealed with gunite and that the surface of McKinney pillow lava in the right abutment will be similarly sealed. The plans further call for grouting under the spillway section. The applicant has also considered seepage through bed 4, a unit of sand grading upward to silt that forms a horizontal stratum as much as 47 feet thick under the proposed dam (figs. 3 and 9). It is recognized that the transmissivity of bed 4 must be determined in order to design a relief well system. The purpose of these various methods for controlling seepage is to achieve suitable tailwater hydrostatic conditions in the embankment section, such that water leaking from the dam will be discharged below river level rather than through the exposed face of the dam. My discussion of the present plans for control of seepage is limited to features of the McKinney pillow lava and to bed 4.

In light of the geologic conditions explained in the preceding section of this report, McKinney pillow lava in the right abutment of the dam can be expected to transmit the full hydrostatic head of the proposed reservoir. Accordingly, the applicant proposes to seal the McKinney with concrete and to install curtain and consolidation grouting. Indeed, considerations of safety clearly require that all McKinney pillow lava under the proposed structure be sealed and grouted so that significant amounts of water will not reach the downstream part of the earth-fill embankment.

However, a matter that is less certain is the effect of seepage from McKinney pillow lava into an underlying unit that the applicant has named the "older alluvium." As explained below, the older alluvium may prove to be structurally weak when wet. Furthermore, its ability to prevent seepage is uncertain. Thus, depending on findings about the physical properties of the older alluvium in the area under the proposed dam, and its predicted behavior under conditions that would be imposed by the dam, consideration of additional engineering factors may be necessary. For example, seepage into McKinney pillow lava under the intake and spillway sections might need to be prevented by installing surrounding grout curtains. On the other hand, prudent design may dictate complete excavation of the McKinney from the area below these structures.

The position of bed 4 under the proposed dam has been determined from several drill holes (DH-41, 48, 80, 81, 86, 88, and 96), and some of its physical properties have been identified--presumably from core samples recovered from silt and fine sand in the upper part. No samples have been recovered from coarser sand and conglomerate found in the lower part, but "field pressure test results" indicate permeability (hydraulic conductivity) of 10^{-3} cm/s, or 3 ft/day. This value seems anomalously small. As in the case of related tests of permeability reported by the applicant for the McKinney pillow lava (Part 4.4), detailed information about the testing procedure might shed light on the reported value.

The hydraulic conductivity of bed 4 is of interest not only for designing the relief well system but also because of the potential for piping (internal erosion) in silt and fine sand that make up its upper part. Substantial seepage through the permeable lower part could erode the silt and fine sand and lead to failure of the overlying earth-fill structure.

On the other hand, piping in bed 4 might be inhibited by an overlying layer of clay, bed 3. Bed 3, however, is only a few feet thick, and its distribution in the area of the earth-fill embankment is poorly determined by drilling. Thus, it is possible that bed 3 is not continuously present in the area under the core of the dam, as represented in figure 9. If bed 3 proves to be missing, or if it can be shown to be inadequate as an inhibitor of piping under the embankment section, another impermeable cap may be needed to protect the core from water that could percolate upward from bed 4.

In summary, the potential for piping in bed 4 should be evaluated to assess whether the existing geologic conditions could cause problems for the integrity of the proposed structure.

5.2 Rapid Weathering of Banbury Basalt

During the field conference on October 21, an outcrop of Banbury Basalt was found about 1 1/2 miles upstream from the proposed dam, in which the basalt exhibits the phenomenon of rapid weathering (left bank of Snake River, NE1/4 sec. 18, T. 6 S., R. 13 E., Bliss quad.). Later, another outcrop of Banbury Basalt with a similar appearance was found on the left bank half a mile downstream from the dam site. These discoveries are of interest because basalt from the same stratigraphic interval, although not necessarily with identical physical properties, makes up the left abutment of the proposed structure.

In the upstream outcrop, Banbury Basalt forms a vertical cliff about 50 feet high. Large slices of basalt have fallen from the cliff and lie at its base, where they are disintegrating more or less rapidly into heaps of basaltic sand and brownish clay. Seepage of irrigation water from a cultivated field above the cliff may account for the collapse of the large blocks of basalt, but their decay into sand and clay is evidently a response to weathering under existing climatic conditions.

Basalts that weather rapidly are recognized as an engineering problem in many parts of the world. The phenomenon is insidious because basalt that appears to be sound when freshly exposed may become degraded and unserviceable in a matter of a few months (Colin, 1969; Orr, 1979; Reynolds, 1972). Also, when used as aggregate, such basalt may exhibit an unfavorable degree of drying shrinkage (Orr, 1979), undesirable heaving on wetting and drying (Cole, 1979), and even adverse plasticity (Day, 1962). These properties make basalt that is susceptible to rapid weathering unsuitable for roads (Collett, Warnick, and Hoffman, 1962; Van Atta and Ludowise, 1976a), earth-fill dams (Higgs, 1976), and many other engineering uses (Farjallet, 1974). Hence, procedures to determine the behavior of basalt before it is used in construction are a matter of active interest.

The phenomenon of rapid weathering of basalt has been attributed in Germany to alteration of interstitial feldspathoidal minerals, such as nepheline and its relatives, which may form in lavas undersaturated in silica (Ernst, 1960). However, the phenomenon is more generally explained to be a result of swelling and shrinking of interstitial clay under repeated cycles of wetting and drying (Higgs, 1976; Orr, 1979; Reynolds, 1972). The clays found in basalt have long been described under the names chlorophaeite and palagonite (Stokes, 1971), but these constituents are more properly identified as clays of the montmorillonite group (Sarbadhikari and Bhattacherjee, 1966; Van Atta and Ludowise, 1976b). Montmorillonitic clays are produced in basalt as secondary alteration products and are abundant in Banbury Basalt found along the Snake River, probably because of former hydrothermal conditions associated with hot ground water at a time when the Banbury was deeply buried (Stone, 1967, p. 231). Such clays have the property of expanding greatly when wet. According to Ray E. Wilcox of the U.S. Geological Survey, interstitial feldspathoids are also vulnerable to weathering and are said to cause rapid breakdown if present. Thus, because secondary clays and felspathoids in altered basalt are not conspicuous in hand specimens, and because a basalt susceptible to rapid weathering may look deceptively sound, an examination of the engineering properties of a particular basalt should begin with microscopic, chemical, and instrumental study of its mineralogy and its petrographic properties (Farjallat, 1974; Higgs, 1976; Orr, 1979; Reynolds, 1972; Van Atta and Ludowise, 1976b).

The petrographic findings, however, do not always correlate consistently with the actual behavior of a basalt when it is exposed to weathering. Thus, empirical tests of accelerated weathering are increasingly used to predict how a given basalt will behave when placed in service.

The objective of laboratory tests of weathering is to accomplish in a few days or weeks what would happen under natural conditions after several months or years. Obviously, long term tests of performance are not practical, and--if determined under actual conditions of use--could be unsafe.

Two "accelerated degradation tests" are commonly used: the ethylene glycol test (U.S. Waterways Experiment Station, 1969) and the slake-durability test (Franklin and Chandra, 1972; International Society for Rock Mechanics, 1972). The slaking test is usually done by immersing rock samples in water, but ethylene glycol can also be used as the slaking medium (Orr, 1979). These tests accelerate the effect of natural wetting of expansive clays in basalt by causing maximum expansion of the clay minerals. They can be completed in from 15 to 30 days. The ethylene glycol test used by the Idaho Transportation Department is attached to this report as Appendix D. It is of interest that R. G. Charboneau of the Department points out that Banbury Basalt in the area has an "inherent ability to degrade" (letter, Nov. 25, 1980).

Depending on climatic conditions in a region, various other tests can be used to evaluate the potential response of basalt to weathering. Thus, to simulate development of laterite in Brazil, basalt is tested by continuous leaching, but other tests that do not reproduce the local climatic conditions in Brazil are also used--namely, the sodium sulfate soundness test and saturation and drying with ethylene glycol (Farjallat, Tatamiya, and Yoshida, 1974). Further, in northern Idaho, a procedure using periods of wetting, freezing, thawing, and drying has been tested on basalt that degrades when used in roads (Collett, Warnick, and Hoffman, 1962).

If a potential for rapid weathering is identified, attention must then be given to obtaining adequate samples. That is, the presence of small patches of unsound basalt in strategic locations may be of greater significance than the overall character of an outcrop. Not uncommonly, because of early conditions that caused alteration of a particular basalt, an area susceptible to rapid weathering may be totally enclosed by unaltered rock.

Banbury Basalt at the site of the proposed dam does not appear to be conspicuously vulnerable to the phenomenon of rapid weathering, but it would be prudent to examine the rock petrographically and to make suitable accelerated degradation tests on representative samples, as explained above (see Deficiency L/N-2). If testing shows that the basalt has a potential for degradation when exposed to weathering, it probably could be protected from cycles of wetting and drying by a suitable sealant, perhaps gunite. On the other hand, depending on the test results, it could be unwise to use any Banbury Basalt in parts of the proposed dam where potential degradation of the basalt would be undesirable. Thus, the plan to use basalt fragments to protect the slope in zone 5 of the earth-fill embankment (fig. 9) and as riprap in zone 6 should be further evaluated. Higgs (1976) reports that basalt placed on the surface of the Keene Creek Dam in southern Oregon slaked badly before construction could be completed, and basalt used in the embankment of the Rio Sucuriu Bridge in Brazil disintegrated a few weeks after its exposure to air (Farjallat, 1974).

5.3 Doubtful Stability of Mixed Debris under McKinney Pillow Lava

Drilling by the applicant in the area of the proposed dam has found a peculiar layer of mixed debris immediately below the McKinney pillow lava. Under the name "older alluvium," the debris is described as consisting of "sandy gravelly clay, mixed with sand, gravel, and silt layers." The debris underlies the northern part of the embankment section as a horizontal layer from 7 to 16 feet thick (drill holes DH-41, 48, and 81) and then dips downward and thickens under the spillway section to a thickness of about 37 feet (drill holes DH-80 and RA-1). A short distance west of the proposed spillway the thickness reaches 56 feet (drill hole DH-19).

During the field conference on October 21, an outcrop on the right bank of the river half a mile downstream from the dam site was identified by Donald Westcott as being the kind of debris found by drilling, namely the applicant's older alluvium (SE1/4 NE1/4 sec. 11, T. 6 S., R. 12 E., Bliss quad.). Lithologic features exposed in the outcrop show that the debris lacks the sorting, rounding, and bedding that are characteristic of stream deposits (alluvium) and instead has the wide range in sizes, angularity, poor stratification, and abrupt changes in lithology which characterize deposits that form by mass movement (fig. 10). Although the origin of the deposit is a matter for further study, my comparison of the outcrop with features described in a review of slope-movement processes (Varnes, 1978) suggests to me that the deposit represents a debris flow that reached its present position by viscous flow. In short, the term "alluvium" is a misnomer. Even more serious, however, identifying the debris as alluvium reflects a misunderstanding of geologic conditions at the dam site, in the sense that the supposed alluvial origin fails to consider the actual physical properties of the debris, its probable variability at the site, and its potentially unstable behavior under conditions that would be imposed by building the dam.

As shown in figure 10, a conspicuous feature of most of the debris is mixed sizes of basaltic blocks surrounded by a matrix of light-colored clay, silt, and sand. The basalt pieces range in size from small pebbles to blocks several feet across. They are highly altered and resemble the lithology of Banbury Basalt in the area, although some of them may have been derived from a local lava flow in the Glenns Ferry Formation, which is also strongly altered. Many of the basalt pieces are angular, even to the extent that corners form acute angles. In contrast, the matrix is almost entirely fine grained, although small pebbles of clay and silt can be found that are undoubtedly coherent pieces derived from older sedimentary deposits, probably the Glenns Ferry Formation. A few such pieces are several feet across (fig. 11). Also, some parts of the debris consist of small fragments of sediment and basalt in approximately equal proportions (fig. 12). During the field conference, Jack Duckworth found that pieces of the matrix slake and fall apart when placed in water.

In figure 10, the debris can be roughly divided into three layers, although the contacts between layers are gradational. Neither layer can be said to be sorted, but some sorting into thinner intervals with contrasting textures can be discerned in the middle layer. These layers have very limited lateral extent. About 150 feet along the outcrop northwest of the area of figure 10, the same layers are no longer recognizable, and the debris has a very different appearance (fig. 12).

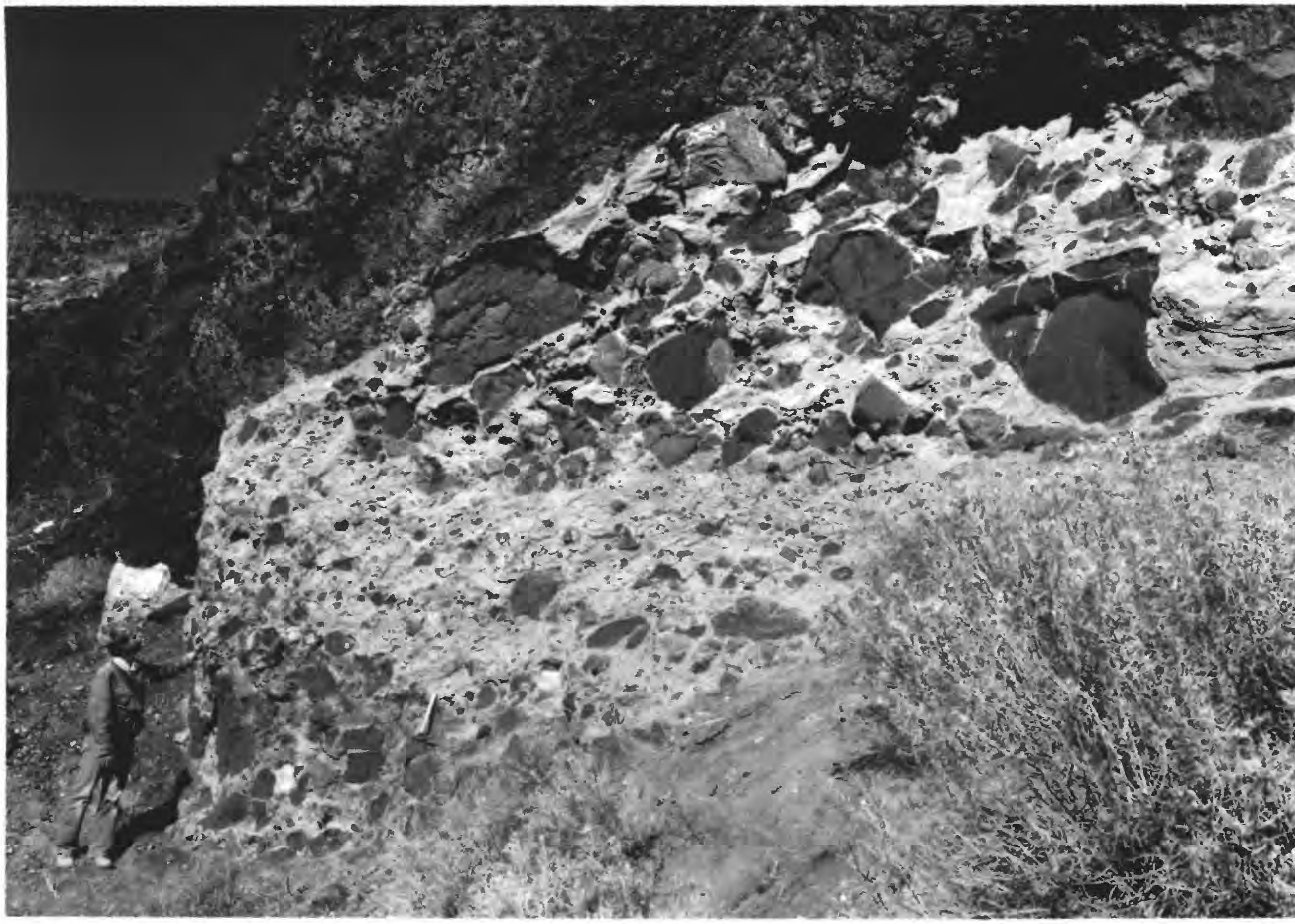

Figure 10.--Part of a layer of mixed debris equal to the applicant's "older alluvium" beneath fragmental basalt of McKinney pillow lava at an outcrop half a mile downstream from the proposed dam and 50 feet above the Snake River (2,500 ft. S., 400 ft. W., NE cor., sec. 11, T. 6 S., R. 12 E., Bliss quad.).

Figure 11.--Laminated clay, silt, and sand in a more or less coherent block of sedimentary material in the debris found below McKinney pillow lava, which seems to have survived as a fragment of the Glenns Ferry Formation. The block of sediment can be seen near the right edge of figure 10, next to a trapezoidal boulder of basalt.

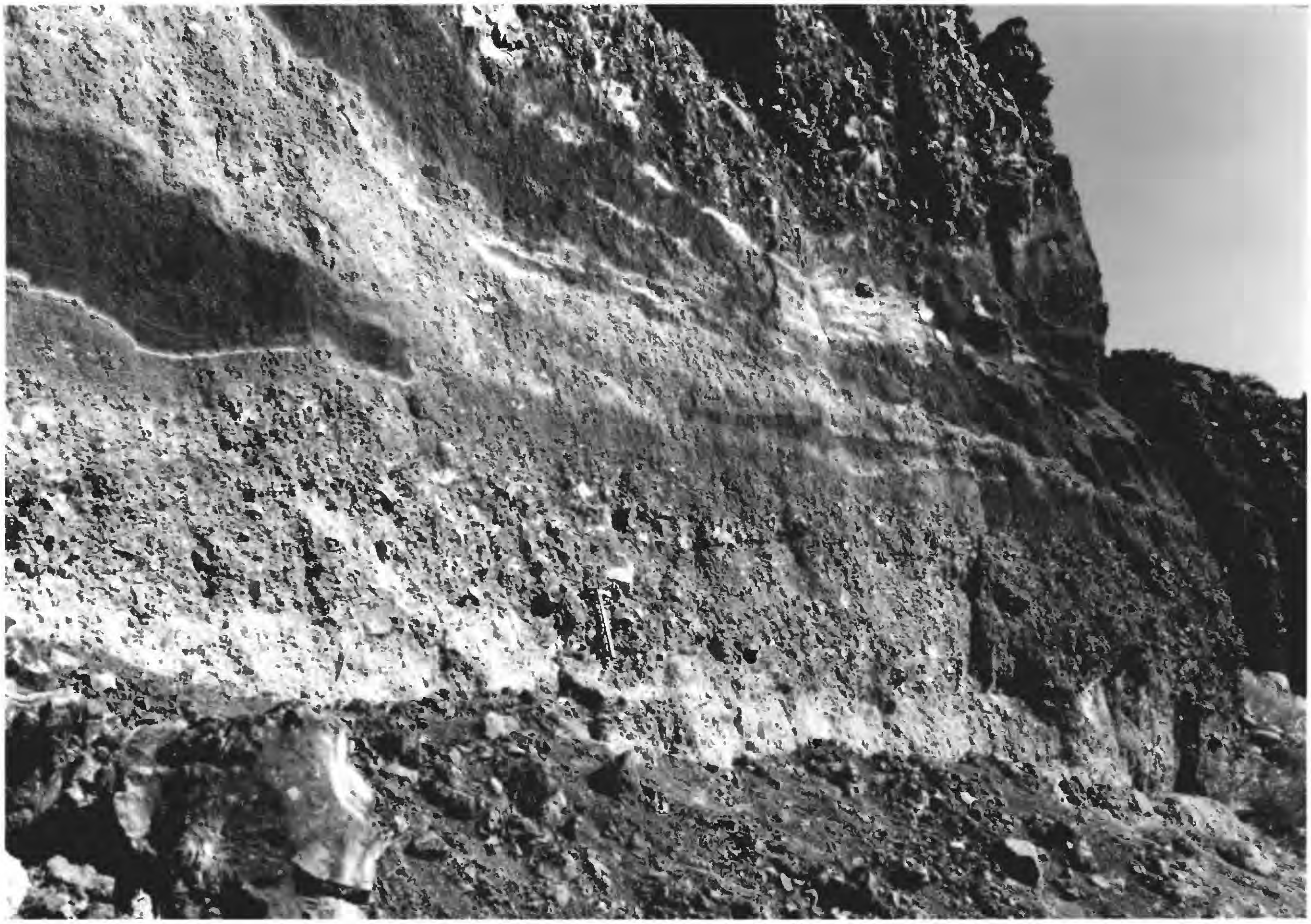

Figure 12.--Debris under fragmental basalt of McKinney pillow lava at a place 150 feet northwest of the area of figure 10. Material at the level of the geologic hammer is a mixture of irregular pieces of basalt and poorly consolidated sediment (primarily clay and silt) in approximately equal proportions. At the left, the debris surrounds a tongue-shaped layer of McKinney fragmental basalt. At the upper center, the contact between the debris and the overlying McKinney appears to be gradational. The stratigraphic relations imply that the debris was being deposited during the first stages of accumulation of the pillow lava.

Together, the poor stratification and lack of sorting of the debris, its discontinuous lithology, and the acute angularity of its larger components support the concept that the debris was deposited as a viscous fluid. Such an origin is also indicated by the nature of the contact with the overlying McKinney pillow lava, which in places displays convolutions that are best attributed to a high degree of fluidity in the matrix of the debris (fig. 13).

The contact of the debris with the pillow lava may have been deformed by processes associated with deposition of the pillow lava itself--for example, expansion of interstitial water in the debris by the heat of volcanic activity, even to the extent that the moving force may have been expanding steam. If so, the debris might be considerably older than the pillow lava. However, intertonguing and gradational relations found between the debris and the pillow lava (fig. 12) establish that they were deposited nearly contemporaneously. Thus, it is reasonable to infer that local deformation of the contact is simply a feature related to the initial viscous state of the debris.

In summary, the debris has features that indicate deposition by viscous flow, its composition is highly variable from place to place, and its contact with the overlying pillow lava is gradational. Such features make the behavior of the debris at the proposed dam site hard to predict. For example, pods of fragmental pillow lava intercalated in the upper part of the debris could strongly influence its behavior by providing access for percolating water. Also, parts of the debris that consist dominantly of matrix material can be expected to be structurally weak when wet, even as they were when they were being deposited.

The presence of the debris at the proposed dam site poses difficult problems in engineering (see Deficiency L/N-2). Its physical characteristics must be explored with the knowledge that significant lithologic changes can be expected in distances as short as a few feet. Its hydraulic conductivity will likely vary in accord with changes in the mixture of basaltic fragments and matrix, and in accord with gradational relations to McKinney pillow lava. Finally, the debris appears to be susceptible to a loss in strength when wet.

Plans by the applicant call for placement of "transition-drain filter material" directly on the debris (older alluvium) in the downstream part of the embankment section (zone 2 in fig. 9). In other words, the debris would be kept continuously wet by seepage through the drain material. The debris might thereby become saturated and lose its strength, thus causing failure of the dam. To evaluate the potential loss of strength in the debris, I am advised by R. W. Fleming of the U.S. Geological Survey, that

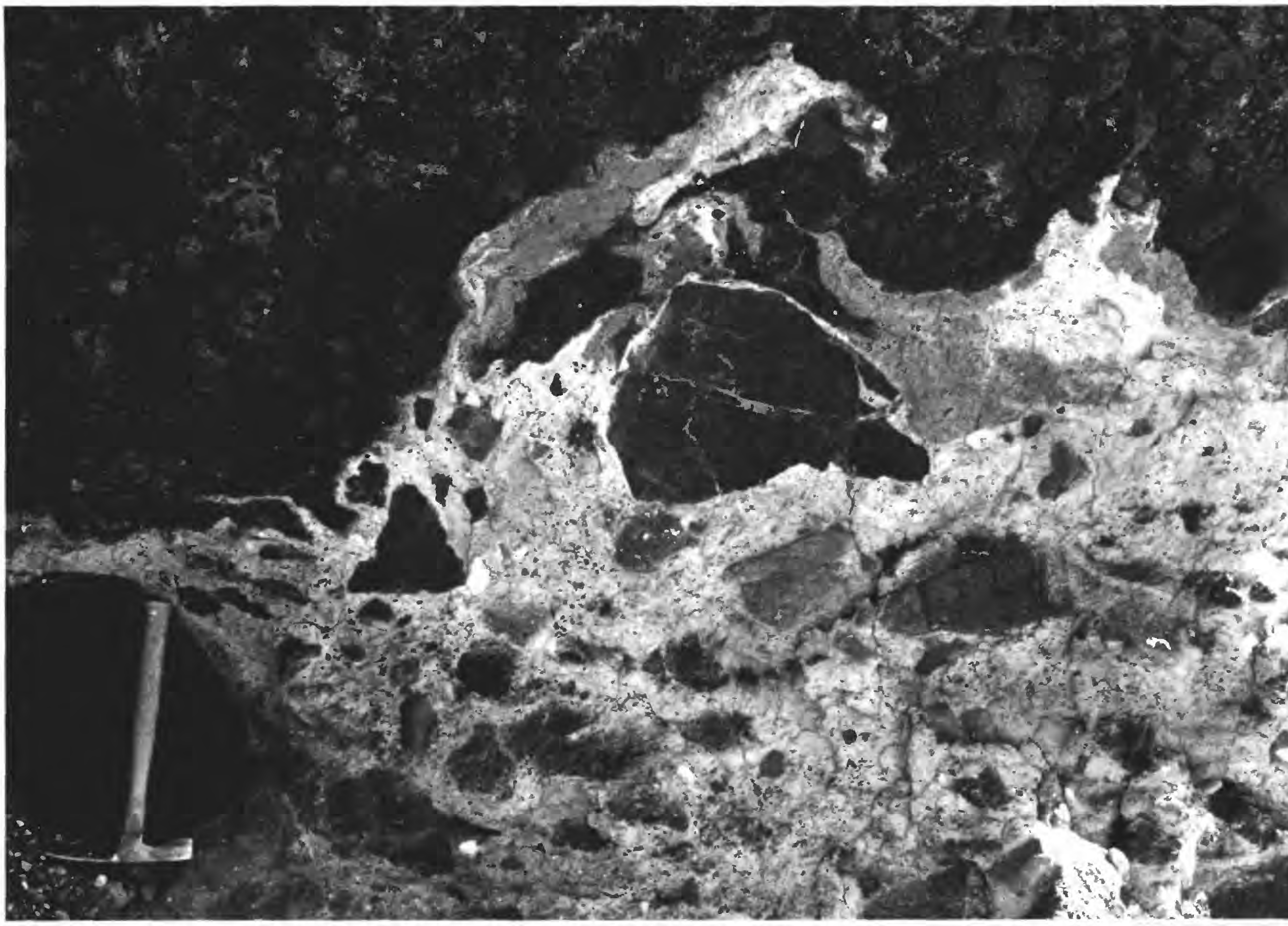

Figure 13.--Deformed contact of fragmental McKinney pillow lava on debris at a place 75 feet northwest of the outcrop shown in figure 10. Light-colored clay, silt, and sand that makes up the matrix of the debris forms plumes, or "flame structures" (Potter and Pettijohn, 1977, p. 199-200), that rise complexly into the overlying fragmental basalt. Features of this kind reflect deformation by viscous flow.

appropriate tests should be made to determine its behavior when wet. Based on these determinations, a stability analysis through the embankment would provide an estimate of predicted stability. For the intake and spillway sections, a similar analysis is needed, together with an evaluation of the potential for differential settling. Unequal subsidence could be caused by differences in consolidation characteristics of the debris and the pillow lava. Depending on the tests and the findings about the lithologic variability of the debris under the proposed structure, the wise course might be to completely excavate the debris from the area of the dam site.

PART 6

POTENTIAL HAZARD OF LANDSLIDES IN THE RESERVOIR AREA

6.1 The Bliss Landslide

From an engineering point of view, the harmful effects of some landslides can be mitigated without any particular knowledge of their origin and physical nature. On the other hand, many landslides are large and have been formed under conditions of geology, topography, or climate, such that the complex causes for their existence and behavior must be understood if damaging effects are to be avoided or controlled (Varnes, 1978, p. 26-28).

The Bliss landslide is an example of a geologically complex landslide that will require considerable exploration, testing, and analysis before it is adequately understood (see Deficiency W-2, Appendix A). An understanding of the landslide is necessary for further consideration of the A. J. Wiley Hydroelectric Project because of the possible effect of the proposed reservoir in aggravating landslide movements. The potential hazard of increased movements above the level of the proposed reservoir is particularly worrisome because of private property near the foot of the landslide, because of the presence of public roads, and because of the possible risk to the town of Bliss, which lies near the head of the slide. Landslide movements might also cause a loss in reservoir capacity--conceivably, even a catastrophic displacement of reservoir water by sudden large-scale collapse of the landslide area.

The Bliss landslide forms the right-hand wall of the canyon about a mile upstream from the A. J. Wiley site, rising from the Snake River to the canyon rim at Bliss, about 500 feet higher (fig. 14). The surface of the slide is dominated by blocks of Root Lake clay, but blocks that have slumped from sediments of the Glenns Ferry Formation and from lava flows that form the canyon rim are found in the upper part.

The slide covers half a square mile. A conspicuous bench at an altitude of 2,925 feet extends across most of its width, such that the part descending to the Snake River has a gradient of about 22 percent, and the slope above the bench has a gradient of about 15 percent. Because the top of the Banbury Basalt in the area is at an altitude of 2,875 feet, and because the Banbury is undoubtedly present beneath the landslide (Part 4.2), the bench is possibly a topographic expression of the comparatively resistant Banbury, concealed by at least 50 feet of landslide deposits.

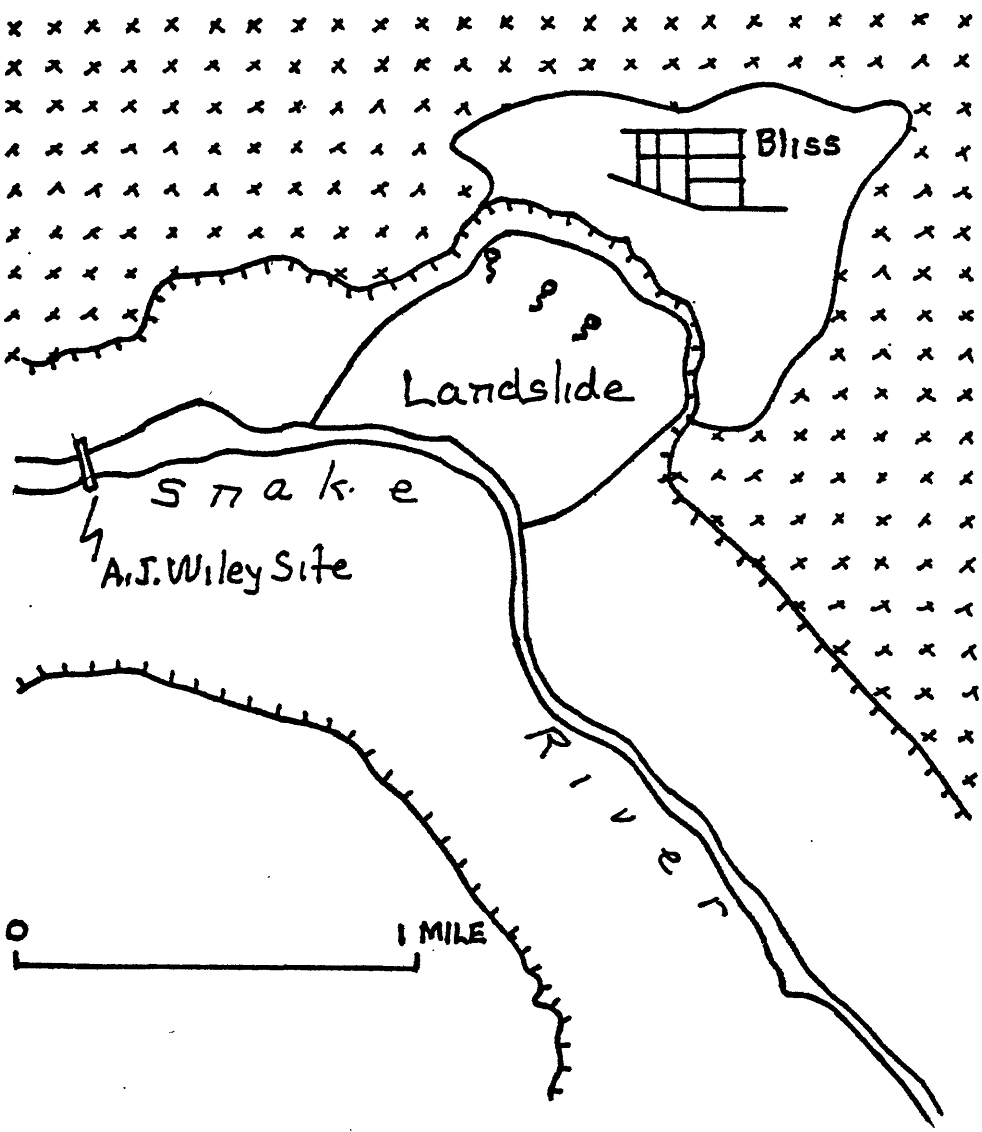

Figure 14.--Sketch map of the area around the Bliss landslide showing the town of Bliss, Idaho, on poorly consolidated sediments, surrounding lava flows of McKinney Basalt that form the canyon rim to the west and south (pattern), and a line of seeps that trends northwestward near the head of the landslide.

The Bliss landslide apparently owes its existence to the presence of a subdued hill of poorly consolidated sediments (Glenns Ferry Formation and Tuana Gravel), which rises a few feet above surrounding lava flows of McKinney Basalt (fig. 14). The hill is part of the interfluve between the ancestral canyons of the Wood River and the Snake River (fig. 2). Because the weak sedimentary deposits that make up the hill are not protected by a cap of McKinney lava flows, they are vulnerable to erosion and are, accordingly, subject to slumping where exposed on the steep slope of the canyon wall. Indeed, failure by slumping is a common feature in the same deposits on the opposite side of the canyon.

The topographic relations of the McKinney lava flows to the hill of older sedimentary deposits at Bliss suggest that the lava flows may have once extended across the upper part of the landslide area, but perhaps only as a narrow band. This inference would be strengthened if McKinney pillow lava is found to be concealed at the toe of the landslide, as discussed in Part 4.2. Nonetheless, the presence of Root Lake clay throughout the area of the landslide is convincing evidence that the landslide area had approximately reached its present dimensions when the clay was being deposited--hence, perhaps even earlier when the pillow lava was being formed. The most significant outcrop of Root Lake clay in this regard is found near the head of the slide at an altitude between 3,150 and 3,175 feet, a height nearly equal to the highest deposits of Root Lake (outcrop no. 4 described in Part 3.3). In short, the landslide is an old geologic feature, dating back to the time of Root Lake.

The evidence that the landslide is old is curious because at least some parts of the slide are still active today. Continuous movement up to the present time might be expected to have produced an even larger area of disturbance, given the presence of Root Lake clay near the highest reach of the slide. Perhaps portions of the slide have moved at unequal rates. The place of greatest recent movement is on a scarp that trends northwestward across the upper part of old U.S. Highway 30. Displacement on the scarp has dropped the pavement downward several feet since the road was built.

Current movement in the upper part of the Bliss landslide may be induced in part by water that seeps out in the slide area below Bliss at an altitude of 3,000 feet (fig. 14). The seeps are along the trend of the scarp mentioned above. Water usually contributes to the movement of landslides by increasing shear stress (the added weight of the water) and by reducing shear strength (decreased intergranular friction, softening, and the like). It is common knowledge in the area that discharge from the seeps has increased with growing use of septic tanks at Bliss, and this observation is seemingly supported by odors at the seeps themselves. However, according to records at the U.S. Geological Survey district office in Boise, the ground-water level at Bliss is not far below the seeps--namely, at an altitude of 2,974 feet. Thus, although it appears likely that the seeps consist largely, or entirely, of effluent from Bliss, and that the management of sewage at Bliss may be contributing to landslide movements, natural sources for the seeps are also possible. In short, an understanding of seepage as related to the Bliss landslide requires further investigation.

Water is also contributed to the Bliss landslide from above as waste-irrigation water, which spills over the canyon rim at a place about half a mile south of Bliss. This water, of course, is seasonal.

In spite of the existence of sources of water in the upper part of the Bliss landslide, the actual cause--or causes--of contemporary movements is uncertain. Thus, further investigation of the landslide is needed before the interaction of the proposed reservoir with the slide can be evaluated. In other words, even if the landslide is active by reason of existing natural or external causes, it is necessary to evaluate how the proposed project might aggravate existing conditions. Then, if adverse impacts can be anticipated, control procedures should be proposed and evaluated for their feasibility, effectiveness, and cost.

The applicant's present understanding of the Bliss landslide is based only on geologic mapping, although "drilling and testing is planned . . . to assure continued resistance of the hillside to large scale failure" (letter of Carter B. King to Ralph I. Clements, March 17, 1980). The geologic problem presented by the Bliss landslide is not whether it is indeed resisting failure, but whether the landslide will fail during the life of the A. J. Wiley Hydroelectric Project, whether failures can be expected to be caused by the project, and whether failures represent a potential risk to the project itself.

Detailed guidance for investigating the Bliss Landslide is given in a recent book published by the Transportation Research Board (Schuster and Krizek, 1978). The chapters dealing with field investigation, measurement of strength properties, and methods of stability analysis are particularly relevant. An investigation of the Bliss landslide is warranted not only because it has a long geologic history and is currently active, but also because reservoirs that encroach on poorly consolidated deposits of the kind found at the Bliss landslide commonly aggravate existing instability and promote more extensive failure (Dupree and Taucher, 1974; Jones, Embody, and Peterson, 1961; Lane, 1967; Schuster, 1979).

The proposed reservoir would cover and saturate the lower 80 feet of the Bliss landslide. Thus, some disturbance by calving and sliding of blocks of Root Lake clay in the lower part of the slide appears to be inevitable, although the actual extent of failure can be expected to be influenced by subsurface conditions. Concealed deposits of McKinney pillow lava, for example, might limit surface deformation. Thus, the influence of subsurface conditions must be determined by making suitable field investigations (for example, core drilling and seismic surveys) and by completing an adequate stability analysis.

Subsurface conditions are also likely to be of special interest in evaluating the effect of the proposed reservoir on the stability of the upper part of the Bliss landslide. Exposed features indicate that large rotated blocks of the Glenns Ferry Formation are present, probably resting on steeply dipping slippage surfaces.

Of particular concern in the upper part of the landslide is the position of the Banbury Basalt, which underlies the Glenns Ferry Formation. If the concealed Banbury is relatively near the front of the slide, at position A in figure 15, it can be expected to increase the stability of the upper part of the landslide--at least in the sense of providing a relatively resistant buttress to movements that may begin at a higher level. On the other hand, if the Banbury is deeply buried by the upper part of the landslide, lying at position B in figure 15, or if it is below the reach of existing slippage surfaces, it would provide little or no resistance. In this circumstance, movements in the upper part of the slide might be propagated to the lower part. An even greater potential danger is that calving at the reservoir might advance upward to the head of the landslide, perhaps leading to enlargement of the slide by headward retreat.

Elsewhere along the canyon of the Snake River, some large landslides in the Glenns Ferry Formation seem to have formed by sudden failure of massive sections of the canyon wall, thus producing widespread sheets of debris in lowland areas. Good examples may be seen in a landslide that covers about 2 1/2 square miles in an area 2-3 miles northwest of King Hill and on the north side of the canyon at the head of Indian Cove. Therefore, large-scale instantaneous collapse of the Bliss landslide is possible, even though large slides of more or less coherent masses are more generally to be expected primarily in indurated rocks (Müller, 1968). Because of the potential hazard, it would be prudent to evaluate the likelihood of widespread failure of the Bliss landslide by making a complete stability analysis. Sudden large-scale collapse of the landslide could displace a substantial part of the proposed reservoir. In this event, the displaced water almost surely would overtop the dam.

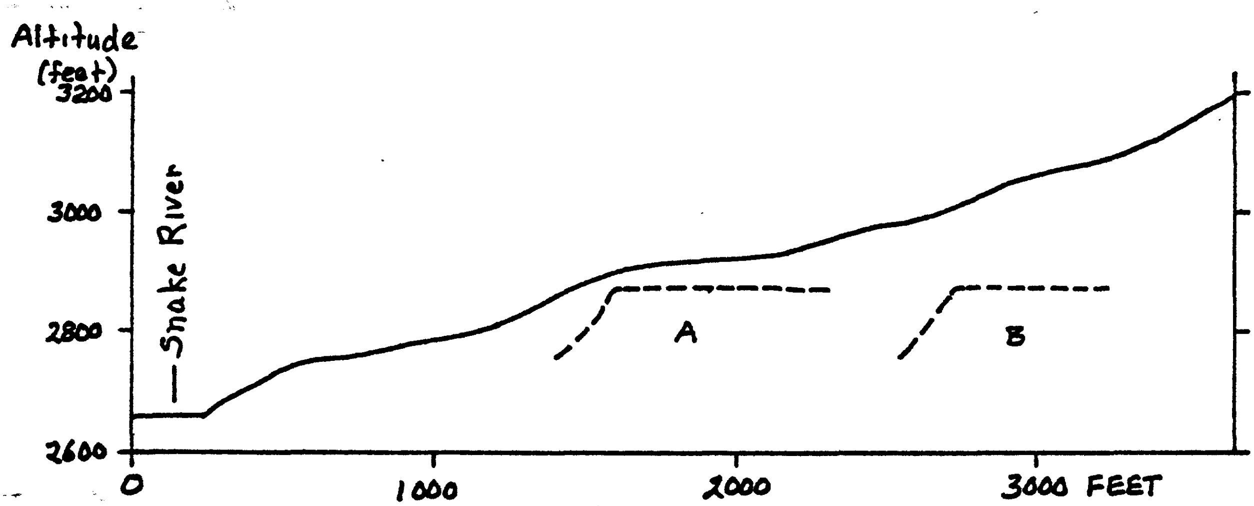

Figure 15.--Representative profile of the Bliss landslide showing two hypothetical positions of concealed Banbury Basalt: A, close to the front of the slide; and B, deeply buried by the upper part. The vertical scale is exaggerated by a factor of two.

6.2 Other Landslides, or Potential Landslides, That Could Reduce Reservoir Capacity

Scattered deposits of Root Lake clay in the area of the proposed reservoir either have areas of active landslides or are potentially unstable. Landslides in these outcrops are not a significant hazard to existing land uses, but each of the deposits represents some risk in maintaining reservoir capacity. The deposits are listed here in the belief that the possible loss of reservoir capacity and its implied economic cost should be evaluated when making a full assessment of the proposed project.

1. Root Lake clay covers about half a square mile on the left side of the canyon in the middle reach of the proposed reservoir (W1/2 sec. 20, T. 6 S., R. 13 E., Bliss quad.). A small part of the outcrop is an active landslide. The toe of the landslide, together with the lower reach of the clay, would form about 3,000 feet of shoreline.

2. Root Lake clay, mantled by Melon Gravel, defines the steep left bank of the Snake River about 4 1/2 miles above the dam site (river bend between sec. 21 and sec. 28, T. 6 S., R. 13 E., Bliss quad.). The steepest part of the outcrop is an active landslide. The proposed reservoir would cover the lower 40 feet of the outcrop, and the overlying 65 feet of clay would likely be subject to slumping.

3. In the area of the former siphon for the King Hill Canal (SE1/4 sec. 28, SW1/4 sec. 27, and NW1/4 sec. 34, T. 6 S., R. 13 E., Hagerman quad.) about 6,500 feet on the left side of the river is subject to active landsliding because of a deposit of Root Lake clay. The disturbed area currently reaches 175 feet above the river. The proposed reservoir would raise the water level from 10 to 25 feet. Saturation and weakening of the toe of this extensive landslide area can be expected to promote further slumping of the clay.

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APPENDIX A

OEPR-EL
Project No. 2845 - Idaho
Idaho Power Company

Mr. Paul L. Jauregui
Secretary and General Counsel
Idaho Power Company
P. O. Box 70
Boise, Idaho 83707

OCT 8 1980

Dear Mr. Jauregui:

Your application for a license for the A.J. Wiley Project No. 2845 has been reviewed, and it does not meet all of the relevant application requirements of the Commission's regulations. A list of the deficiencies found in the application is enclosed as Schedule A.

On October 22, 1979, the Federal Energy Regulatory Commission issued Order No. 54 amending its general regulations concerning processing of applications for preliminary permits and licenses for power projects under Part I of the Federal Power Act. Section 4.31(d) of the regulations provides that an applicant whose application for a license fails to conform to the requirements of the regulations may be given an additional 90 days in which to correct those deficiencies. If the application is then found to conform to the regulations, it will be accepted for filing. If it does not, it will be rejected.

Accordingly, you have 90 days from the date of this letter to correct the deficiencies in your application. If you fail to correct your application within that time, it will be rejected.

Please contact Mohammad Akbar in the Division of Hydropower Licensing at 202-376-9807 if you have any questions.

Sincerely,

William W. Lindsay
Director, Office of Electric
Power Regulation

Enclosures:
Schedule A

OEPR/Akbar, M.:mw/10-3-80

cc: SFRO DHL OGC OPI FILES DA PA PSL SUSPENSE

SCHEDULE A

Deficiencies found in the application for license for the A. J. Wiley Project No. 2845

Exhibits L and N:

The following information should be included in Exhibits L and/or N:

1. Determine and describe the permeability of the basalt, and other foundation materials, and the extent of the clayey material in the right abutment which must be removed prior to embankment construction, and the estimated cost of removal and material replacement.

2. Plans and cost of foundation treatment necessary to prevent excessive pore pressure from causing excessive leakage and/or instability of downstream embankment. The plans should be based upon physical tests of all foundation materials.

Exhibit S

1. The soil survey proposed in the Exhibit S and requested in staff's March 17, 1980, letter must be conducted in order to determine the scope and requirements of the mitigation plan to be developed for riparian vegetation within the proposed reservoir.

2. Identify the species of riparian vegetation which would be lost as a result of the project.

Exhibit V

1. A description, in sufficient detail as appropriate, of the existing rights-of-way and transmission lines located in the vicinity of the proposed project to include physical description, technical drawings and illustrations.

2. A discussion, in sufficient detail, of the extent to which any of the existing rights-of-way and/or transmission lines could be used. The discussion should include paralleling a portion of, or the entire length of, any single line or lines and/or the underbuilding of an existing or new structure.

3. The archeological survey must be completed, along with a list of eligible properties for the National Register of Historic Places and a mitigation plan for these properties.

Exhibit W

1. Under alternatives to the proposed action, the Applicant should discuss the systematic procedure used to arrive at the specific site for the transmission line.

2. Provide thorough stability analyses (including liquefaction potential) of the Bliss slide area and the adjacent Bruneau (Root Lake) Formation between the existing river channel and the canyon rim, based upon actual soil properties and in situ pore pressure. Based on the results of the above studies, determine and discuss the potential for the probability of occurrence of natural and project-induced landslides in those areas, and proposed mitigation measures to be conducted and their cost.

3. Describe the location and extent of the old buried Snake River canyon and the material within that burried canyon (basalt, alluvium, etc.) Also describe the potential leakage and discuss the probability of occurrence of project-induced leakage through that buried canyon, and proposed measures to mitigate and their cost.

4. Provide a classification, by a qualified stratigrapher, of the geologic units at the project, based on all surface and subsurface explorations and testing.

APPENDIX B

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. 913
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

January 30, 1980

Idaho Power Company
Attention: Mr. James E. Bruce, President
Box 70
1220 Idaho Street
Boise, Idaho 83707

Subject: A. J. Wiley Project No. 2845, Bliss, Idaho

Dear Mr. Bruce:

For some time, I have been aware of your interest in building the earth dam that is the subject of this letter, but I have hesitated to write because a formal application for a license seemed remote. Now, I understand that your application to the Federal Energy Regulatory Commission may not be far off. Thus, I am prompted to raise my concern about certain geologic aspects of the A. J. Wiley site in the hope that these aspects will not be overlooked in future proceedings. My concern centers on the site itself and on the geology of the reservoir.

I understand the proposed site to be on the Snake River near the middle of Section 12, T. 6 S., R. 12 E., although you may have now narrowed your choice of location more closely because of recent drilling and field studies. From an early report (A J Wiley Hydro Electric Development . . . Interim Report, June 5, 1953), I know that you are aware that the choice of a safe site depends critically on the geology. That is, a site a short distance downstream or upstream would have distinctly different geologic features. The reason for these differences is that several kinds of geologic deposits are found along this stretch of the river (H. E. Malde and H. A. Powers, Geologic map of the Glenns Ferry-Hagerman area, west-central Snake River Plain, Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-696, 1972). Moreover, a former course of the Snake River, which is filled with pillow lava to a depth of 500 feet, is intercepted by the present canyon in this area (H. E. Malde, History of Snake River canyon indicated by revised stratigraphy of Snake River Group near Hagerman and King Hill, Idaho: U.S. Geological Survey Professional Paper 644-F, 1971). By a curious coincidence, a still earlier ancestral canyon of the Snake River in this area is filled to a depth of several hundred feet with lacustrine clay of the Bruneau Formation (H. E. Malde, The canyons of western Idaho, the Snake River Plain, and the Bonneville Flood, in International Association for Quaternary Research, VII Congress Guidebook for Field Conference E, Northern and Middle Rocky Mountains, p. 90-103, 1965; H. E. Malde, Snake River Plain, in The Quaternary of the United States, Princeton University Press, p. 255-263, 1965).

In the case of the canyon-filling pillow lava, otherwise known as the McKinney Basalt, I assume that finding its position and trend on both sides of the present canyon would be necessary because all of it would need to be removed from the dam site. Also, it would be unsafe to leave any remnants of pillow lava upstream that are connected through the canyon walls with the concealed canyon downstream, or with the present Snake River.

Clay of the Bruneau Formation may make for engineering problems at the dam site, as recognized in your 1953 report, depending on its permeability and its mechanical properties when wet. These possible problems, if not controllable by engineering design, could not be avoided by choosing another site in this reach of the canyon. The clay is continuous along the right (north) bank except where it is replaced by the deep fill of pillow lava.

The Bruneau Formation presents another hazard upstream in the area of the proposed reservoir, namely the threat of augmented landsliding in the canyon wall under Bliss. A massive landslide, reaching from river level to the canyon rim, and occupying about half a square mile below Bliss, has been sporadically active for many years. Weakening this landslide by saturating its toe with water, a circumstance that could not be avoided in the presence of a reservoir, would clearly increase the risk of landsliding. Experience at other reservoirs where this phenomenon has been observed, suggests that landsliding below Bliss might be augmented to a disastrous degree.

From your current studies, I assume that you now have detailed geologic information on the possible problems that I have outlined here. In that my perception of the problems is predicated on my general geologic studies of some years back, I would welcome the opportunity to review your detailed findings in the event that these are made available to the public.

Sincerely yours,

Harold E. Malde

Harold E. Malde

cc: Ronald A. Corso, Federal Energy Regulatory Commission
Vincent D. Sullivan, U.S. Department of the Interior
Idaho Public Utilities Commission

APPENDIX C

EARTH MANUAL

A WATER RESOURCES TECHNICAL PUBLICATION

A guide to the use of soils as foundations and as construction materials for hydraulic structures

SECOND EDITION
1974

REPRINTED 1980

U.S. DEPARTMENT OF THE INTERIOR
WATER AND POWER RESOURCES SERVICE

FIELD PERMEABILITY TESTS IN BOREHOLES

Designation E–18

1. Scope.—This designation describes water tests for determining the approximate values of permeability of individual strata penetrated by borings. The reliability of the values obtained depends on the homogeneity of the stratum tested and on certain restrictions of the mathematical formulas used. However, if reasonable care is exercised in adhering to the recommended procedures, useful results can be obtained during ordinary boring operations.

Another procedure for computing permeability is found in Geology Report G–97 [1], which is available from the Engineering and Research Center. Either procedure is acceptable. When submitting permeability test results, the formulas used should be included with the data.

2. Apparatus.—These tests are not required for construction control; therefore, the apparatus is not listed in the field laboratory equipment list, designation E–4.

(1) For open-end tests (fig. 18–1), a drill rig or other means of excavating a borehole and driving pipe casing is needed. (*Note:* Drilling mud or other additives must not be used in unconsolidated materials.) A watermeter, pressure gage, pump, and the necessary water pipe and connections are also required.

(2) For packer tests (fig. 18–2), a supply of packers, perforated water pipe, and necessary fittings are needed in addition to the equipment listed under (1) above.

3. Water.—The following tests are of the pumping-in type, that is, they are based on measuring the amount of water accepted by the ground through the open bottom of a pipe or through an uncased section of the hole. Unless clear water is used, these tests are invalid and may be grossly misleading. The presence of even small amounts of silt or clay in the added water will result in plugging of the test section and give permeability results that are too low. By means of a settling tank or a filter, efforts should be made to assure that only clear water is used. It is desirable for the temperature of the added water to be higher than ground-water temperature, so as to preclude the creation of air bubbles in the ground which may greatly reduce the acceptance of water.

4. Open-End Tests.—(a) *Procedure.*—Figures 18–1 (A) and (B) show tests made through the open end of a pipe casing which has been

[1] "Permeability Tests Using Drill Holes and Wells", Geology Report No. G–97, Research and Geology Division, Bureau of Reclamation, January 3, 1951.

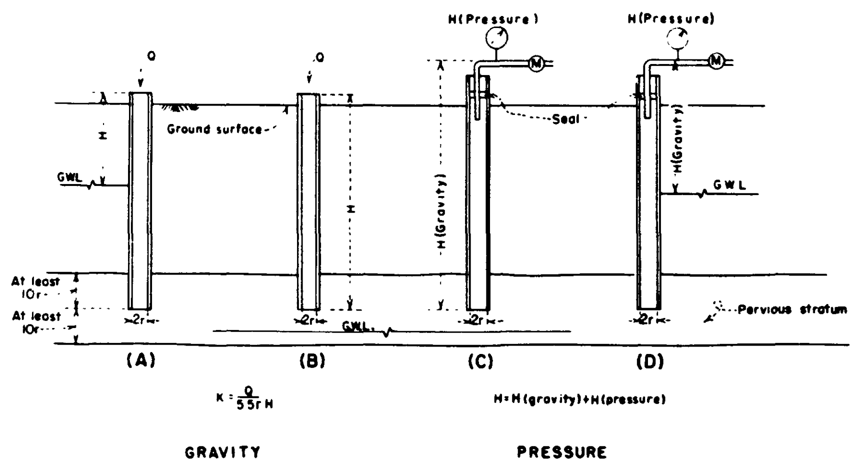

Figure 18-1.—An open-end pipe test for soil permeability which can be made in the field. PX-D-16267.

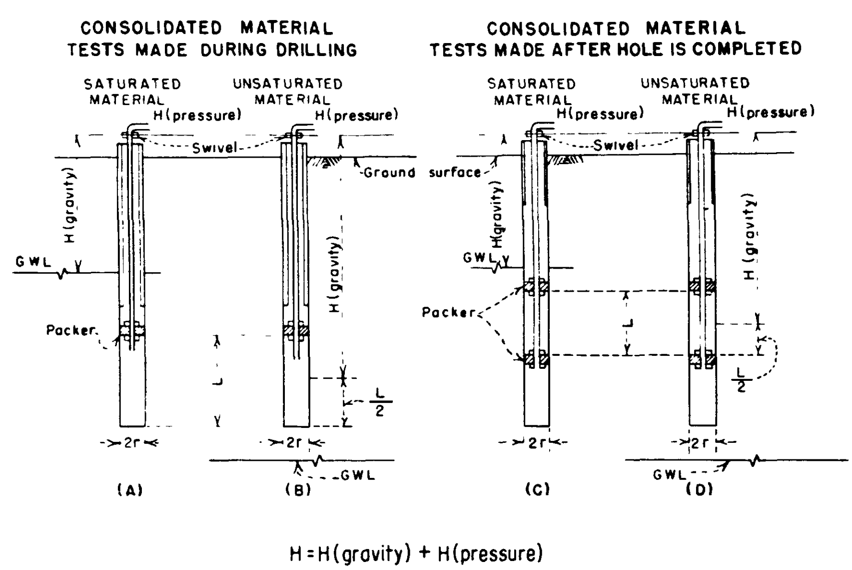

Figure 18-2.—The packer test for soil permeability. PX-D-4785.

sunk to the desired depth and which has been carefully cleaned out just to the bottom of the casing. When the hole extends below the groundwater table, it is recommended that the hole be kept filled with water during cleaning and especially during withdrawal of tools to avoid squeezing of soil into the bottom of the pipe. After the hole is cleaned to the proper depth, the test is begun by adding clear water through a metering system to maintain gravity flow at a constant head. In tests above the water table (fig. 18–1 (B)) a stable, constant level is rarely obtained and a surging of the level within a few tenths of a foot at a constant rate of flow for about 5 minutes is considered satisfactory.

If it is desired to apply pressure to the water entering the hole, the pressure, in units of head, is added to the gravity head as shown in figures 18–1 (C) and (D). Measurements of constant head, constant rate of flow into the hole, size of casing pipe, and elevations of top and bottom of casing are recorded. The permeability is obtained from the following relation determined by electric analogy experiments:

$$k=\frac{Q}{5.5rH} \qquad (1)$$

where: k = permeability,
Q = constant rate of flow into the hole,
r = internal radius of casing, and
H = differential head of water.

Any consistent set of units may be used. For convenience, if k is measured in feet per year, Q in gallons per minute, and H in feet, equation (1) can be written:

$$k=C_1\frac{Q}{H}$$

Values of C_1 vary with the size of casing as follows (see figs. 2–18 through 2–22):

Size of casing	EX	AX	BX	NX
C_1	204,000	160,000	129,000	102,000

The value of H for gravity tests made below water table is the difference in feet between the level of water in the casing and the groundwater level. For tests above water table, H is the depth of water in the hole. For pressure tests the applied pressure in feet of water (1 pound per square inch = 2.31 feet) is added to the gravity head to obtain H.

(b) *Example for Condition Shown in Figure 18–1 (A).*— Given: NX casing

Q = 10.1 gallons per minute
H = 21.4 feet

$$k=C_1\frac{Q}{H}=\frac{(102{,}000)\ (10.1)}{21.4}=48{,}100 \text{ feet per year.}$$

(c) *Example for Condition Shown in Figure 18–1 (D).*—

Given: NX casing

$Q=7$ gallons per minute
H (gravity) $=24.6$ feet
H (pressure) $=5$ p.s.i. $=5\times2.31=11.6$ feet of water.

Then: $H=24.6+11.6=36.2$ feet

$$k=C_1\frac{Q}{H}=\frac{(102{,}000)\ (7)}{36.2}=19{,}700 \text{ feet per year.}$$

5. Packer Tests.—(a) *Procedure.*—Figure 18–2 shows a permeability test made in a portion of a drill hole below the casing. This test can be made both above and below the water table provided the hole will remain open. It is commonly used for pressure testing of bedrock using packers, but it can be used in unconsolidated materials where a top packer is placed just inside the casing. When the packer is placed inside the casing, measures must be taken to properly seal the annular space between the casing and drill hole wall to prevent water under pressure from escaping.

The formulas for this test are:

$$k=\frac{Q}{2\pi LH}\log_e\frac{L}{r};\ L\geqq 10r \qquad (2)$$

$$k=\frac{Q}{2\pi LH}\sinh^{-1}\frac{L}{2r},\ 10r>L\geqq r \qquad (3)$$

where:
$k=$ permeability,
$Q=$ constant rate of flow into the hole,
$L=$ length of the portion of the hole tested,
$H=$ differential head of water,
$r=$ radius of hole tested,
$\log_e=$ natural logarithm, and
$\sinh^{-1}=$ inverse hyperbolic sine.

These formulas have best validity when the thickness of the stratum tested is at least $5L$, and they are considered to be more accurate for tests below ground-water table than above it.

For convenience, the formulas can be written:

$$k=C_p\frac{Q}{H}$$

where k is in feet per year, Q is in gallons per minute, and H is the head of water in feet acting on the test length. Where the test length is below the water table, H is the distance in feet from the water table to the water swivel (see fig. 18–2) plus applied pressure in units of feet of water. Where the test length is above the water table, H is the distance in feet from the center of the length tested to the swivel plus the applied pressure in units of feet of water. For gravity tests (no applied pressure) measurements for H are made to the water level inside the casing (usually the level of the ground).

Values of C_p are given in the following table for various lengths of test sections and hole diameters:

Length of test section in feet, L	C_p values			
	Diameter of test hole			
	EX	AX	BX	NX
1	31,000	28,500	25,800	23,300
2	19,400	18,100	16,800	15,500
3	14,400	13,600	12,700	11,800
4	11,600	11,000	10,300	9,700
5	9,800	9,300	8,800	8,200
6	8,500	8,100	7,600	7,200
7	7,500	7,200	6,800	6,400
8	6,800	6,500	6,100	5,800
9	6,200	5,900	5,600	5,300
10	5,700	5,400	5,200	4,900
15	4,100	3,900	3,700	3,600
20	3,200	3,100	3,000	2,800

The usual procedure is to drill the hole, remove the core barrel or other tool, seat the packer, make the test, remove the packer, drill the hole deeper, set the packer again to test the newly drilled section, and repeat the test (see fig. 18–2 (A)). If the hole stands without casing, a common procedure is to drill it to final depth, fill with water, surge it, and bail it out. Then set two packers on pipe or drill stem as shown in figures 18–2 (C) and (D). The length of packer when expanded should be at least five times the diameter of the hole. The bottom of the pipe holding the packer must be plugged and its perforated portion must be between the packers. In testing between two packers, it is desirable to start from the bottom of the hole and work upward.

(b) *Example for Condition Shown in Figure 18–2 (A).—*

Given: NX casing set to depth of 5 feet

$Q = 2.2$ gallons per minute

$L = 1$ foot

H (gravity) = distance from ground-water level to swivel

= 3.5 feet

H (pressure) = 5 p.s.i. x 2.31 = 11.6 feet of water

$H = H$ (gravity) + H (pressure) = 15.1 feet.

From table, $C_p = 23{,}300$

$$K = C_p \frac{Q}{H} = \frac{(23{,}300)(2.2)}{15.1} = 3{,}400 \text{ feet per year.}$$

APPENDIX D

IDAHO TRANSPORTATION DEPARTMENT
Division of Highways
Boise, Idaho

T-116-78

METHOD OF TEST FOR DISINTEGRATION OF
QUARRY AGGREGATES (ETHYLENE GLYCOL)

1. SCOPE

1.1 This method outlines three variations of the preparation and test procedure for measuring the presence of deleterious clay in quarry aggregates.

2. APPARATUS

2.1 Oven - 140°F ± 5°F.
2.2 Sieves - 3/8" and 1/2".

3. PROCEDURE

3.1 Alternate 1 - Wash and dry (140°F oven) enough material passing the 1/2" and retained on the 3/8" to provide 500 grams when shaken to refusal. Immerse in technical grade ethylene glycol or dimethyl sulfoxide for a period of 15 days. Then decant and dry aggregate in 140°F oven. Shake to refusal over 3/8" sieve and calculate percent retained.

3.2 Alternate 2 - Cover one or two, 1-1/2" to 3" size fractured rock fragments from a materials source, with ethylene glycol or dimethyl sulfoxide and daily observe physical change (cracks, crumbling, disintegration) for a period of 15 days.

3.3 Alternate 3 - Drop a solution of benzidine dihydrochloride (read caution on label) on a recent fractured face of a rock or aggregate specimen. A blue color indicates the presence of montmorillinite.

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