GLACIAL GEOLOGY OF THE MUD MOUNTAIN DISTRICT, KING COUNTY, WASHINGTON

by

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GLACIAL GEOLOGY OF THE MUD MOUNTAIN DISTRICT, KING COUNTY, WASHINGTON

INTRODUCTION

Mud Mountain Dam and the surrounding area (hereafter referred to as the Mud Mountain District) is approximately six miles east of Enumclaw, Washington (see Figs. 1 and 2). Here the White River emerges from its valley in the Cascade Range and enters the Puget Lowland.

The general problem with which this paper is concerned is the relationship along the Cascade front between the Cascade valley glaciers and the ice that occupied the Puget Lowland. Willis (1897) and Willis and Smith (1899) in the Tacoma Quadrangle, immediately to the west of the Mud Mountain District, mapped a till that they considered to be deposited by a piedmont lobe of Cascade ice. Bretz (1913) did not deal specifically with the area adjacent to the White River, but in the Eatonville area to the south, he found that Puget ice had moved up onto the lower slopes of the Cascades. Mackin (1941), in the Snoqualmie-Cedar area to the north of the

District, noted that Puget ice blocked the mouths of valleys cut into the foothills of the Cascades.

In the 1930's, before and during the construction of Mud Mountain Dam, Mackin and Cary established relationships between the major units in the Pleistocene succession at the dam site. The writer's interest in the District began in 1948 when he served as an inspector on a series of churn drill holes in the right bank of the reservoir of Mud Mountain Dam. In addition to logging the drill holes, he mapped the contact of bedrock with glacial material in the vicinity of the dam. This was done for U. S. Army Engineers under the supervision of Cary. Later, at the suggestion of Mackin, a more detailed study of the District was undertaken. Because of close relationships between the writer and Mackin and Cary, no attempt is made to designate the contributions of each.

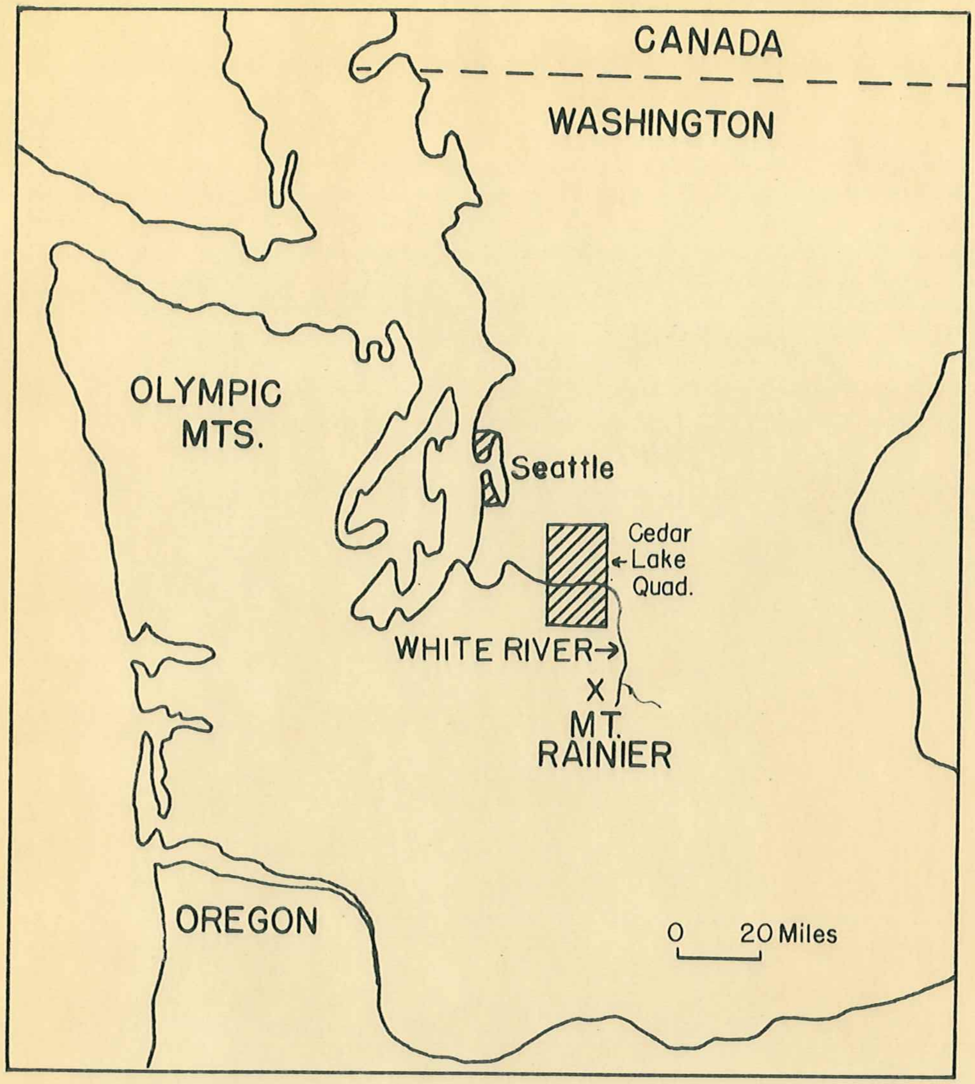

Fig. 1

INDEX MAP

Fig. 2

MAP OF A PORTION OF THE CEDAR LAKE QUADRANGLE

(1) flat plain of the Puget Lowland (2) steep slope of the Cascade front (3) Scatter Creek flat (4) Mud Mountain Dam (5) Bear Swamp scarp (6) Tugaw-Olson gravel pit.

GENERAL TOPOGRAPHIC RELATIONS

The boundary between the Puget Lowland and the Cascade foothills in the vicinity of Enumclaw is well marked. The flat plain of the Lowland is bounded on the east by the foothills which rise abruptly 1000 to 1700 feet above the Lowland (see Fig. 2).

At the Cascade front the foothills have a rounded and smooth profile. To the east and southeast the higher inter-valley ridges have an arete-like sharpness (see Plate I). The slopes of Grass Mountain and the surrounding hills of the westernmost foothills have been modeled primarily by weathering, wash and creep. The more angular topography is the result of gouging by Cascade valley ice.

The White River flows in a broad, mature valley at the Cascade front, but the lower part of the valley profile is interrupted by a wide, flattish surface, locally known as Scatter Creek flat. The western edge of the flat is marked by an irregular scarp that descends steeply to Bear Swamp. The White River has cut an inner valley into the flat along its southern margin (see Plate I).

Mud Mountain is a finger-like southwesterly extension of Scatter Creek flat, which is bounded on the southeast by the inner valley of the White River and on the northwest by the Bear Swamp scarp. The "Mountain" is aptly named, as only on its southernmost end, at the dam site, is there any bedrock exposed. The remainder of the "Mountain" consists of Pleistocene sediments.

The inner valley of the White River at the dam site is an extremely narrow gorge (see Plate I). The upper 250 feet of the gorge wall is glacial material and the lower 150 feet is bedrock.

POST GLACIAL EROSION

The time since the retreat of the last Wisconsin glacier from the lower White River valley has been so short that there has been relatively little modification of the topography by interstream erosion. The most noticeable effect is the cutting of the inner valley of the White River in the unconsolidated Pleistocene sediments and, locally, into relatively weak rock (see Fig. 3).

The location of the inner valley is probably due to the fact that the White River flowed along the southern margin of the valley during the early retreatal stages of the last glacier. It occupied a "gutter position" between the ice and the valley sides. After the retreat of the ice, the river maintained this position. The large Ohop valley near Eatonville was described by Bretz to be of similar origin.

Fig. 3

INNER VALLEY OF WHITE RIVER

View looking northeast.

PLEISTOCENE STRATIGRAPHY

General Statement

The Pleistocene sediments that underlie Scatter Creek flat and Mud Mountain consist of a thick sequence of morainal deposits, stream gravels and sands, lake clays and peaty sediments. This sequence represents more than one Pleistocene stage. In general, the material was derived from the Cascades, although at least one unit consists of material that came from the Puget Lowland.

The two problems presented by the Pleistocene stratigraphy of the District are (1) differentiation between the various units and determining the source of the material and (2) establishing time breaks between the major time-rock units.

The only fossils that have been found in the District are fragments of wood which are so carbonized that they are beyond accurate identification. Specimens examined by Professor H. D. Erickson, a member of the faculty of the University of Washington School of Forestry, were determined to be from trees of the same general type as are growing in the forests of the Cascade foothills today (personal communication).

Two methods, pebble counting and examination of heavy mineral assemblages, were used to determine the source of the sediments that make up the various units. Pebble counts were made by breaking open from 100 to 200 pebbles and cobbles in specific outcrops, and determining the percentage of different rock types present. In this study the most useful rock types were the plutonics, as the Cascade area provides only a small variety of granitic rocks, while the Puget Lowland derived sediments contain a highly varied assemblage of granitic and metamorphic rock types. The volcanic rocks were also used. The volcanic rock assemblages of both the Lowland and the Cascades contain a large amount of the greenish andesite of the Keechelus series, an early Tertiary volcanic unit of western Washington. In addition, Cascade assemblages of the late Pleistocene also contain the porous, purplish lavas of Mt. Rainier.

The heavy mineral assemblages of some of the units were also studied. The concentrations of the heavy minerals were obtained by the use of a prospector's pan. The same amount of material was used in each pan to give approximately the same size samples for each concentrate. Examination of the minerals under the microscope showed that there was a different assemblage of minerals in the sediments derived from the Cascades as compared with those from the Puget Lowland.

The texture of the tills is a useful, but not always dependable, criterion for correlation. It must be used with caution, especially if the units to be correlated are separated by a distance. There is a general similarity in texture of individual tills that is fairly consistent throughout the District. In some of the better exposures each till can be distinguished on the basis of texture as well as stratigraphic position.

Establishing the existence of time breaks between glacial stages in the Pleistocene sequence is at best a difficult task. Features that are considered to represent a period of non-glaciation are (1) evidence of a period of erosion and (2) presence of a fossil soil. In the following paragraphs a brief discussion of these features is given.

There are only a few places in the District where there is evidence of inter-glacial erosion. These are nearly all limited to Wisconsin sediments. The sides of valleys that have been filled with sediments are found, but the occurrences are so scattered that it is difficult to trace the former valleys any distance.

The occurrence of a fossil soil is considered evidence for a period of non-glaciation. Zones of extreme decomposition are present in the District, but it is not always possible to prove that they were formed as the result of exposure to the atmosphere. In some cases the decomposition was probably caused by the circulation of oxygenated ground water in zones of more than normal permeability.

A diagramatic summary of the Pleistocene stratigraphy of the Mud Mountain District is given in Plate II. The section is that found in the vicinity of the right bank of the spillway of the dam. This is the thickest and most completely exposed section in the District. Although the section shows the approximate relative thicknesses of the units, no attempt is made to give a scaled representation, because of the extreme variability of thickness within a short distance.

A diagramatic cross section is also presented in order to show the relative positions on the various till or till-like units in the Pleistocene fill in the mouth of the White River valley.

Wisconsin Deposits

Scatter Creek Till*

Scatter Creek flat and Mud Mountain are capped by a flattish surface which is formed by a thin but extensive sheet

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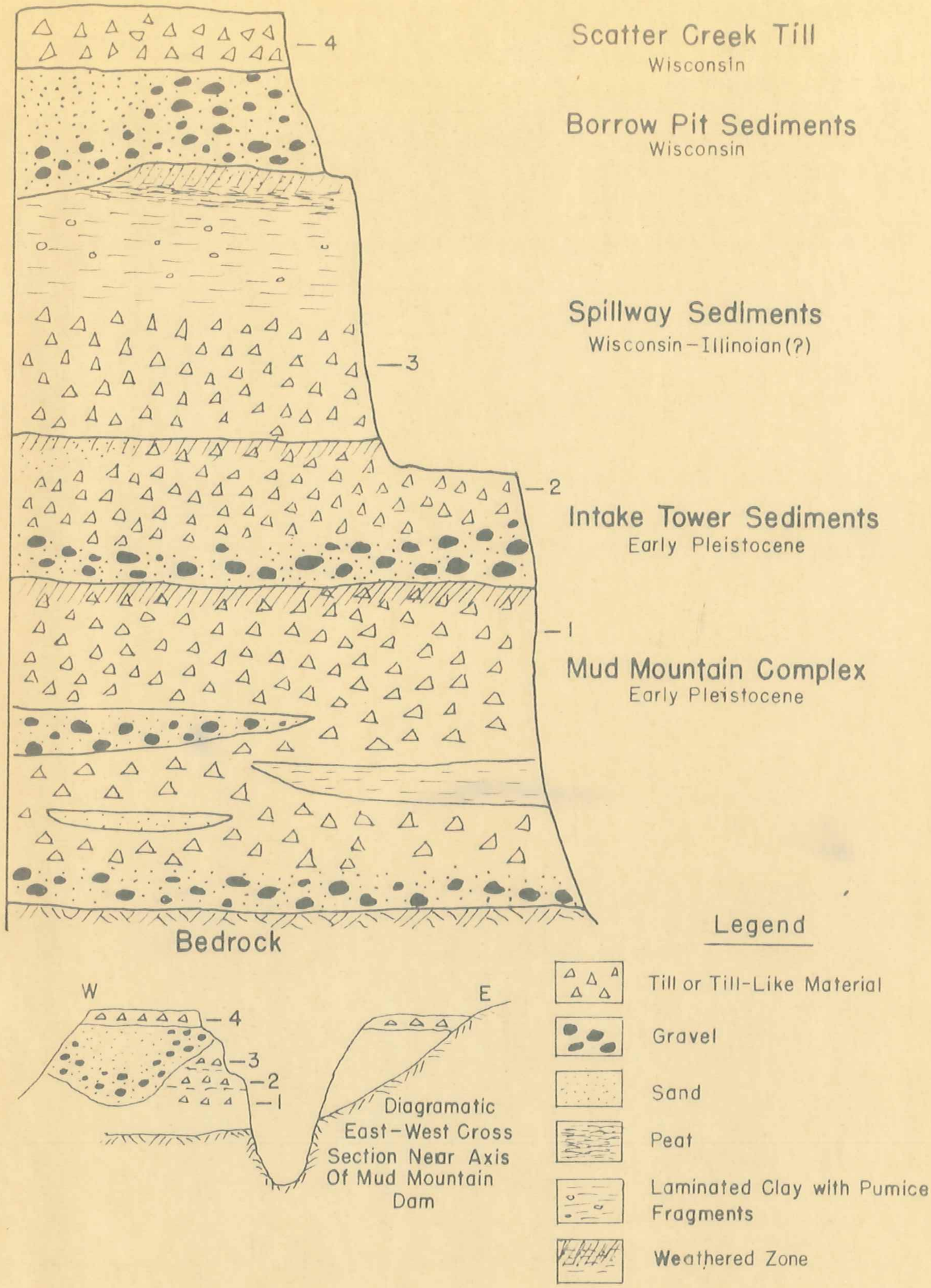
* After the completion of this study, Dwight R. Crandell and Henry H. Waldron of the United States Geological Survey found evidence favoring the theory that the Scatter Creek Till of this report was formed by a mudflow descending from the northeast side of Mt. Rainier during post Wisconsin time. If this theory is correct, the term Scatter Creek Till is a misnomer, but except for this one unit, the sequence of Pleistocene events will be little changed.



DIAGRAMATIC STRATIGRAPHIC SECTION
RIGHT BANK OF SPILLWAY
MUD MOUNTAIN DAM

Plate II

of Wisconsin till (see Plates III and IV). As it extends over all of Scatter Creek flat, this uppermost till in the mouth of the White River valley is here designated the Scatter Creek Till.

The till consists of a four to ten feet thick sheet of clay and rock fragments. The matrix is a purplish-gray, gritty clay (see Fig. 4). In it are embedded pebbles and cobbles of volcanic rocks largely of two types. The most common type is a dense, greenish andesitic rock, occasionally porphyritic, characteristic of the early Tertiary Keechelus series. It commonly makes up nearly 75% of the rocks in the till. The other type, normally 20% or less, is a porous, purplish colored andesite which is typical of the lavas of Mt. Rainier. In addition to the volcanics, 2% to 4% of the rock fragments are the Snoqualmie granodiorite, a medium-grained granitic rock which crops out in the upper drainage basin of the White River. The rock types in the Scatter Creek till clearly indicate a Cascade origin.

The majority of the rocks in the till are fresh and hard. However, there also are present pebbles and cobbles which are greatly decomposed. These rock fragments were probably incorporated in the ice from an earlier Pleistocene surface as the glacier moved down the White River valley. An alternative explanation is that the decomposed material was derived from an area which had been affected by hydrothermal

Fig. 4

OUTCROP OF CONTACT BETWEEN SCATTER CREEK TILL AND UNDERLYING SAND MEMBER OF BORROW PIT SEDIMENTS

View along northeastern edge of borrow pit.

solutions. Some of the area immediately upstream from Scatter Creek flat does show indications of hydrothermal alteration, but most of it has been in the form of silicification rather than decomposition.

The ice that deposited the Scatter Creek Till extended at least as far down the White River valley as the present northwestern margin of Mud Mountain, as the till outcrops at the top of Bear Swamp scarp. The glacier may have extended farther, as there is no evidence of a terminal moraine in the Mud Mountain District. Low hills of possible lateral morainal material are found at the foot of Grass Mountain on the north of the flat.

Borrow Pit Sediments

In approximately the middle of Mud Mountain there is a borrow pit opened by the U. S. Army Engineers during the construction of Mud Mountain Dam. Along the northeastern margin of the borrow pit, the Scatter Creek Till is underlain by a buff to brown sand. Along the southern edge of the pit the till is underlain by a bouldery gravel. Throughout the District, the Scatter Creek Till is consistently underlain by either the sand or gravel similar to that exposed in the borrow pit (see Plate III). Because of the good exposure in this area, the unit is named the Borrow Pit Sediments.

Gravel. The Borrow Pit Sediments contain both sand and gravel, but in general the gravel is more common along Bear Swamp scarp and the southern half of Mud Mountain. With the exception of the upper four to ten feet of the capping till and some lenses of the sand, the face of the Bear Swamp scarp is composed largely of the gravel member of the Borrow Pit Sediments. The gravel commonly contains boulders up to two feet in diameter, but just south of the place where Red Creek crosses the scarp, boulders of volcanic rocks up to eight feet in diameter occur. Everywhere the gravel member contains lenses of finer material, chiefly buff to brown sand, with occasional coal fragments up to one-half inch in diameter.

The gravel member of the unit has a conspicuous "open-work" texture. The fragments are commonly coated with clay. The openwork texture is most commonly associated with steep forest bedding (see Figs. 5 and 6). Cary discussed this texture and concluded that "openwork gravel is deposited by swift streams on the downstream face of a gravel bar or as sloping beds on a delta face" (Cary, 1950, p. 1).

A comparison of the rock types in the gravel member of the Borrow Pit Sediments with those in the modern White River was made. There is considerable similarity in the volcanic rock types as both are heavily charged with Keechelus andesite. However the plutonic assemblage of the gravel member is quite distinct from that of the modern White River gravel. In the borrow pit, an average of several pebble counts showed between

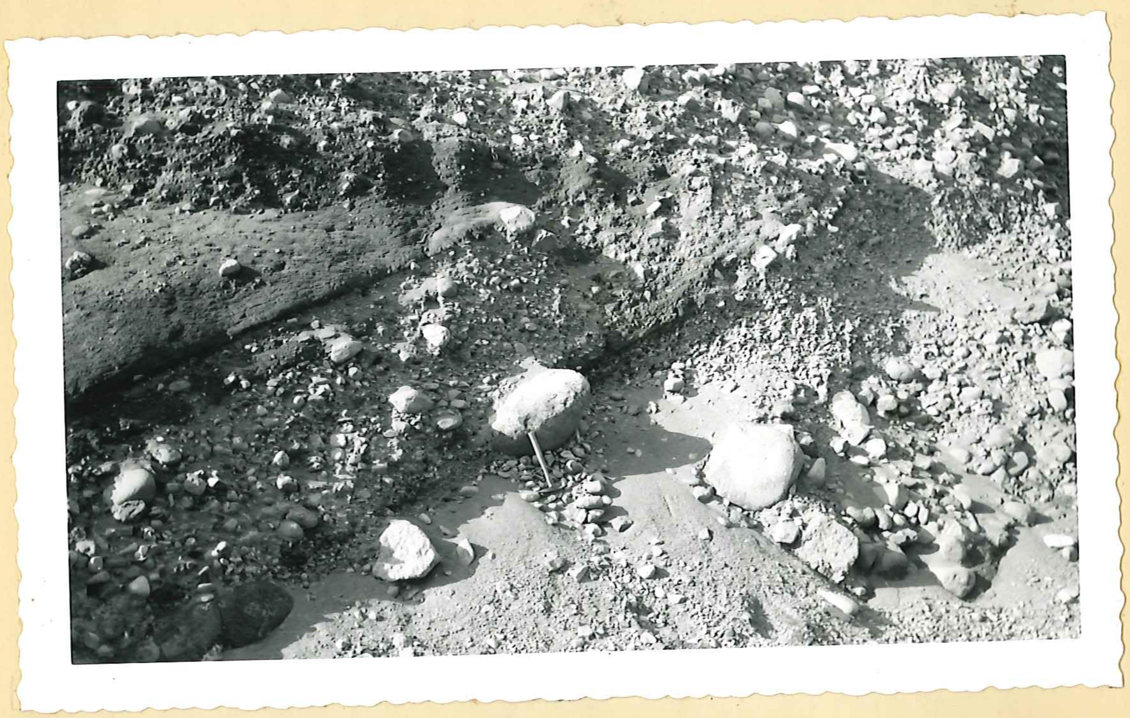


Fig. 5

TYPICAL OUTCROP OF GRAVEL MEMBER OF BORROW PIT SEDIMENTS

Shows typical cross bedding and variation in size of material. Note lens of sand in upper left and also boulder near pick in center of picture.

Fig. 6

OPENWORK GRAVEL IN GRAVEL MEMBER OF BORROW PIT SEDIMENTS

Note space between cobbles.

5% and 10% of the rocks in the gravel member to be plutonics. Of this, less than 1% were Snoqualmie granodiorite. The majority of the plutonics are coarse-grained foliates and granite porphyries. Also present is a greenstone that is not found in the White River gravel. From this it is concluded that the source of the gravel member of the Borrow Pit Sediments was not in the present White River drainage basin.

Sand. The sand portion of the Borrow Pit Sediments is well exposed along the northeastern edge of the borrow pit and in the cut along Highway 410 as it crosses the Bear Swamp scarp. Similar deposits of sand, interbedded with gravel, occur west of the District in the vicinity of the Tugaw-Olson gravel pit (see Fig. 2). The sand is buff to light brown colored and medium-grained. It is roughly bedded, commonly showing cut and fill channeling and cross bedding (see Fig. 7). Fragments larger than sand size are not common, although pebbles of various rock types do occur. Also present are fragments of coal, up to one-half inch in diameter. They usually occur in a rough alignment, parallel to the bedding of the sand (see Fig. 8). A search for coal fragments on the bars of the White River was made, but none were found. Coal is mined in the Puget Lowland, to the northwest of the District, and outcrops exposed during the Wisconsin probably provided the source for the coal in the sand member of the Borrow Pit Sediments.

Fig. 7

TYPICAL BEDDING IN SAND MEMBER OF BORROW PIT SEDIMENTS

Fig. 8

COAL FRAGMENTS IN SAND MEMBER OF BORROW PIT SEDIMENTS

Shows texture of sand and the alignment
of black coal fragments.

Samples of both the sand and gravel of the Borrow Pit Sediments were examined for heavy mineral content. Samples of the sand were taken from the borrow pit and the cut along Highway 410. Gravel samples were taken from the right bank of the spillway, Bear Swamp scarp on the southern end of Mud Mountain and the Tugaw-Olson gravel pit, three miles north of the borrow pit. All of the samples contained a conspicuous amount of pink garnet, estimated to be 10% to 15% of the heavy mineral fraction. Samples from the present White River gravel contain less than 1% pink garnet. The relatively large amount of garnet in the concentrates of both the sand and gravel members of the Borrow Pit Sediments indicates that they had a common source. This is also indicated by the presence of the coal fragments in the massive sand and in the sand lenses interbedded with the gravel.

The above, coupled with the evidence afforded by the differences of the plutonic content of the Borrow Pit Sediments as compared with the White River gravel, is considered proof that the source of the Borrow Pit Sediments was in the Puget Lowland and not in the Cascades. The sand and gravel was carried to the mouth of the White River valley by meltwater from a glacier which lay in the Puget Lowland, to the west of the District. The water probably moved as a torrential stream in a "gutter" between the eastern edge of the ice and the steep Cascade front. A thick deltaic deposit of sand, gravel, cobbles and large boulders was formed in the mouth of the White River valley because it was a local indentation in the otherwise straight Cascade front (see Fig. 2). Mackin described a similar situation in the northern part of the Cedar Lake Quadrangle in the valley mouths of the Cedar River and the South and Middle Forks of the Snoqualmie River.

The Scatter Creek Till was deposited on a flattish surface. Nowhere in the District is there any appreciable irregularity in the contact between the Till and the Borrow Pit Sediments. The contact is also quite sharp and distinct (see Fig. 4). In places there is a one-half to three-fourths inch layer of iron oxide marking the upper limit of the Borrow Pit Sediments. In some of the outcrops the lower portion on the Till is heavily charged with wood, ranging from finely ground material to large tree trunks. Near the spillway during the construction of the dam, a root hollow was observed in the upper part of the gravel member of the Borrow Pit Sediments by Cary (personal communication).

The amount of time which lapsed between the end of the deposition of the Borrow Pit Sediments and the Scatter Creek Till is unknown. A soil profile developed in the sand member of the Borrow Pit Sediments in several exposures suggests an appreciable interval of time. It is the opinion of the writer that the Borrow Pit Sediments and the Scatter Creek Till may represent different substages in the Wisconsin.

The lower boundary of the Borrow Pit Sediments is not as clearly defined as its upper limit. The only places where the base of the Borrow Pit Sediments is seen are at the dam site and along the right bank of the inner valley, upstream from the dam. Everywhere else in the District, the base of the Borrow Pit Sediments is either below the valley bottom or covered with brush or talus.

The valley in which the Borrow Pit Sediments were deposited must have been nearly as wide as the present White River valley and in places the bottom must have been at least four hundred feet below the level of Scatter Creek Flat. The material into which the valley was eroded consisted of earlier Pleistocene sediments and possibly bedrock.

Wisconsin-Illinoian (?) Deposits

Spillway Sediments

Disconformably beneath the Borrow Pit Sediments there is exposed in the spillway of Mud Mountain Dam a thirty to sixty feet thick succession of peaty sediments, laminated clay and till. It is thickest and best exposed in the right bank of the spillway, along a road leading to the floor of the spillway. It also crops out in the left bank of the spillway and in the left bank of the river, both above and below the axis of the dam, and in the vicinity of the intake tower (see

Plate IV). It is proposed that this succession be named the Spillway Sediments.

Peaty sediments. The uppermost unit consists of one to three feet of crossbedded and iron stained gravel which rest on two to three feet of peat and peaty sediment. The overlying Borrow Pit Sediments show no staining and its crossbedding is at a distinct angle to that of the subjacent material.

The peaty material consists of highly compacted and rumpled wood fragments and a layer of dark clay which contains much finely comminuted organic matter (see Fig. 9). The wood fragments are, in places, lignitic and none of the wood is identifiable. The lateral extent of the exposure of the peat in the spillway is not greater than twenty feet. Near the intake tower, there is a similar zone of stained gravel in the same stratigraphic position, but no peat is present.

Laminated clay. Beneath the peat is twenty to thirty feet of light brown laminated clay. Although definitely stratified, the clay is not varved. It is generally free of rock fragments, although occasional pebbles, some that were probably ice rafted, do occur. The most common rock type is pumice in fragments up to one inch in diameter. This is the only unit in the District which carries any pumice. It probably indicates that there was explosive volcanic activity on Mt. Rainier at the time the clay was deposited.

Fig. 9

PEAT OF SPILLWAY SEDIMENTS

Overlain by Borrow Pit Sediments.

Fig. 10

TILL OF SPILLWAY SEDIMENTS

Note rounded to subrounded rocks and the smooth mold in center of picture left by a rock.

Till. The clay grades downward into a brownish-gray till consisting of pebbles, cobbles and boulders up to fifteen inches in diameter embedded in a matrix of clay, sand and grit (see Fig. 10). The majority of the larger fragments are rounded to subrounded; angular and subangular fragments are rare. The rocks are generally fresh and hard; less than 10% are weathered or decomposed. Where the rock fragments are dug out of the matrix, there is left a very smooth mold. None of the other tills in the District display this feature so strikingly.

The rocks in the till are largely dense volcanics. The most common volcanic rock is the greenish Keechelus andesite; approximately 8% to 10% of the volcanics are the Rainier lavas. The non-volcanics, which make up from 5% to 7% of the total rock types in the till, are chiefly the even grained Snoqualmie granodiorite.

Generally speaking, the Spillway till is very fresh, much more so than the younger Scatter Creek Till. Locally, however, there are zones up to twelve inches thick of decomposed material. Some zones are nearly horizontal, while others approach verticality. The degree of decomposition sometimes is quite intense, and is nearly equal to that of the much older Mud Mountain Complex. The zones of extreme decomposition are not limited to any special horizon within the till. It appears that they were controlled by localized zones of greater permeability which allowed ground water to penetrate only some parts of the till.

The base of the till is in contact with an older and more weathered till. The contact is not everywhere distinct, and in places it is possible that there was basal contamination of the Spillway by the older material. The thickness of the possible zone of contamination is less than five feet. The amount of the older till that may have been eroded by the ice which deposited the Spillway till is unknown.

Along the southwestern flanks of Grass Mountain deposits of a weathered till are found. It occurs chiefly in exposures along the White River Lumber Company road that zigzags up the side of the Mountain. The exposures range in elevation from 1700 to 3000 feet. All of the weathered till outcrops are above the exposures of the Scatter Creek Till. The rock types present are largely dense volcanics, chiefly green Keechelus andesite with a minor amount of purplish Rainier lava and even grained granite. The dense rocks, when cracked open, have a distinctive "rind" formed by weathering since the retreat of the ice which deposited the till. The rind is one-quarter to one-half an inch thick, with the thinner rinds on the denser rocks. The position of this material immediately above the deposits of the Scatter Creek Glacier indicates that it is probably correlative with the first till below the Scatter Creek Till in the valley fill.

From its stratigraphic position in the vicinity of the dam and the degree of weathering of the deposits on the slopes of Grass Mountain, it seems probable that this unit of sediments is either early Wisconsin or Illinoian (?) in age.

Early Pleistocene Deposits

Intake Tower Sediments

Beneath the Spillway Sediments is seventy-five to one hundred feet of sand, gravel and till. This sequence is named the Intake Tower Sediments as it is most completely exposed in the vicinity of the intake tower of Mud Mountain Dam. It is also exposed in the immediate vicinity of the axis and spillway of the dam (see Plate IV).

Upper sand and gravel. In the intake tower area, the Spillway till is underlain by three feet of weathered sand. The sand is underlain by six to eight feet of weathered gravel. Both the sand and gravel have a distinctive orange color. The sand and gravel are not present in the outcrop in the spillway.

Till. The next underlying unit is forty to sixty feet of a brilliantly colored orange till (see Fig. 11). It consists of subrounded to subangular rock fragments embedded in a matrix of clay. The degree of decay in the upper ten feet of the till is intense. The outlines of the boulders are distinct, but the decomposition has progressed to such a

Fig. 11

ORANGE COLORED TILL OF THE INTAKE TOWER SEDIMENTS

View looking downstream at right bank of spillway. Above the orange is the gray of the Spillway Sediments. Below the orange is the Mud Mountain Complex.

degree that a solid blow with a pick will sink the point deeply into the boulder. Outlines of feldspar phenocrysts which have been converted to a soft white clay are visible in some of the rocks. The degree of decomposition decreases toward the bottom of the till.

Lower gravel. The till grades downward into a cobble and boulder gravel which also has the orange color. The gravel is approximately twenty-five feet thick and is well exposed just at the upstream lip of the spillway (see Fig. 12). It is also present in the vicinity of the intake tower. The cobbles and boulders commonly have one or two inch "rinds" of decomposed material. A completely decayed boulder is the exception rather than the rule in the lower gravel.

The rocks in the Intake Tower Sediments are predominately dense andesites and andesite porphyries, typical of the Keechelus series. Even grained granites make up less than 1% of the total. None of the purplish lavas of Mt. Rainier are present. This gives rise to the speculation that Rainier was not a source area of the White River glacier during the early Pleistocene.

The intense degree of decomposition, especially of the upper part of the till, indicates that the surface of this unit was exposed to weathering for a long interval of time prior to the deposition of the Spillway till. The stratigraphic position and degree of weathering in the Intake Tower Sediments

Fig. 12

MUD MOUNTAIN COMPLEX AND LOWER GRAVEL OF THE INTAKE TOWER SEDIMENTS

View along road that runs under upstream lip of spillway. Sequence from bottom to top is (1) partially decayed Mud Mountain Complex (2) greenish-gray weathered zone at top of Mud Mountain Complex (3) lower gravel member of Intake Tower Sediments.

suggest that they long pre-date the Spillway Sediments and are probably early Pleistocene in age. Other early Pleistocene sediments have been reported in the Puget Lowland by Mackin and Hanson (1950) and Mullineaux and Stark (1950). No other occurrence of till of this age has been reported in the Cascades.

Mud Mountain Complex

The lowest and oldest part of the Pleistocene sequence in the Mud Mountain District is best exposed near the intake tower and along the right bank near the upstream lip of the spillway of Mud Mountain Dam. It is also exposed along the walls of the gorge which has been partially filled with the earthfill dam (see Plate IV). This sequence, between bedrock and the lower gravels of the Intake Tower Sediments, is named the Mud Mountain Complex.

It is composed of several lenses of varied materials, including sand, gravels and at least three layers of deeply decayed material consisting of angular rock fragments in a matrix of clay. The latter is very till-like in appearance. The Mud Mountain Complex is separated from the Intake Tower Sediments locally by a zone of intensely decomposed material, which is best seen along the road leading from the upstream lip of the spillway to the intake tower. Here it is a three foot layer of greenish-gray material, in which the angular to subangular rock fragments are embedded in a matrix of sandy clay. The decomposition is so complete that everything in the zone has been altered to a clay-like consistency. The greenish-gray material weathers to a smooth face, while below it the face of less altered material which was originally of the same composition shows numerous irregularities caused by the projection of less decayed angular rock fragments (see Fig. 13).

The material below the deeply decayed zone consists of angular to subrounded rock fragments, twelve to fifteen inches maximum diameter, embedded in a brownish-gray matrix of clay and sand (see Fig. 13). Also present is a considerable amount of wood, some of which has been thoroughly carbonized. Locally, some of it has been replaced by iron sulphide. The unit lacks any definite layering or structure. It is crossed by iron stained "veins" or "veinlets" from one to six inches in width. They range in attitude from horizontal to nearly vertical. It is in, and/or near these veins that the wood which is replaced by marcasite is found.

The rock fragments vary in color from dark gray to greenish-gray with occasional brick red fragments. The rock is predominately volcanic; andesite porphyry, andesite and basalt being the most common types. There are no metamorphic, sedimentary or plutonic rocks. Most of the rock fragments are in various stages of decay, but the less dense rocks show the

Fig. 13

WEATHERED ZONE AT TOP OF MUD MOUNTAIN COMPLEX

Lower part of picture shows less weathered portion of till-like material. Hole near pick is where a piece of wood has been removed.

greatest amount of alteration.

The matrix, which at one time was probably quite gritty, is now almost completely decomposed. However, the outlines of variously colored, decayed granules are still visible.

Because of a cover of loose material, the lower portions of the Mud Mountain Complex cannot be seen in the section near the upstream lip of the Spillway. A bedrock lip is exposed at the base of the slope and resting on it can be seen a layer of gravel, cobbles and boulders.

In the vicinity of the intake tower a complete section of the Mud Mountain Complex between bedrock and the Intake Tower Sediments is exposed. From bottom to top the section is as follows: (1) bedrock; (2) river gravel - 6-8'; (3) angular to subangular fragments of rock in a matrix of decomposed clay and grit, includes carbonized wood fragments, well cemented - 15'; (4) river gravels, rounded, streaked with orange, many decomposed pebbles and cobbles - 10'; (5) silt and sand, ½" iron stained zone at base, various shades of orange and gray, weathered, with 6" zone of light colored clay at top; (6) same as (3) with 6' streak of orange material in it - 14'; (7) orange gravel - 10'; (8) peaty material - 1'; (9) same as (3) and (6) with upper 6' completely decayed, a greenish-gray zone which grades down into fresher material - 45'. This is overlain by the orange colored lower gravels of the Intake Tower Sediments.

The origin of the till-like material is uncertain. The unsorted, angular appearance, in a region in which tills are present, suggests that it also is a till. The presence of wood similar to that found in known tills also tends to confirm this idea. It must be kept in mind however, that mudflow and landslide deposits also have a similar appearance. The writer has seen an outcrop of similar material that is known to be a mudflow in a gravel pit west of Salt Lake City, Utah. This mudflow deposit has all the characteristics of the till-like material of the Mud Mountain Complex. From the evidence so far found in the Mud Mountain District, it is impossible to conclude with certainty that the till-like material of the Mud Mountain Complex is the result of deposition by ice.

Beneath the till-like material there is six to eight feet of river gravel, which in turn overlies bedrock. It is similar to the gravel of the present White River except that there are no Rainier lavas, and the plutonics are not quite as common. The heavy mineral assemblage is the same as that of the modern White River.

The sediments between bedrock and the bottom of the Intake Tower Sediments are considered one unit. The till-like members are so similar in appearance that they must have had a common origin.

The evidence for a time lapse between the deposition of the Mud Mountain Complex and the Intake Tower Sediments is the presence of the zone of intense decomposition at the top of the former. The bleached greenish-gray color and the degree of decomposition of the material are best explained as the result of an extended period of weathering. This decomposed zone is not everywhere at the contact of the two units, but the streams that carried the lower gravel of the Intake Tower Sediments could have easily destroyed the decomposed zone.

The stratigraphic position and degree of decomposition of the Mud Mountain Complex leaves no doubt that its age is early Pleistocene regardless of the origin of the till-like material. No other deposits of similar nature or stratigraphic position have been reported in the Cascade Mountains or the Puget Lowland.

PRE-PLEISTOCENE ROCKS

Bedrock

Wherever the bottom of the Pleistocene sedimentary sequence is seen in the Mud Mountain District, it rests on a "basement" of volcanic rock. It consists of both flows and volcanic conglomerates. In some places the rock is considerably altered by either weathering or hydrothermal action. The only place in the District where any amount of bedrock is exposed is in the vicinity of the dam. The rock types in the bedrock are similar to those found in the various units in the Pleistocene sequence.

SUMMARY

In the Mud Mountain District, especially in the vicinity of Mud Mountain Dam, there is exposed a rather complete sequence of Pleistocene sediments including both glacial and non-glacial material ranging in age from early Pleistocene to Wisconsin. The source of the sediments was chiefly from the Cascades, but at least one unit was derived from the Puget Lowland. It is the most nearly complete section of Pleistocene material which has been reported from either the Cascades or the Puget Lowland.

From the evidence found in the sediments, it is possible to summarize the history of the District. By the beginning of the Pleistocene, a mature landscape had been developed on the early Tertiary Keechelus series. The oldest Pleistocene event of which there is a record in the District was the deposition of the Mud Mountain Complex. This involved the deposition of a series of mudflows, landslides and/or glacial deposits as well as lenses of sand and gravel. The Mud Mountain Complex was then subjected to an extended period of weathering during which a zone of decomposition developed on its surface.

Next followed the deposition of the Intake Tower Sediments. The first event was the deposition of a bouldery

gravel followed by a till and then deposit of sand and gravel. This also was subjected to weathering and erosion. The deep orange color of the Intake Tower Sediments is an indication of its early Pleistocene age.

The Spillway till was deposited on top of the weathered Intake Tower Sediments. The presence of lavas from Mt. Rainier in the till is an indication that by this time Mt. Rainier was furnishing material to the White River glaciers, a situation which had not existed up to this time. After the deposition of the till, the laminated clay was laid down. During this time also there apparently was some explosive vulcanism on Mt. Rainier, attested to by the presence of the pumice fragments in the clay. On top of the clay a deposit of peaty clay and peat was formed and, above the peat, some sand and gravel was deposited.

Following the deposition of the Spillway Sediments a large valley was eroded in all of the earlier material. It was probably nearly as wide as the present broad White River valley, and in some places it extended to a depth of at least four hundred feet below the present surface of Scatter Creek flat. In this valley a torrential meltwater stream, from the continental ice sheet which lay in the Puget Lowland, deposited the crossbedded and openwork gravel of the Borrow Pit Sediments. Following its deposition, a weak soil profile developed on the sand member of the Borrow Pit Sediments.

Then came the ice that laid down the Scatter Creek Till. Since the retreat of the ice, the White River has incised a narrow inner valley into the Pleistocene sediments, cutting into bedrock only in the vicinity of the dam.

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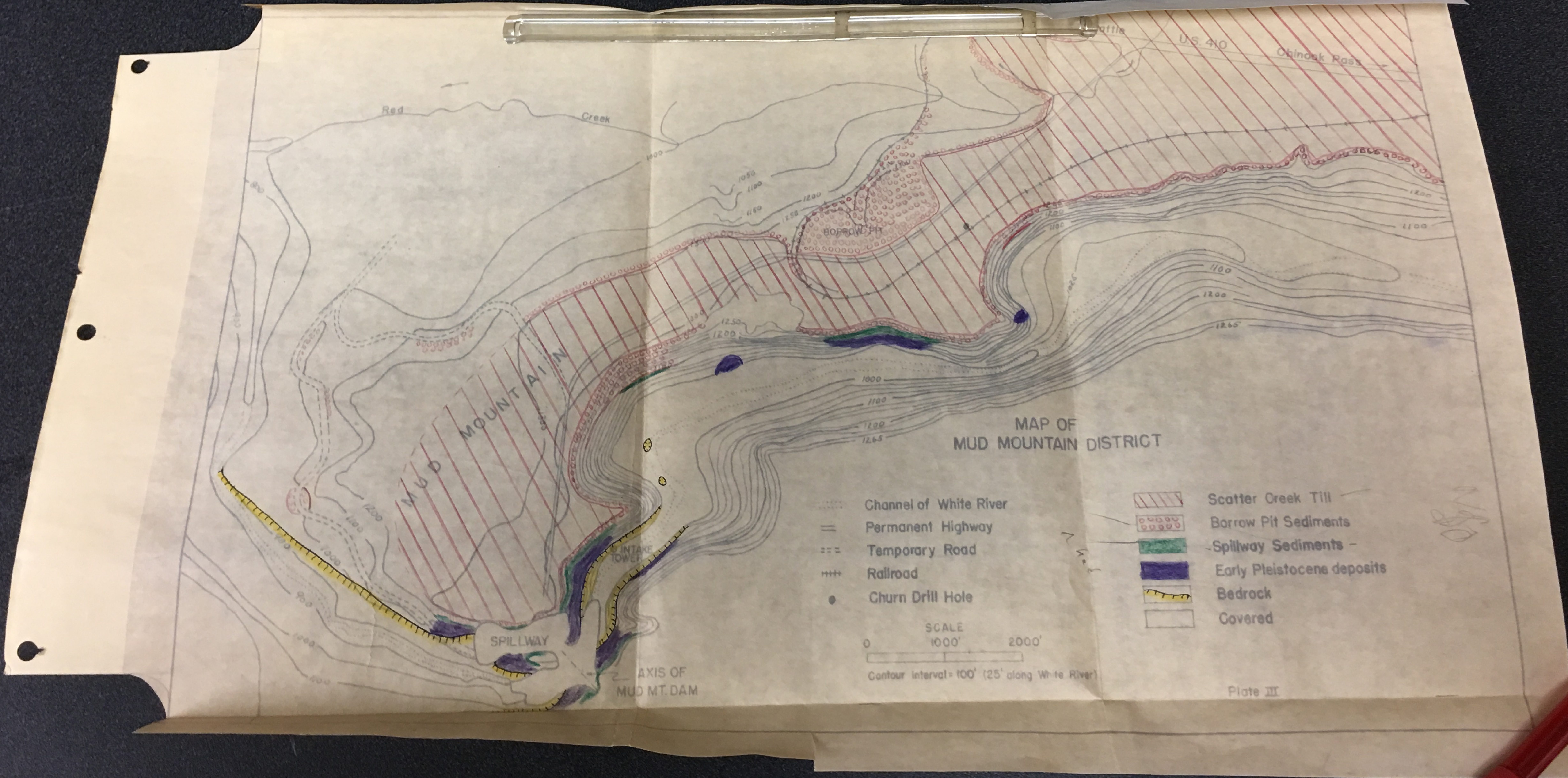
Red
Creek
U.S. 410
Chinook Pass
MUD MOUNTAIN
SPILLWAY
AXIS OF
MUD MT. DAM
MAP OF
MUD MOUNTAIN DISTRICT
Channel of White River
Permanent Highway
Temporary Road
Railroad
Churn Drill Hole
Scatter Creek Till
Borrow Pit Sediments
Spillway Sediments
Early Pleistocene deposits
Bedrock
Covered
SCALE
0
1000'
2000'
Contour interval = 100' (25' along White River)
Plate III

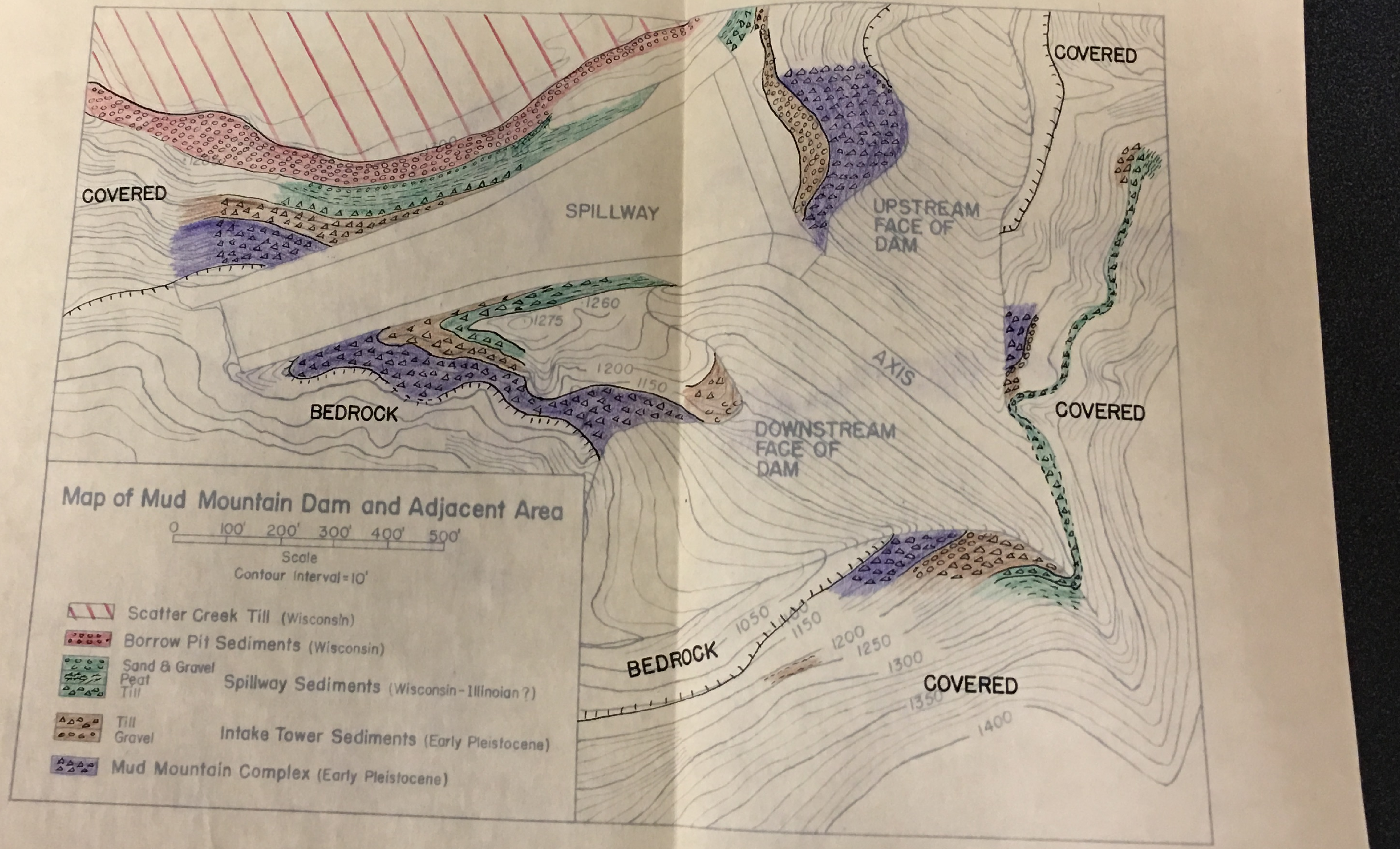
COVERED
SPILLWAY
UPSTREAM FACE OF DAM
COVERED
1275
1260
1200
1150
AXIS
BEDROCK
COVERED
DOWNSTREAM FACE OF DAM
Map of Mud Mountain Dam and Adjacent Area
0 100' 200' 300' 400' 500'
Scale
Contour Interval = 10'
Scatter Creek Till (Wisconsin)
Borrow Pit Sediments (Wisconsin)
Sand & Gravel
Peat
Till
Spillway Sediments (Wisconsin-Illinoian?)
Till
Gravel
Intake Tower Sediments (Early Pleistocene)
Mud Mountain Complex (Early Pleistocene)
BEDROCK
1050
1150
1200
1250
1300
1350
1400
COVERED

Plate IV