UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE NORTH FORK OF FLODELLE CREEK DRAINAGE BASIN AND SURFICIAL URANIUM DEPOSIT, STEVENS COUNTY, NORTHEASTERN WASHINGTON

by

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ABSTRACT

The north fork of Flodelle Creek drainage basin (NFC) in Stevens County, northeastern Washington, contains the first surficial uranium deposit to be mined in the United States. The uranium was leached from granitic bedrock and fixed in organic-rich pond sediments. The distribution of these pond sediments and therefore the uranium has been strongly influenced by relict glacial topography and by beaver activity.

The north fork of Flodelle Creek drainage basin was covered by the Cordilleran ice sheet during the Fraser (late Wisconsin) glaciation. As ice receded 13,000 yr B.P., till was deposited on the valley slopes and the valley was partly filled with glacial outwash and stagnant ice. Incision of the outwash resulted in formation of a large valley terrace and relatively wide outwash plains in the lower part of the basin. Kames formed in the valley floor when a portion of the valley terrace that was underlain by stagnant ice collapsed.

Shortly after deglaciation, a small pond formed in the upstream part of the valley when unconsolidated glacial sediment slumped off the valley slopes and restricted drainage. Fluvial processes dominated in the central and downstream parts of the valley for several thousand years after deglaciation, although drainage was partly restricted by kames. Beavers began to occupy and dam the wide outwash plains in the valley floor about 5000 yr B.P. Beaver ponds in the central part of the basin subsequently filled with sediment and were abandoned, while downstream ponds remained relatively free of clastic input and are presently occupied by beavers.

Ponds in the drainage basin have been sinks for fine-grained, organic-rich sediments. These organic-rich sediments provide a suitable geochemical environment for precipitation and adsorption of uranium leached from granitic bedrock into ground, spring, and surface waters. Processes of pond formation have thus been important in the development of surficial uranium deposits in the north fork of Flodelle Creek drainage basin, and may have similar significance in other areas.

INTRODUCTION

Unconsolidated soils and sediments in which uranium accumulations are presently forming are termed "surficial uranium deposits" (Boyle, 1984, Otton, 1984, Culbert and others, 1984). The uranium is mainly fixed by precipitation or adsorption from ground or surface waters and is loosely held and easily remobilized. Because of their young age (typically less than 15,000 years), these deposits lack significant radioactive daughter products, are seldom detectable by scintillometer, and may be far more common than is presently recognized. Surficial uranium deposits primarily occur in clusters along drainages underlain by felsic to intermeidate igneous rock. Because sediment (particularly organic-rich sediment) can be very efficient at fixing uranium, high uranium concentrations in donor bedrock sources are not necessarily required. This type of deposit may become an important source of low-cost uranium. Surficial uranium deposits and associated ground waters may also become recognized as environmental hazards due to the toxicity of uranium (as a cause of radiation carcinogenesis and kidney damage (Cothern and others, 1983)).

The north fork of the Flodelle Creek drainage basin in Stevens County, northeastern Washington (Fig. 1) contains the first surficial uranium deposit

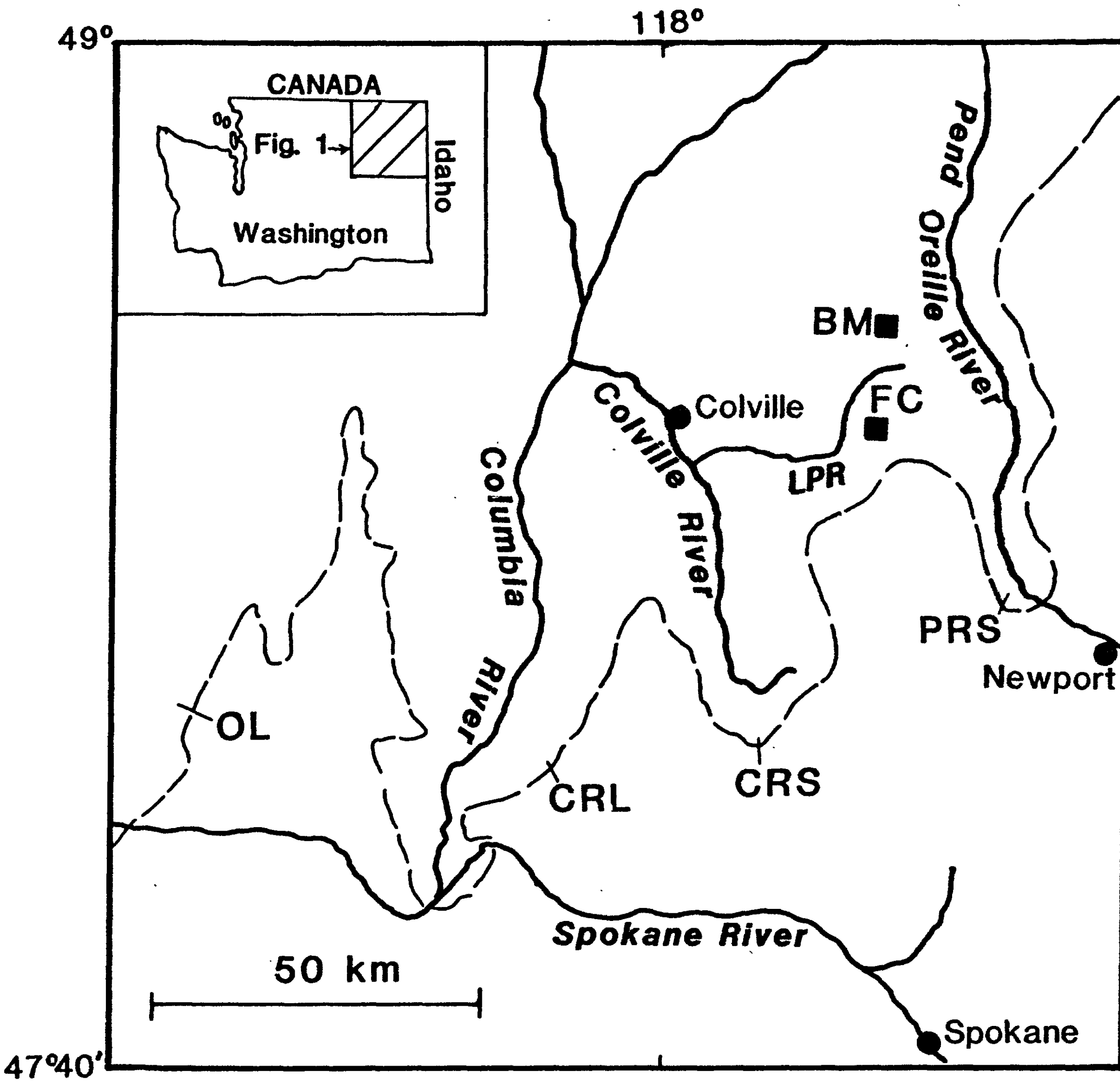

Figure 1. Map showing the location of the north fork of Flodelle Creek drainage basin (FC). Dashed line shows approximate southern limit of Cordilleran ice sheet during the Fraser glaciation (from Richmond and others (1965), Weis and Richmond (1965), and Waitt and Thorson (1983)). Other abbreviations as follows: BM - Big Meadow; CRL - Columbia River Lobe; CRS - Colville River sublobe; LPR - Little Pend Oreille River; OL - Okanogan Lobe; PRS - Pend Oreille River sublobe.

to be mined in the United States. The uranium primarily occurs in postglacial, organic-rich pond sediments of the valley floor, in which uranium values are as high as 0.9 percent (dry weight). This paper describes the latest Pleistocene and Holocene geologic history of the north fork of Flodelle Creek drainage basin, and relates this history to the formation of surficial uranium deposits. It is here postulated that both pond formation and the development of surficial uranium deposits have been strongly influenced by glaciation and by beaver activity. Data and interpretations generated in this case history provide a basis for recognition and evaluation of other surficial uranium deposits in northeastern Washington and in other regions with similar geologic histories.

PHYSIOGRAPHY AND HYDROLOGY

The north fork of Flodelle Creek drainage is located in eastern Stevens County, Washington, approximately 28 km east of Colville and 100 km north of Spokane (Fig. 1). This first-order drainage (Figs. 2, 3) extends north-northeast for 4200 m from an elevation of 1113 m at the drainage headwaters to 1021 m at the confluence with Flodelle Creek. The average stream gradient is about 2.2 percent. Across the drainage divide, water flows north in the Sherry creek (informally named here) drainage. The Flodelle Creek system is tributary to the Little Pend Oreille River, which flows into the Colville River (Figs. 1, 2).

The drainage basin covers 4.1 km^2 and reaches elevations as high as 1305 m. The average slope of the valley walls is about 20 percent. Slope runoff is mainly by sheetwash and by flow in small ephemeral stream channels. Surface water has a maximum discharge of about 350 cm^3/sec in the drainage headwaters; the maximum discharge in the main channel on the upstream side of the confluence with Flodelle Creek is about 6000 cm^3/sec (Joy Mining Company, 1983). During the dry season, flow in the channel is reduced to a few centimenters in depth.

From the drainage headwaters down to the meadow mine (Fig. 3), the north fork of Flodelle Creek passes through a relatively steep-sided valley in a channel about 30 to 60 cm wide and deep. A small spring issues from the valley floor at the spring pool (Fig. 3).

In the central part of the drainage basin, the valley opens up into a boggy meadow (Fig. 4, the meadow mine of Fig. 3) that is currently being strip mined for uranium by Joy Mining Company. To facilitate mining, the mine operators have shifted and confined the stream channel to the west side of the meadow and have lowered the water table by pumping. Prior to diversion, flow through the meadow was within anastomosing channels as wide as 250 cm and as deep as 90 cm. The change in elevation from the upper to the lower end of the meadow is approximately 250 to 300 cm, and the gradient is about one percent.

Downstream from the meadow, the stream channel is about 50 to 80 cm wide and 30 to 60 cm deep, and flow is mostly through narrow riffles and wider pools. The valley floor is as wide as 70 m and the stream is conspicuously underfit.

The channel cuts through an abandoned beaver dam about 1000 m upstream from the confluence with Flodelle Creek (locality 74 on Figure 3). Four modern beaver ponds and dams occupy the valley floor downstream from the abandoned beaver dam (Fig. 3). Dams are sinuous and have a maximum length of about 100 m. Flow through the beaver ponds is in multiple small channels and is spread relatively evenly across the beaver ponds.

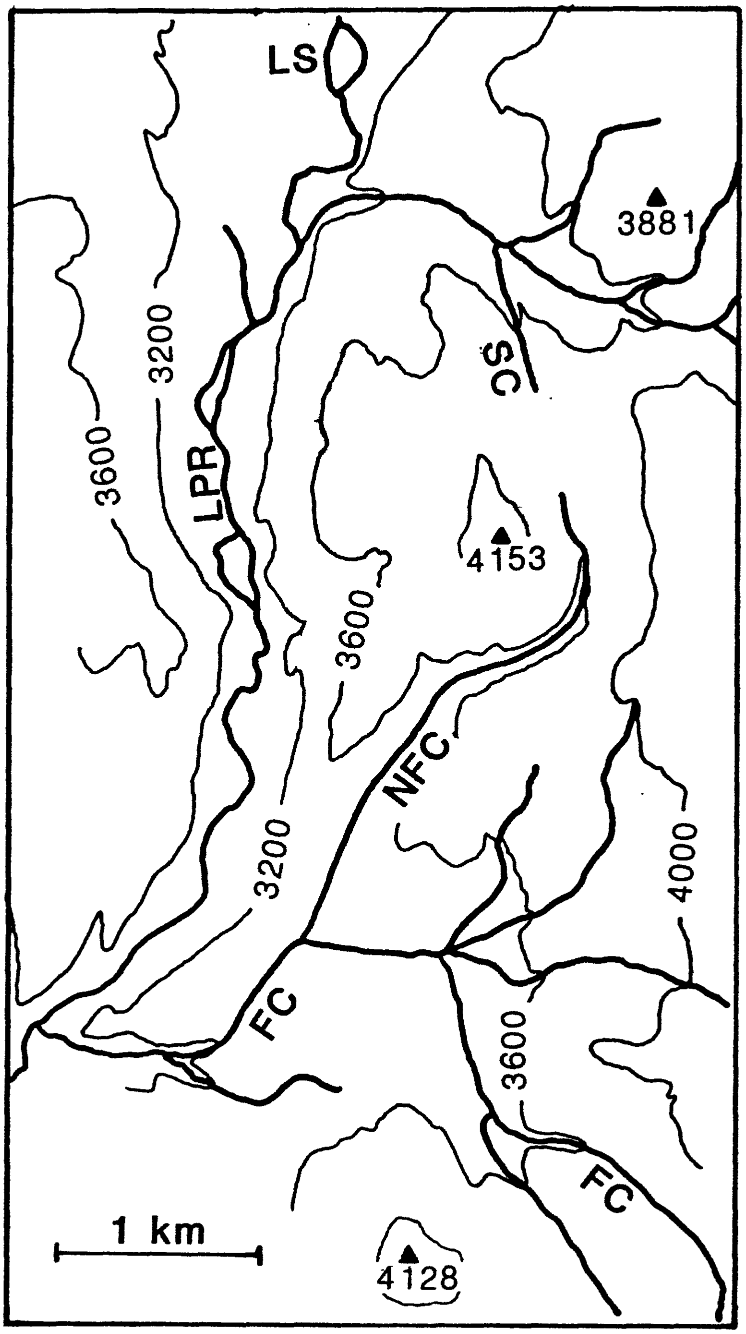

Figure 2. Map showing topography (light lines show contour intervals in feet) and drainage patterns (heavy lines) in the Flodelle Creek area. Abbreviations as follows: FC - Flodelle Creek; LPR - Little Pend Oreille River; LS - Lake Sherry; NFC - north fork of Flodelle Creek; SC - Sherry creek.

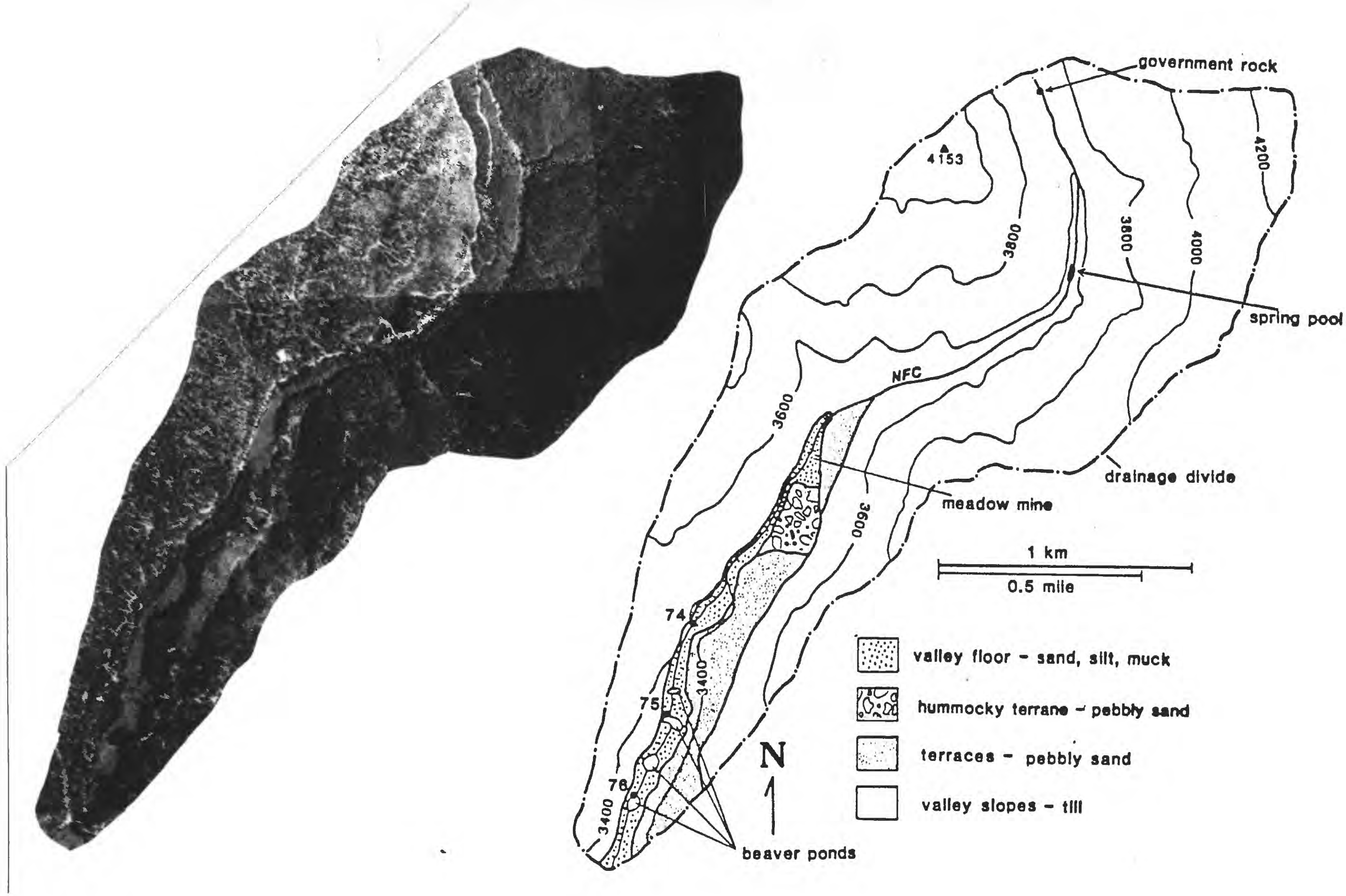

Figure 3. Air-photo mosaic and surficial deposits map of the north fork of Flodelle Creek drainage basin. Numbers show sample localities discussed in text. Note small outcrop of terrace sediment on west flank of valley above locality 74. Contour intervals are in feet.

Figure 4. View (looking upstream) of the meadow mine. See Figure 3 for location.

From the location of the meadow mine downstream to the confluence with Flodelle Creek, a discontinuous terrace is perched above the stream on the east flank of the valley (Fig. 3). The surface of this terrace is about 13 m higher than the stream at the meadow mine and 25 m higher at the confluence with Flodelle Creek (Fig. 2). Thus, the terrace dips more gently downstream than the valley floor. At the meadow mine, the terrace has a maximum width of 60 m and a maximum length of about 200 m.

Immediately downstream from the meadow mine, the terrace disappears and is replaced on the eastern side of the valley for about 300 m by hummocky terrane (Fig. 3). Three prominent mounds as long as 60 m are oriented transverse to the axis of the valley; two prominent mounds as long as 30 m parallel the valley axis. Relief between mounds and swales is as much as three to four meters and the swales lie several meters above the level of the valley floor. Neither swales nor mounds have been dissected by the stream or by side drainages.

The terrace resumes immediately downstream from the hummocky terrane and extends continuously down to the confluence with Flodelle Creek. This terrace segment has been incised parallel to the valley axis in an irregular curvilinear pattern and has a maximum width of about 100 m (Fig. 3). At its widest spot, the outermost approximately 50 m of the terrace have been cut to a level about 3 m below the inner terrace surface.

VEGETATION AND CLIMATE

The valley slopes and terraces are largely vegetated by coniferous forests. The most common species are Douglas Fir, Lodgepole Pine, Western Larch, and Grand Fir. Timber in the valley floor includes willow, Subalpine Fir, and Engleman Spruce. Meadows support a vegetation of sedges, wetland forbs, and grasses (Joy Mining Company, 1983).

From 1930 to 1979, the Colville weather station has registered a mean annual temperature of 7.3°C (45.3°F) and an annual rainfall ranging from 28.6 cm (11.2 in.) to 62.1 cm (24.4 in.) (Joy Mining Company, 1983). Approximately 62 percent of precipitation falls between the first of October and the end of March.

BEDROCK GEOLOGY

The north fork of Flodelle Creek drainage basin is underlain by the Cretaceous Phillips Lake Granodiorite, consisting mainly of massive to highly foliated granodiorite and muscovite-biotite bearing quartz monzonite, and minor pegmatite and alaskite (Miller and Engels, 1975; Castor and others, 1982). These rocks form a portion of the northwestern arm of the Spokane Dome core complex (Cheney, 1980), also known as the Selkirk Complex (Coney, 1980). The Eocene Tiger Formation was derived from this core complex, indicating that the complex was uplifted and exposed during the Eocene (Gager, 1984).

Bedrock outcrops in the north fork of Flodelle Creek drainage basin are scarce and occur mostly on steep slopes and on logging-road cuts. Bedrock typically consists of weathered, fine- to medium-grained biotite-muscovite quartz monzonite and minor granodiorite. Outcrops are commonly fractured, jointed, and sheared.

Sheared plutonic rock in drill core from the upper part of the north fork of Flodelle Creek drainage basin contains as much as 500 ppm uranium (R. E. Miller, Joy Mining Company, oral commun., 1984). A regional airborne radiometric survey detected local anomalies ranging in magnitude from one and one half to more than four times normal background for the Phillips Lake Granodiorite in the drainage basin (Castor and others, 1982). Castor and others (1982) analyzed 79 outcrop samples of Phillips Lake Granodiorite collected outside the basin and obtained a mean uranium concentration ($\pm 1\sigma$) of 12 ± 6 ppm with a range of 4 to 80 ppm.

SURFICIAL GEOLOGY

Late Wisconsin glacial history of northeastern Washington

During the Fraser (late Wisconsin) glaciation, the Cordilleran ice sheet advanced southward from source areas in British Columbia and reached a maximum terminal position in northeastern Washington about 15,000 yr B.P. (Fulton and others, 1984, Waitt and Thorson, 1983). Richmond and others (1965), Weis and Richmond (1965), Waitt and Thorson (1983), and Richmond (oral commun., 1985) have mapped in reconnaissance the location of the Fraser ice margin in northeastern Washington (Fig. 1). Cordilleran ice extended furthest south in the valleys of the Okanogan River (Okanogan lobe), the Columbia River (Columbia River lobe), the Colville River (Colville River sublobe), and the Pend Oreille River (Pend Oreille River sublobe) (Waitt and Thorson, 1983). At maximum ice extent, the Flodelle Creek area lay several kilometers north of the northern margin of the unglaciated ice divide between the Colville and Pend Oreille River sublobes (Fig. 1). Ice had retreated substantially from northeastern Washington by about 11,200 yr B.P., when Glacier Peak tephra was deposited in Big Meadow (Fig. 1) (Mack and others, 1978, Mehringer and others, 1984).

Valley-slope deposits

Most of the valley slopes are covered with a massive, very light gray, diamicton (Fig. 3). The thickness of this sediment layer is variable, but locally exceeds 2 m. Sediment ranges in size from silt to boulders (as large as 2 m in maximum dimension) and has a mean grain size of coarse- to very coarse-grained sand. Cobbles and boulders are typically subrounded and are randomly dispersed in the more fine-grained matrix. There is no apparent stratification or clast orientation. Sand grains are mostly subangular.

Cobbles and boulders are primarily (> 70%) biotite- and(or) muscovite-bearing granitic rocks. The largest clasts (> 20 cm) are almost all plutonic in origin. Secondary clast types include diabase, amphibolite-grade meta-diorite, rhyolite and dacite, quartzite, vein quartz, and siltstone. Sand grains are dominantly quartz and feldspar. Heavy minerals include magnetite, hornblende, apatite, zircon, garnet, and epidote.

On moderate slopes, this diamict is covered with a layer (as much as 23 cm thick) of moderate yellowish brown silt capped by organic forest litter. This silt consists of quartz, feldspar, and volcanic glass.

Soil profiles in the silt and underlying sediments are poorly developed and pedogenic clay is absent. The average maximum thickness of iron oxide weathering rind on a medium-grained surface cobble or boulder is 3 mm. Bleached or iron oxide rinds on aphanitic cobbles are less than 1 mm.

Widespread distribution, textural immaturity, and lack of stratification collectively indicate that diamict of the valley slopes is till. Plutonic boulders and cobbles, and quartzo-feldspathic sands were mostly derived from local plutonic bedrock. Non-plutonic clasts are erratics derived from northern sources. The presence of thin weathering rinds on medium-grained plutonic clasts and the absence of well-developed soil profiles suggest a late Wisconsin age for the till. The yellowish-brown silt that locally overlies the till may be largely loess, which forms a thick layer over much of eastern Washington to the south (Richmond and others, 1965). Based on evidence to be discussed later in this paper, the volcanic glass fraction in this upper layer is probably derived from 6700 yr B.P. Mazama ash.

Terrace and hummocky-terrane deposits

The unconsolidated sediment that underlies the terrace is best exposed along the terrace escarpment. Sediments are very light gray and range in grain size from silt to boulders. Pebbles and boulders are rounded to well-rounded. Sand grains are subangular to subrounded. The composition of these sediments is identical to that of the valley slope deposits. Terrace sediments are massive and poorly stratified to well stratified. In massive exposures, pebbles are randomly dispersed in a matrix of silt and sand. In exposures of poorly stratified sediment, mixed coarse-grained sand and pebbles form poorly defined horizontal or inclined beds. Well-sorted, parallel-bedded to crossbedded, fine- to coarse-grained sand characterizes the well-stratified sediment. Limited outcrop precludes determination of the relative proportions of massive, poorly stratified, and well-stratified sediment in the terrace. There is a small outcrop of well-stratified sand on the west flank of the valley across from and at the elevation of the lower terrace segment (Fig. 3). We did not find similar exposures elsewhere on the west side of the valley.

Like the valley slopes, the terrace is mantled with a moderate yellowish brown silty layer as thick as 25 cm consisting of quartz, feldspar, and volcanic glass. Soil profiles in the silt and in underlying sediments are poorly developed and pedogenic clay is absent.

Sediments in bulldozer trenches cut into the hummocky terrane consist of light gray, massive, poorly sorted pebbly sand similar in composition and texture to terrace and valley-slope sediment. Pebbles are randomly dispersed in a matrix of subangular to subrounded sand. These deposits are overlain by a thin (< 15 cm) silty layer similar to that overlying the terrace.

The distribution, poorly to well-developed stratification, and coarse grain size of the terrace sediment collectively suggest that they were deposited in braided streams. The discharge of a stream needed to carry these coarse sediments is dramatically larger than that of the present north fork of Flodelle Creek. This increased discharge must have occurred during a glaciation, and the inferred larger stream was almost certainly a glacial meltwater stream. This glacial meltwater stream could have only been present in this basin when the retreating ice margin was located above the meadow mine (the upstream margin of the terrace) and below or very close to the divide with the Sherry creek drainage (Fig. 2).

We recognize two possibilitites for the origins of the terrace. In our preferred hypothesis (Fig. 5), a glacial meltwater stream deposited outwash to the present terrace level in the middle and lower parts of the valley (Fig. 5A). The stream flowed over stagnant ice at the site of the hummocky terrane

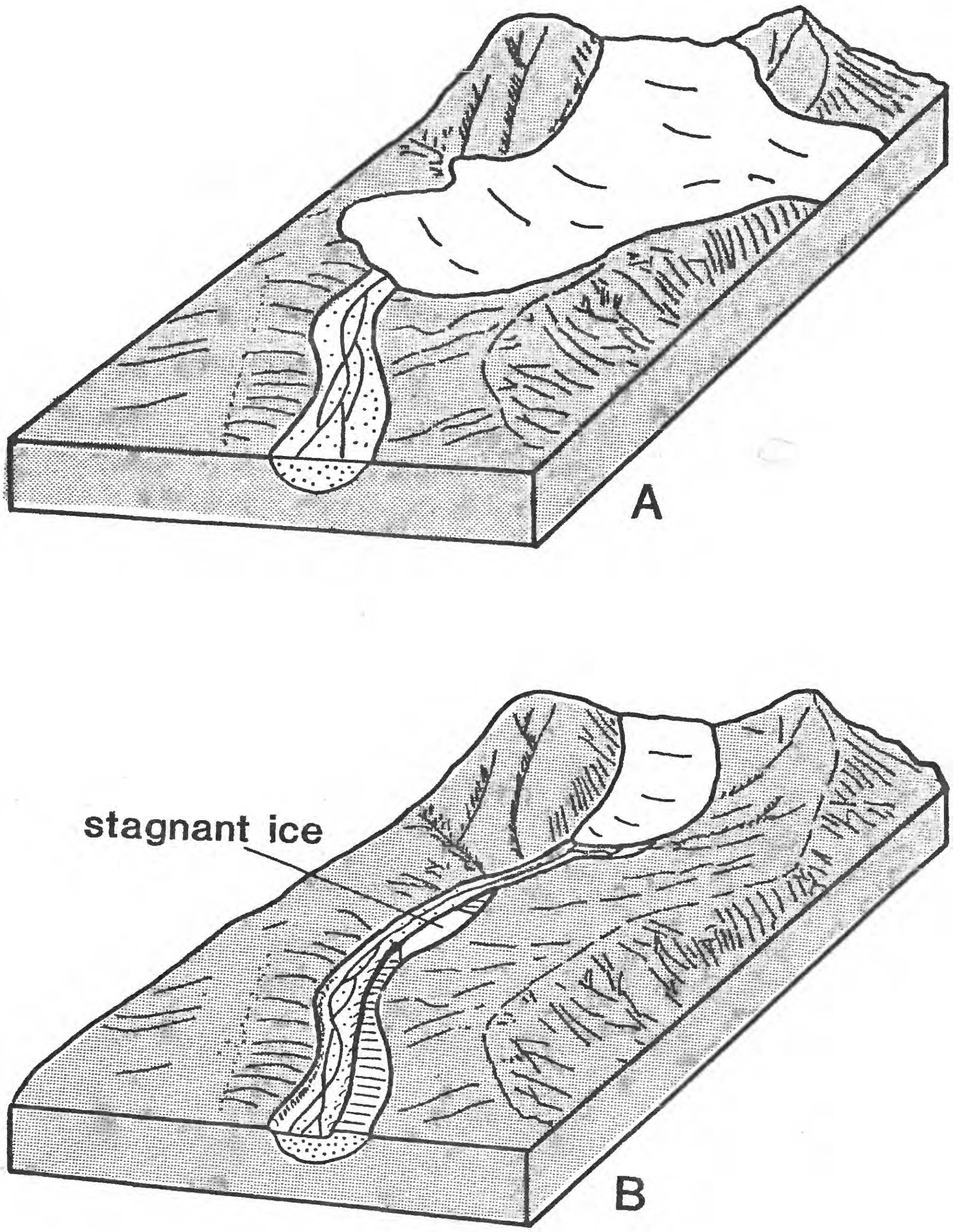

Figure 5. Preferred hypothesis for the late-glacial history of the north fork of Flodelle Creek drainage basin. A. Downstream part of the valley draining receding glacier is filled with outwash and stagnant ice. B. Glacier retreats further and base level is lowered. Outwash stream dissects valley fill, leaving a terrace on the eastern flank of the valley. Following B, melting of stagnant ice leads to collapse of a portion of the terrace, and kames formed in the valley floor.

in the valley. After deposition of the outwash, the stream incised due to lowering of base level or to a decrease in sediment load and a substantial portion of the valley fill was eroded (Fig. 5B). The lower terrace level at the widest spot of the valley terrace could have been cut in the initial stages of this change in stream grade.

A change in base level could be related to removal of an ice dam from downstream in the Little Pend Oreille or Colville river drainages. The Colville River sublobe of the Cordilleran ice sheet (Fig. 1) was probably present farther to the south in the Colville drainage at the time that the Flodelle Creek drainage, on the ice divide between the Colville River and Pend Oreille River sublobes (Fig. 1), was deglaciated.

The hypothesis in Figure 5 requires that both filling of the lower valley with outwash and the incision of the outwash occurred when the margin of the retreating ice sheet was within or very close to the drainage basin. If so, then these events must have occurred over a short time period, perhaps at most a few hundred years.

Our second hypothesis for the origin of the terrace requires that a sliver of dead ice more than 1800 m long filled the valley from the meadow mine down to the confluence with Flodelle Creek. In this model, the stream flowed along the eastern flank of the valley between the valley wall and the dead ice, forming a kame terrace. When the ice melted, the terrace was preserved on the side of the valley and the sediment load of the dead ice was deposited on the valley floor. Subsequently, the inferred irregular meltout topography was mostly infilled or modified by the postglacial stream to give the valley floor its present, mostly subdued, profile.

There are four problems with this second hypothesis. 1) It is unlikely that the small post-glacial stream could have sufficiently modified ice meltout topography in the valley floor to give it its present essentially flat cross-sectional profile. 2) The curvilinear outline of the valley floor opposite the downstream terrace segment has the shape of an older, larger stream course (Fig. 3). 3) Well-stratified, well-sorted sands of inferred fluvial origin are exposed on the western side of the valley (Fig. 3). If stagnant ice filled the valley during terrace formation, then two meltwater streams flanked by dead ice and flowing along the eastern and western valley flanks would be required (otherwise the sands on the western side of the valley would be a terrace remnant). 4) We know of no modern or ancient analogues for a continuous sliver of dead ice 1800 m long in a small valley and therefore consider this possibility less likely.

In each hypothesis, a portion of the terrace was underlain by stagnant ice. On melting of the stagnant ice, this portion of the terrace collapsed and kames (hummocky terrane) formed on the valley floor. Kame orientation probably reflects filling of transverse (crevasses?) and longitudinal cracks in the ice by the meltwater stream. McKenzie (1969) has described a collapsing terrace in southeastern Alaska that is probably a good modern analogue for this occurrence.

The upper layer of silt, volcanic ash, and organic matter on the terrace is similar to the layer that locally overlies the till on the valley slopes, and probably had a similar origin. The lack of an argillic soil profile in this layer or in the underlying alluvial sediments suggest that the terrace is a late-Wisconsin feature.

Deposits of the valley floor

Post-glacial surficial deposits of the valley floor have mainly accumulated at and downstream from the meadow mine (Fig. 3). Short segments of the upper-valley floor were also sinks for post-glacial deposits, but this part of the drainage is largely characterized by incision and sediment bypass. Our studies of the valley-floor deposits at the spring pool site, meadow mine, and in less detail at the downstream beaver dam complex, indicate that post-glacial sedimentation was greatly influenced by landslides from terraces, by kames, and by beaver dams.

Spring pool

The spring pool site occupies about 850 m^2 along a gently sloping, poorly drained, heavily vegetated section of the upper valley floor (Fig. 3). Flanking valley slopes are relatively steep (> 20°). Present surface flow through the site is sluggish and confined to a small, shallow, sinuous channel. The spring pool, for which the site is named, is about 2.5 m wide and 1 m deep, and remains ice-free throughout the year. Samples collected from 11 auger holes and 1 core hole permit recognition of five subsurface units (Fig. 6).

Unit A

Unit A is the lowest unit at the spring pool and was penetrated only in holes 1, 2, and 3 (Fig. 6). The top of the unit has a mean subsurface depth of about 350 cm and maximum penetration was 427 cm. Unit A consists of coarse-grained to granular sand and minor silt, clay, and muck (the terms muck and peat are used after Davis (1946) to define sediment containing more than 25 percent and 65 percent organic matter as estimated in hand specimen, respectively). Sand is mostly subangular quartz and feldspar (as is all fine-grained to granular sand in the valley-floor sediment), and was probably deposited in fluvial channels. Unit A silt, clay, and muck probably formed in overbank environments.

Unit B

Unit B was encountered in holes 1-3 and 5-10, and consists of clay, peat, muck, silt, and minor sand (Fig. 6). The lower contact was penetrated in holes 1-3 at a depth of 350 cm and is marked by an abrupt transition from sand-dominated unit A to fine-grained, organic-rich unit B. The upper contact with unit D volcanic ash dips upstream; it occurs at a depth of about 200 cm in the upstream profile (holes 1-3), 140 cm in holes 6 and 7, and 110 cm in hole 8 (see N-S profile in Fig. 6). Unit B interfingers with unit C sand in holes 9 and 10. The marked lithologic change between units A and B suggests a transition from a fluvial to a more restricted bog or pond environment.

Unit C

Unit C consists of poorly to moderately sorted, light gray coarse-grained to granular sand. It interfingers with unit B in holes 8-10, and underlies unit D volcanic ash in holes 11 and 12. The base of unit C was not penetrated. From east to west along profile 9-12, the depth of the top of unit C increases from about 60 to about 165 cm, as does the amount of interfingering with fine-grained sediments of unit B. These changes, the absence of unit C in upstream holes, and the similarities between unit C and

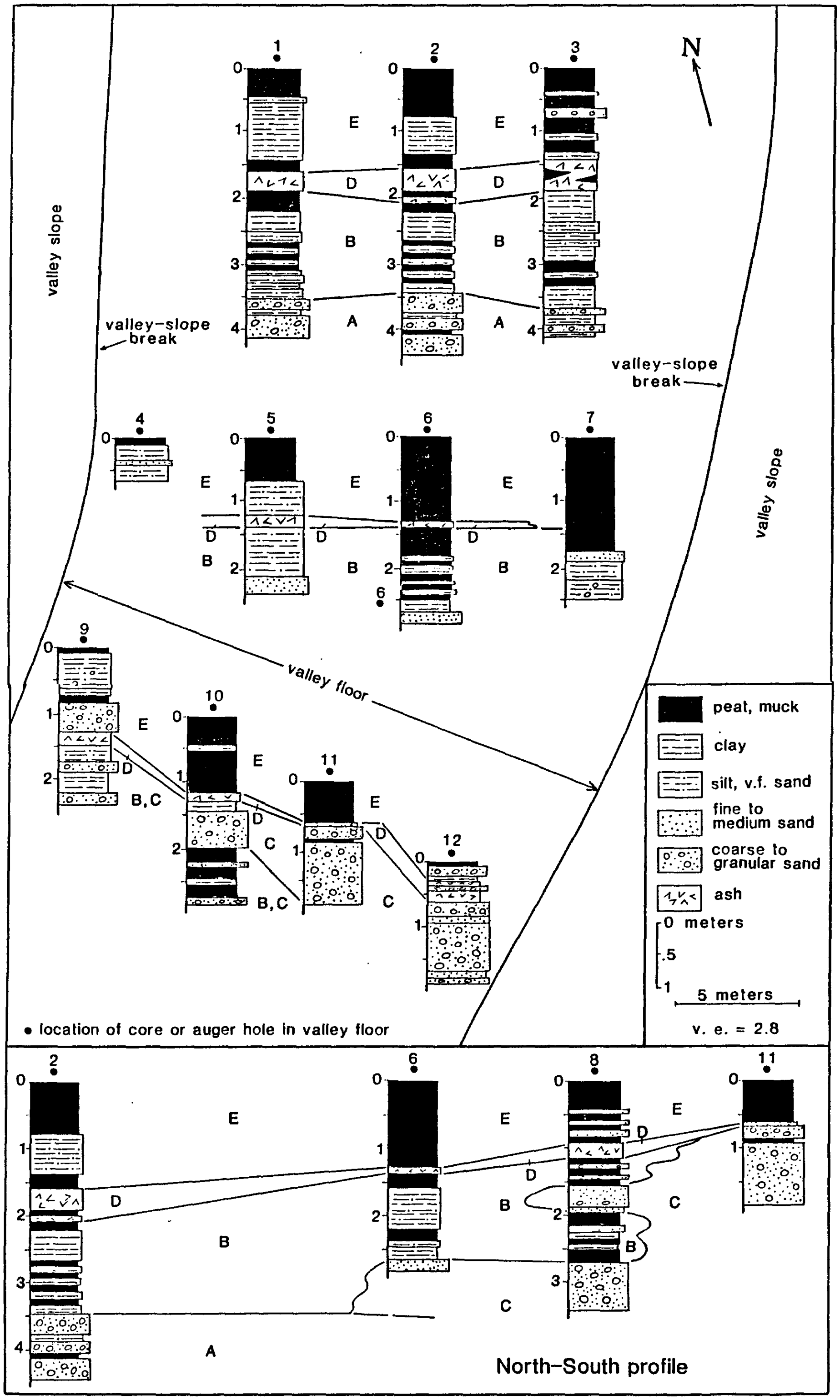

Figure 6. Stratigraphy of the spring pool site. See Figure 3 for location.

the sediments that underlie the valley slopes suggest that unit C probably formed as a small slump fan or apron off the eastern valley slope. The positive topography on this fan raised local base level and led to ponding of the unit A fluvial system.

Unit D

Unit D overlies units B and C in the upstream and downstream portions of the spring pool site, respectively. It consists of well-sorted, pinkish-gray to white volcanic ash that is locally mixed with sand, silt, and organic matter. Glass shards finer than 0.03 mm are the dominant ash component. The unit has a maximum thickness of about 40 cm (hole 3) and is absent in hole 7. The thickest beds generally contain the largest non-ash component, suggesting that considerable ash was washed off valley slopes and redeposited in the valley floor. The depth of the base of unit D in the subsurface decreases from north to south along the valley axis from 190 cm in hole 2 to 66 cm in hole 11 (see N-S profile in Fig. 6). Since the base of unit D approximates an isochronous surface, this depth variation indicates that there was approximately 130 cm of relief between the upper surface of the pond sediments of unit B and the inferred slump-fan sediments of unit C. Similarly the depth of the base of unit D volcanic ash increases from east to west along line 9-12 from 60 cm to 150 cm, indicating the cross-valley slope on the inferred slump fan.

Based on instrumental nuetron activation analysis of volcanic glass (Table 1), we correlate the ash of unit D with the 6700 yr Mazama ash, erupted from Mount Mazama (Crater Lake) in southern Oregon (Bacon, 1983). Mullineaux (1974) has shown that this typically yellowish-orange to pale-brown ash is commonly white where it is interbedded with peaty material.

Unit E

Unit E consists of woody peat and muck (59 percent), organic-rich silt and clay, and minor fine-grained to granular sand. The dominance of fine-grained, organic-rich sediments in unit E suggests that the spring pool site continued to be a bog for most of the last 6700 years. Minor fine to granular sands in unit E primarily occur on the margins of the spring pool site and were probably largely derived from slope wash off the valley flanks. Unit E extends from the surface to depths of 160 cm in hole 2 and 60 cm in hole 11 (see N-S profile in Fig. 10). Because the contact climbs downstream, the constructional topography on unit C must have continued to act as a downstream control of base level.

Summary

Following glacial recession, unit A was deposited at the spring pool site in a small stream (Fig. 7A). The stream was flanked to the east by relatively steep slopes underlain by unconsolidated glacial sediments. A bog formed when unconsolidated slope sediments slumped across the narrow valley and blocked drainage (Fig. 7B). The site has continued to be a bog until the present. Pond deposits include fine-grained, organic-rich sediments of units B and E, and 6700 yr B.P. Mazama ash of unit D. Along profile 1-3, units B and D have thicknesses of 150 and 160 cm, respectively. Assuming approximately uniform sediment accumulation rates, the base of unit B is probably at least 11,000 yrs B.P., suggesting that the spring pool pond formed shortly after deglaciation.

TABLE 1. INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS OF GLASS SEPARATES FROM ASH

Element	Mazama ash[2]	Unit D[3]	Glacier Peak ash[2]
Fe[1]	1.39	1.36	0.701
Na[1]	3.76	3.70	3.00
Ba	762	757	654
Co	2.25	2.10	1.14
Cr	<1.5	0.83	0.60
Cs	3.02	3.04	2.46
Hf	5.81	5.89	3.12
Pb	52.8	51.2	53.5
Sb	0.444	0.496	0.301
Ta	0.452	0.467	0.489
Th	4.95	4.89	6.89
U	1.90	2.08	2.71
Zn	38.6	39.6	23.9
Zr	205	203	96.1
Sc	5.39	5.36	2.25
La	20.3	20.3	15.2
Ce	44.9	42.5	30.9
Nd	22.3	21.8	11.9
Sm	4.46	4.45	1.95
Eu	0.893	0.884	0.530
Gd	--	--	--
Tb	0.616	0.612	0.236
Tm	--	--	--
Yb	2.24	2.35	0.978
Lu	0.352	0.353	0.160

1 - Fe and Na expressed as percent. All other values in ppm

2 - data from cleaned glass separates of ash samples from type or reference localities, provided by R. E. Wilcox. Glacier Peak ash data shown for comparison. All data obtained by R. A. Zielinski.

3 - data from cleaned glass separate of ash from hole 6, spring pool site (Fig. 6).

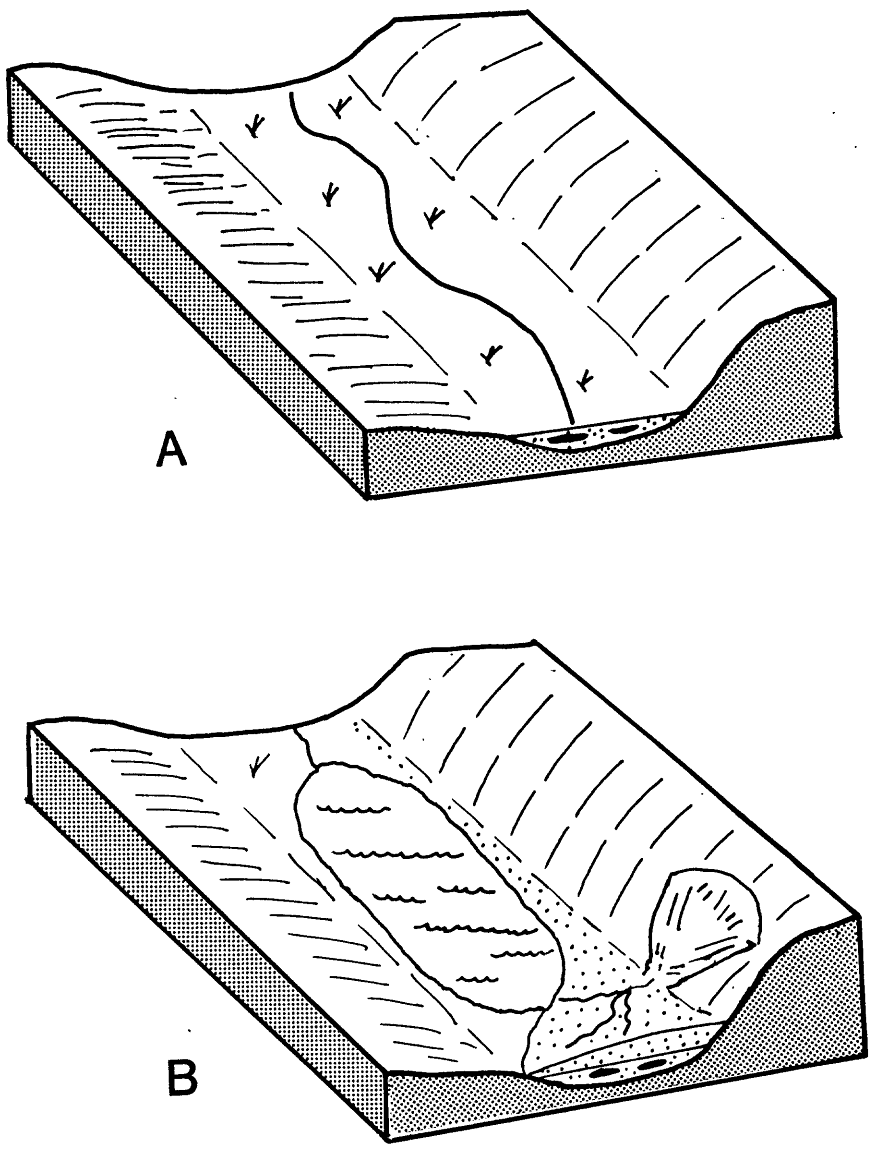

Figure 7. Post-glacial sedimentary history of the spring pool site. A. Small stream flows through the valley. B. Unconsolidated till slumps off valley slopes and blocks drainage, creating a small pond.

Meadow mine

The meadow mine (Figs. 3, 4) occupies approximately 15,600 m^2 (about 3.7 acres). Joy Mining Company began to strip mine the meadow in the summer and fall of 1983, and has built a pilot uranium ore processing plant on the terrace above the meadow. When we conducted our field studies in the summer of 1984, the upper, approximately 150 cm of the sediment (ore) section had been removed from a large area in the upstream part of the meadow and the operators were beginning to remove ore from downstream portions. Our data on the sedimentary fill of the meadow consist of observations of the mine cuts and of sediments extracted from 61 auger and core holes (Fig. 8). Based on stratigraphic position and lithology, we recognize four subsurface units.

Unit F

Unit F is the lowest known stratigraphic unit beneath the meadow. Its upper contact in 38 of the auger holes occurs at the base of a distinctive volcanic ash bed, unit G. The depth of this contact ranges from 76 to 178 cm (mean ($\pm 1\sigma$) of 134 $\pm$ 28 cm), however the shallowest occurrences (< 122 cm) all occur along the meadow margins. When these shallow values are not considered, the contact has a mean depth of 146 $\pm$ 20 cm. Where unit G does not occur, we infer that it was removed by erosion in stream channels and place the upper contact of unit F at the base of the first significant sand interval below 146 cm (inferred to represent the base of the channel that eroded unit G). We do not place a lower contact on unit F. Maximum depth of sample recovery was 335 cm and maximum penetration was 366 cm.

Based on auger and core data, unit F consists of 31 percent coarse-grained to pebbly sand, 33 percent fine- to medium-grained sand, 28 percent very fine-grained sand and silt, 4 percent clay, and 4 percent peat and muck. However, the water table in the meadow occurs at a depth of about 180 cm and sandy sediments below this level are typically saturated, lack cohesion, and wash off the auger bit. If it is assumed that sediments in horizons of no recovery (Figure 8) are sandy, then the relative proportion of sand in unit F would increase. Sediment is most commonly olive gray, light olive gray, dark yellowish brown, and moderate brown. Lowermost sands are commonly light bluish gray. In the downstream mine cut (Figs. 9, 10), sand, silt, and clay typically form thin lenses that pinch out laterally within a maximum of a few hundred centimeters.

Wood fragments, charcoal, and fibrous organic matter are common in unit F sediment of all grain sizes. A composite sample of wood fragments collected from four auger holes at depths between 180 and 250 cm yielded a C^{14} age of 6650 $\pm$ 120 yr B.P. (U.S.G.S. sample 2098). Sediments below 270 cm are almost exclusively sand, and we noted only very minor amounts of organic matter in samples below 270 cm.

We infer that unit F was largely deposited by a stream in channel and overbank environments. Since the modern stream is small and carries mostly a fine-grained sediment load, the large proportion of sand in unit F is striking. Most of this coarse-grained material was probably very locally derived from till on the valley flanks, or represents reworked or redistributed glacial outwash. The contact between glacial and postglacial fluvial deposits is hard to pinpoint. Sediments below 270 cm are almost completely sand, lack organic matter, and therefore may have been deposited in outwash streams.

There was at least 100 cm of relief in the meadow when unit G volcanic ash was deposited. Low relief areas were probably active or abandoned stream

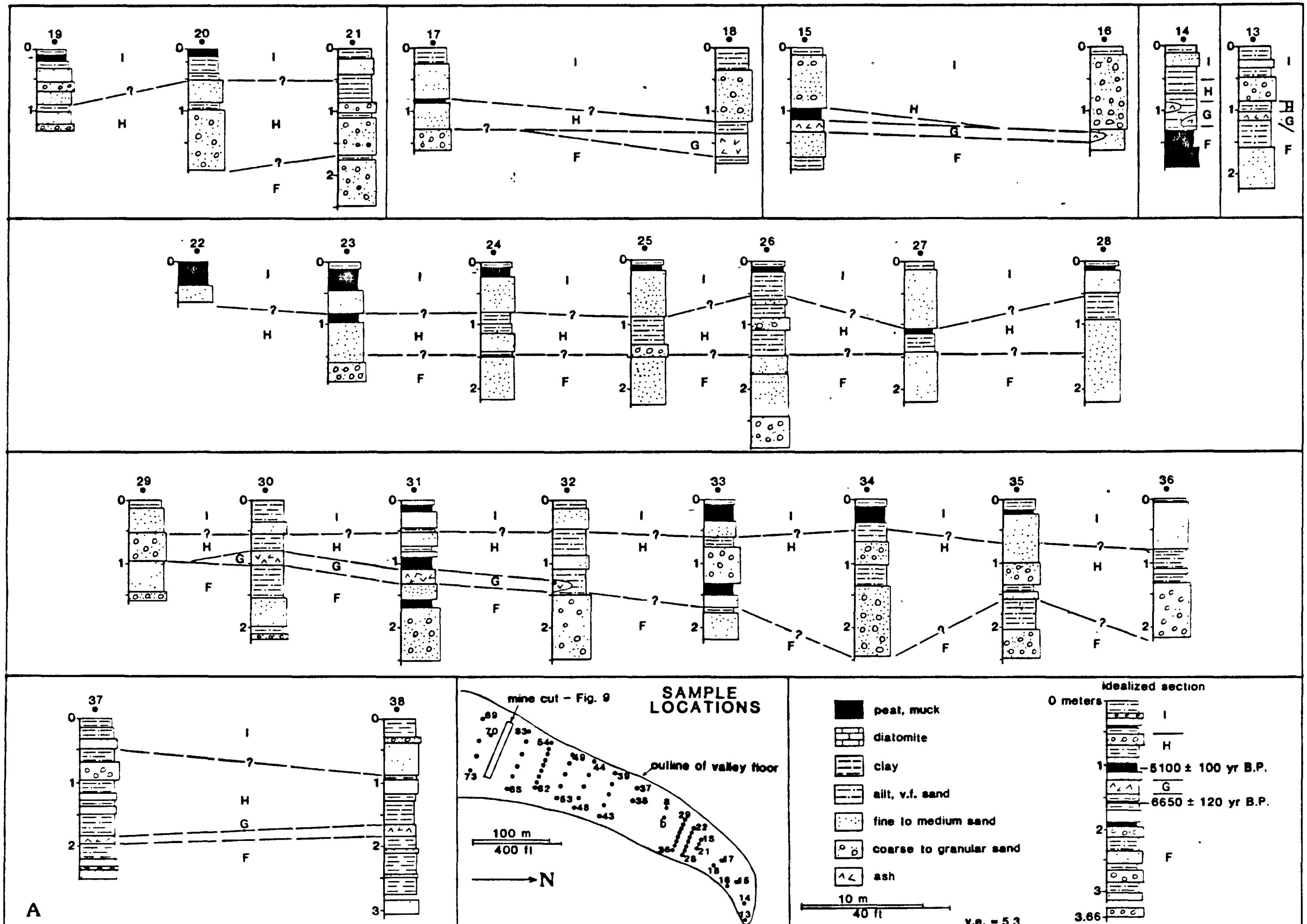

Figure 8A. Stratigraphy of the meadow mine; "a" and "b" show locations of Figures 13 and 14.

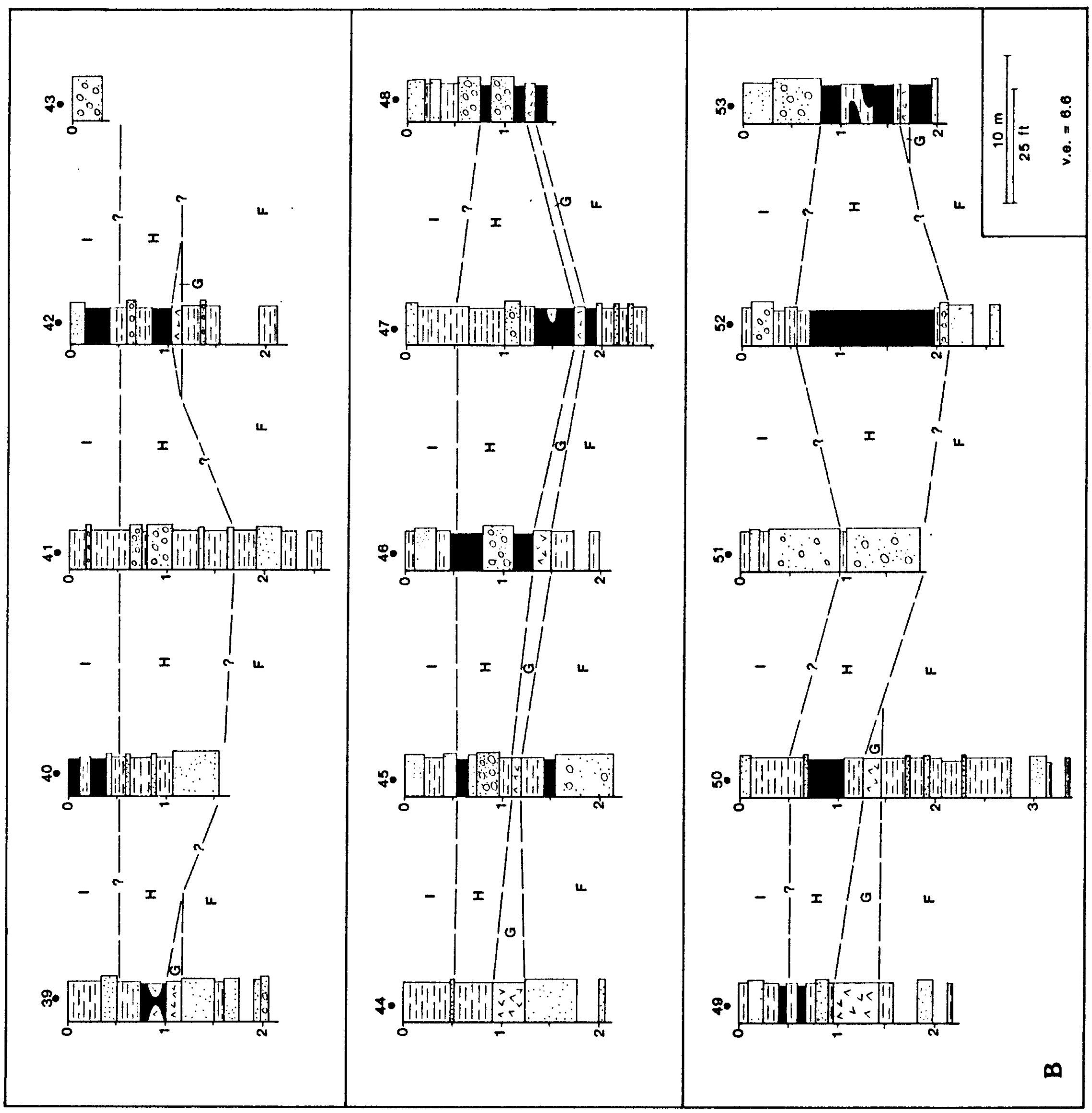

Figure 8B.

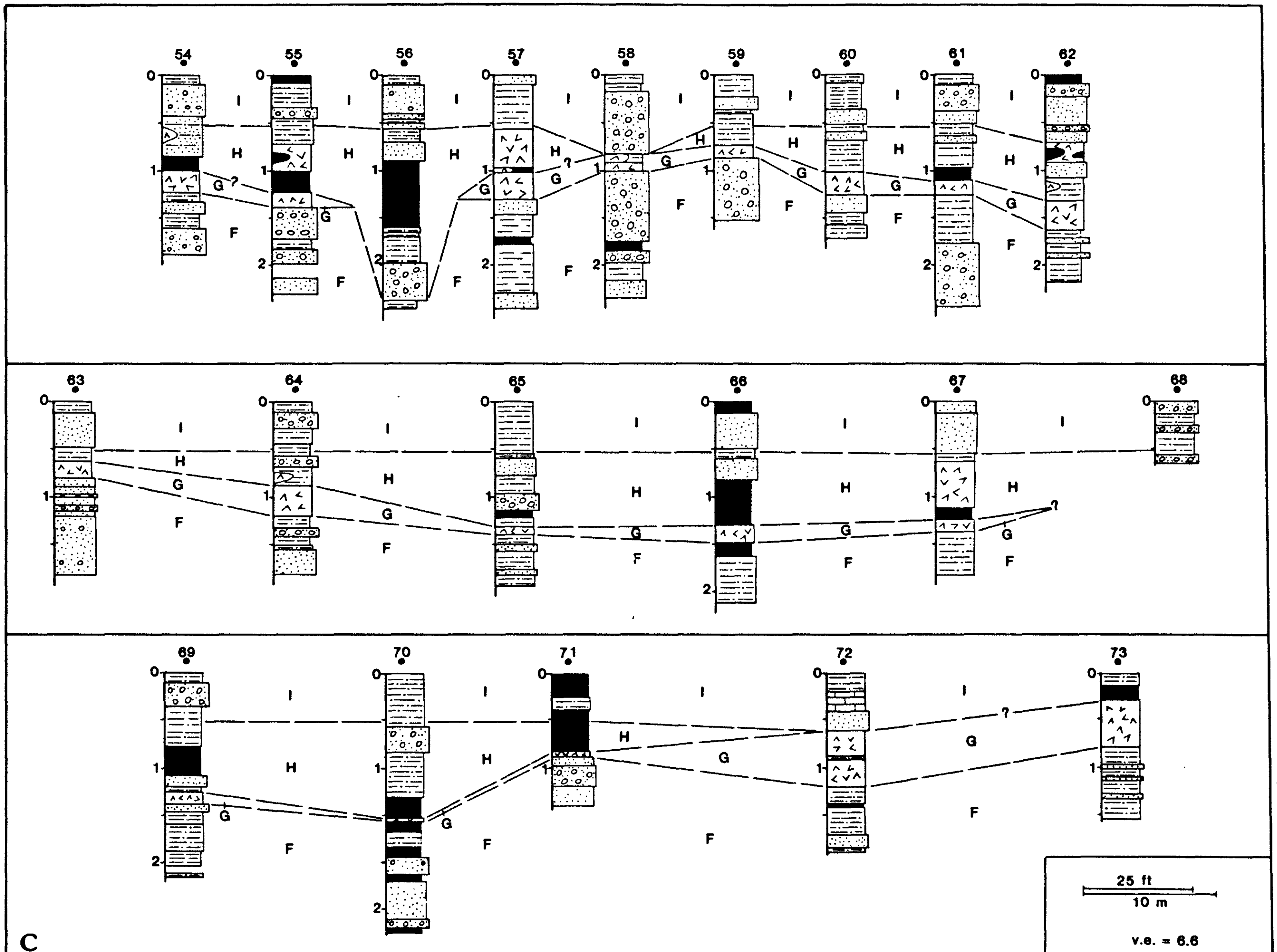

Figure 8C.

channels. High paleo-relief areas may have been deposited by sheetwash or very small side drainages off the valley flanks. The amount of paleo-relief is similar to that observed in the modern, pre-mining meadow. Outflow of the postglacial stream must have been diverted to the west side of the meadow by the kames on the downstream meadow margin (Fig. 3).

Unit G

Unit G consists of well-sorted, pinkish-gray to white, fine volcanic ash, and is distributed unevenly in the meadow subsurface (Fig. 8). In the 38 holes where unit G occurs, it has a mean thickness of 24 ± 19 cm, and a maximum thickness of 60 cm. The primary (ash fall) thickness is probably about 20 cm, the thickness of a pure, flat-topped layer of unit G exposed in the eastern half of the lower meadow mine cut (Figs. 9, 10, 11). Where the ash bed is thicker (> 20 cm), the upper part of the bed typically contains interlayers of silt, sand, and organic matter, indicating reworking and redeposition. Much ash was probably transported by sheet erosion from the valley walls into the meadow. Nine of the eleven holes where the ash is thicker than 25 cm are located on the meadow margins. The thick ash beds in the two remaining holes may have been deposited in abandoned stream channels. Thin ash lenses and pods are also common in overlying units, suggesting that redeposition may have continued for a considerable period of time. Stream erosion (note channels up to 250 cm wide in Fig. 9) was mostly responsible for removal or thinning of the ash. The ash is present in only six of the twenty-four auger holes in the upper part of the meadow where fluvial processes are inferred to have been most active.

Unit G is lithologically and stratigraphically similar to unit D at the spring pool site (Fig. 6) and is likewise inferred to be 6700 yr B.P. Mazama ash. This inference is supported by bracketing C^{14} dates from underlying unit F and overlying unit H (Fig. 8A). Williams and Gole (1968) and Lidstrom (1971) have previously suggested that the thickness of Mazama ash at this location should be approximately 2 to 4 cm and 5 to 15 cm, respectively. They used these thickness estimates to speculate on the volume of Mazama ash fall. Because the primary thickness of Mazama ash at Flodelle Creek appears to be about 20 cm, their ash-fall volume estimates may need upward revision. Rigg (1956) and Mack and others (1978) have also noted anomalously thick accumulations of Mazama ash in northeastern Washington.

Unit H

Unit H overlies units F and G and underlies unit I (Fig. 8). The lower contact of unit H is typically at a depth of about 122 cm, however in many places unit G has been thinned or removed by erosion and the contact is lower. Similarly, although the upper contact of unit H is typically at a depth of about 52 cm, at places the top of unit H has been eroded by unit I channels (Figs. 12, 13, 14) and the contact between units H and I is lower. Based on auger and core samples, unit H consists of 28 percent coarse- and very coarse-grained sand, 21 percent fine- and medium-grained sand, 24 percent very fine-grained sand and silt, 11 percent clay, and 15 percent silty-clay muck or peat. Downstream of sample line 29-36 (Fig. 8), the relative proportion of very fine-grained sand and silt, clay, and muck and peat increases to 33 percent, 15 percent, and 16 percent, respectively. Thus, unit H is notably more fine-grained and organic rich than unit F and unit I (see next section), particularly in the central and downstream portions of the meadow. Wood fragments, charcoal, and fibrous organic matter are abundant and common in sediments of all grain sizes. Sand, silt, and clay are most

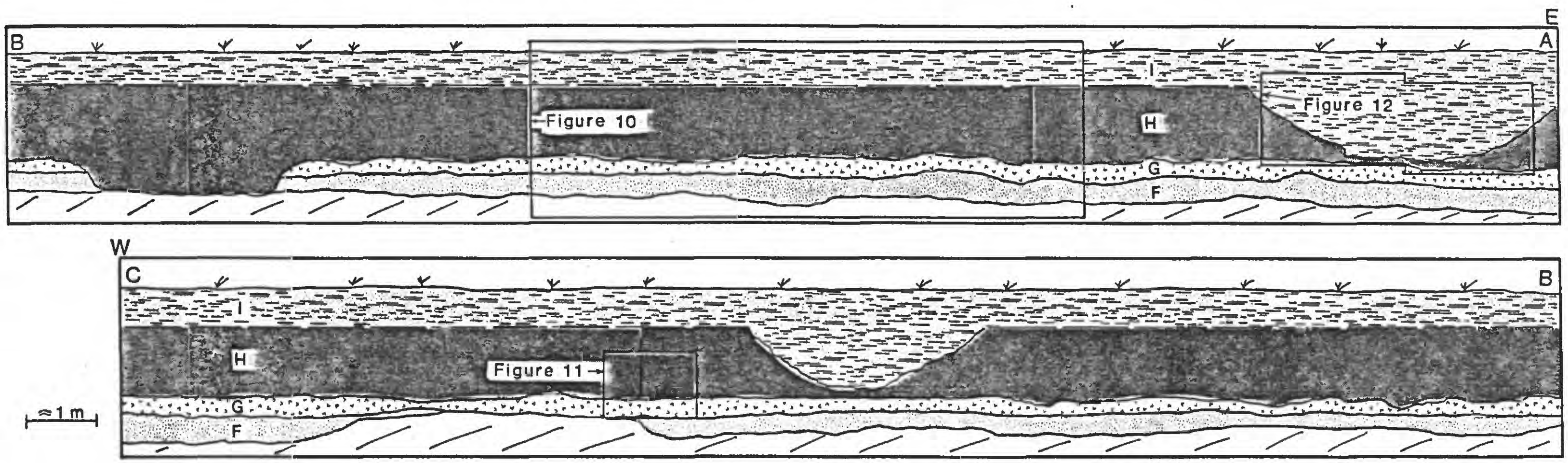

Figure 9. Drawing (from photo mosaic) of the north (upstream) wall of the mine cut at the downstream end of the meadow mine (Fig. 8). Drawing runs from east (A) to west (C). Units F, G, H, and I are labelled. Note locations of Figures 10, 11, and 12.

Figure 10. Stratigraphy of the meadow in the lower-meadow mine cut. See Figure 9 for location.

Figure 11. Close up of units G and H in the downstream meadow mine cut. Note abundant woody debris in unit H peat. See Figure 9 for location.

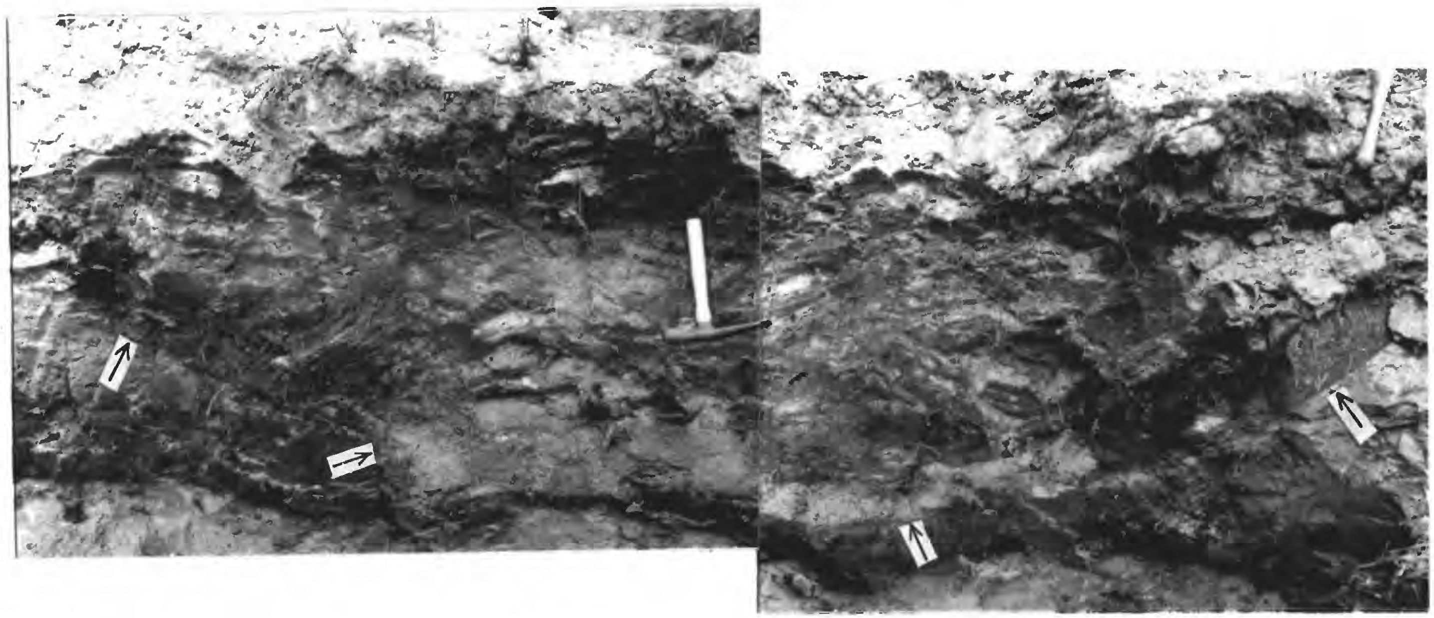

Figure 12. Unit I sand-, silt-, and muck-filled channel in the lower-meadow mine cut. Arrow marks the channel base. See Figure 9 for location.

Figure 13. Unit I sand-filled channel in upper-meadow mine cut. See Figure 8A for location.

Figure 14. Stratigraphy of upper-valley mine cut, showing (from base to top) unit F silt, unit G volcanic ash, unit H silty muck, and unit I sand, silt, and clay. Note thin, lenticular, sand-filled channels in unit I. See Figure 8 for location.

typically dark yellowish brown, olive gray, light olive gray, and dusky yellowish brown. Muck and peat are typically olive black to brownish black.

Sedimentation of unit H was strongly influenced by beaver dams. The best evidence for a beaver dam occurs in the mine cut at the downstream end of the meadow (Figs. 8, 9, 10, 11). In this cut, unit H consists of a 75-cm-thick sheet of woody peat and muck that extends across the width of the meadow. This sheet contains abundant randomly oriented sticks with faceted and tooth-marked terminations. Based on the sheet geometry, the organic-rich sediment, and the abundant beaver-cut sticks, unit H in this cut is interpreted as an ancient beaver dam. The presence of a large channel through the underlying unit G in this mine cut (subsequently filled during dam construction) and the absence of unit G in many holes suggest that fluvial processes were re-established following Mazama ash deposition in the meadow before the beaver dam was built. Wood fragments from auger samples immediately above unit H upstream from the dam yielded a C^{14} date of 5100 ± 110 yr B.P. (U.S.G.S. sample 2099), an approximate time for the beginning of beaver construction.

Drainage behind the dam of Figure 9 must have been ponded to a depth of about 75 cm, the thickness of the sediments that make up the dam. Since the total elevation drop in the meadow is about 250 to 300 cm and the meadow gradient was nearly uniform (based on the depth of the top of unit G), this dam ponded only the downstream portion of the meadow. By analogy with the group of beaver dams in the the lower portion of this valley (Fig. 3) and in similar valleys throughout northeastern Washington, and because unit H is notably organic rich and fine grained in most of the meadow, it seems likely that beavers built additional dams at upstream meadow locations. The thick organic-rich sediments of unit H along line 49 to 53 (Fig. 8B) may represent a portion of a second beaver dam. The surface of the meadow along this line of sample holes is approximately 75 cm higher than at the downstream meadow mine cut (Fig. 9). A second dam in this approximate location would thus be likely. Although we have no direct evidence for additional beaver dams above line 49-53 in either auger samples or mine cuts, we suspect that much of the organic-rich sediment deposited in the middle and upper parts of the meadow (Fig. 8) was also deposited in beaver ponds and that the presence of one or more additional ancient beaver dams in the meadow subsurface is likely. Thick accumulations of woody, organic-rich sediment recovered in holes 47 and 56 do not appear to have lateral continuity and may represent ancient beaver lodges.

There is a surprising amount of fine- to coarse-grained sand in unit H. Because of the inferred presence of several beaver dams, it seems unlikely that much of this relatively coarse sediment was transported from upvalley. We have observed small side fans of till-derived coarse-grained sand on the margins of modern beaver ponds in the north fork of Flodelle Creek and in the Sherry creek drainage (Fig. 2), and suggest a similar origin for most of the sand in unit H in the downstream and central parts of the meadow.

Sediments of unit H in the upstream part of the meadow (holes 13 to 36) are more coarse-grained and less organic rich than unit H sediments in the downstream part of the meadow. In the upstream meadow mine cuts (Figs. 8, 13, 14) unit H consists mostly of flat- and ripple-laminated lenses of silt, clay, muck, and sand. These strata are probably primarily fluvial or deltaic.

Rutherford (1964) has shown that beavers favor wide of valleys and streams of low gradient. Beaver ponds will flood a valley floor and raise base level so that stream flood waters will spread over wide areas and have diminished velocity. The destructive power of a flood is therefore much less in comparison with floods in narrow valleys with steep grades, and beaver structures can be more permanent. Also, beaver ponds in wide and low-gradient portions of a valley provide larger areas favorable for growth of plants that beavers eat. In the north fork of Flodelle Creek drainage, the wide, low-gradient section of the valley floor at the meadow was produced by glaciofluvial processes (see section on terrace and hummocky-terrane deposits).

The duration of beaver residency in the meadow is not known. Typically beavers will remain at a site until they no longer have an adequate supply of food, or until their ponds are filled with sediment. After beaver abandonment of this site, beaver dams must have continued to have relief above the valley floor and therefore probably influenced sedimentation not only during beaver residence but long after. This influence must have waned considerably as topography was filled and fluvial drainage through the meadow was re-established. The highest concentration of organic matter other than in inferred beaver dams occurs in the lower part of unit H, consistent with a history of waning influence. The assigned depth of the top of unit H coincides with the top of the downstream well-exposed beaver dam (Fig. 9), and we consider unit H to have been mainly deposited during times of beaver ponding, or when topography relict from beaver activity affected sedimentation.

Unit I

Unit I extends from the meadow surface to the top of unit H (Fig. 8). This contact typically occurs at about 52 cm, however locally unit H has been partly or almost completely eroded and the contact is as deep as 125 cm. Based on auger and core data, unit I consists of approximately 14 percent coarse-grained to granular sand, 36 percent fine- to medium-grained sand, 34 percent silt and very fine-grained sand, 5 percent clay, and 10 percent silty-clay muck and peat. The upper 10 to 15 cm is most commonly a rooted dark-yellowish-brown to light-olive-gray silty loam. Lower sediments of unit I are typically dark yellowish brown, pale yellowish brown, light olive gray, olive gray, brownish gray, and dusky yellowish brown. Wood fragments, charcoal, and fibrous organic matter are common. A 7-cm-thick white diatomite bed occurs in hole 72 (Fig. 8C), and a 10-cm-thick lens of diatomite is exposed in the downstream meadow mine cut.

Unit I sediments are highly variable laterally and vertically and were predominantly deposited by streams in channels and on floodplains. Fluvial channels are well exposed in the upstream meadow mine cuts (Figs. 13, 14). In Figure 13, the channel is approximately 150 to 200 cm wide and has cut out approximately 40 cm of unit H. The channel fill consists of truncated inclined beds of coarse-grained to granular sand overlain by silt and clay drapes. Clay drapes and truncation surfaces imply variable discharge and multiple cut and fill events. In the mine cut shown in Figure 14, shallow sand-filled channels with only minimal erosional relief are visible, indicating that sand transport through the system was not limited to the major channels. Channels in both upstream mine cuts are flanked by ripple- to flat-laminated silt, sand, and clay. These fine-grained strata are probably representative of unit I overbank deposits throughout the meadow.

There are two major unit I channels that cut through the well-exposed beaver dam in the downstream meadow mine cut (Fig. 9). The channel at the eastern end of the cut is 280 cm wide and cuts down to within a few cm of the base of unit H (Fig. 12). The axis of the channel is filled with lenses of coarse-grained sand separated by drapes of silt, clay, and wood fragments. The second channel through the beaver dam at the western part of the cut is about 200 cm wide and is mostly filled with organic-rich silt and clay. There is considerably less coarse-grained sediment in these channels than in the channels in the upper meadow mine cuts, suggesting that a significant portion of the coarse load of the stream was deposited in the meadow. The two lower meadow channels undoubtedly served as the major meadow outlets for the unit I fluvial system. As with the unit F fluvial system, downstream outflow must have been diverted by the kames (Fig. 3) to the western side of the valley. The presence of diatomite layers up to 10 cm thick in the downstream part of the meadow suggests that ponds were present on parts of the floodplain.

Summary

The meadow mine occurs in a wide flat area of the valley floor created by glaciofluvial erosion. After ice retreat and until about 6700 yr B.P., a small underfit fluvial system flowed through the meadow (Fig. 15A). Kames partly restricted drainage and controlled the location of stream outflow. Fluvial sedimentation was interrupted at about 6700 yr B.P. by deposition of Mazama ash. The ash was locally eroded and redistributed by slope wash and fluvial processes. Because the meadow was broad and nearly flat, it provided an ideal site for beavers who first dammed the meadow mine site about 5000 yr B.P. Ponds created by one or more beaver dams (Fig. 15B) created a sink for the accumulation of abundant, fine-grained, organic-rich sediment. The duration of beaver occupation in the meadow is not known, but their dams probably continued to affect drainage and sedimentation long after their ponds began to fill with sediment and they abandoned the meadow. Fluvial processes were reestablished after beaver ponds were filled with sediment (Fig. 15C).

Downstream beaver dam complex

Subsurface data from the downstream beaver dam complex consists of samples collected from three auger holes (Figs. 3, 16). Hole 74 was drilled in the center of the valley about 3 m upstream from the crest of an abandoned and dissected beaver dam. Relief on the upstream and downstream sides of the dam is about 50 cm and 100 cm respectively. Hole 75 was drilled near the margin of the stream valley on the side of a modern beaver pond. Hole 76 was drilled near the center of the valley at the upstream margin of the lowest modern beaver pond.

Stratigraphy of the three holes is similar in that each contains an upper unit of mostly peat, muck, and organic-rich clay, and a lower unit of mostly sand (Fig. 16). Hole 75 is slightly anomalous in that it contains thin sand and ash layers in the upper fine-grained unit. Since hole 75 is on the side of the valley, the sands were almost certainly derived from erosion of the adjacent valley wall. Based on lithology, the thin ash beds in hole 75 are correlated with 6700 yr B.P. Mazama ash (unit D at the spring pool and unit G at the meadow mine). The absence of ash in holes 74 and 76 in the center of the valley and the relative thinness of the ash beds in hole 75 suggest that the ash was removed by fluvial erosion. It therefore seems likely that ponding by beaver dams began after ash deposition.

It is probable that this portion of the valley was first occupied by beavers at approximately the same time as at the meadow mine. Beavers typically live in family-unit colonies that consist of the parent male and female plus their progeny of the previous year and the current year (Rue, 1964; Rutherford, 1964). Two-year olds are driven from the colony by the adults and typically locate living sites downstream from and close to the parent colony. The first suitable site for beaver occupation downstream from

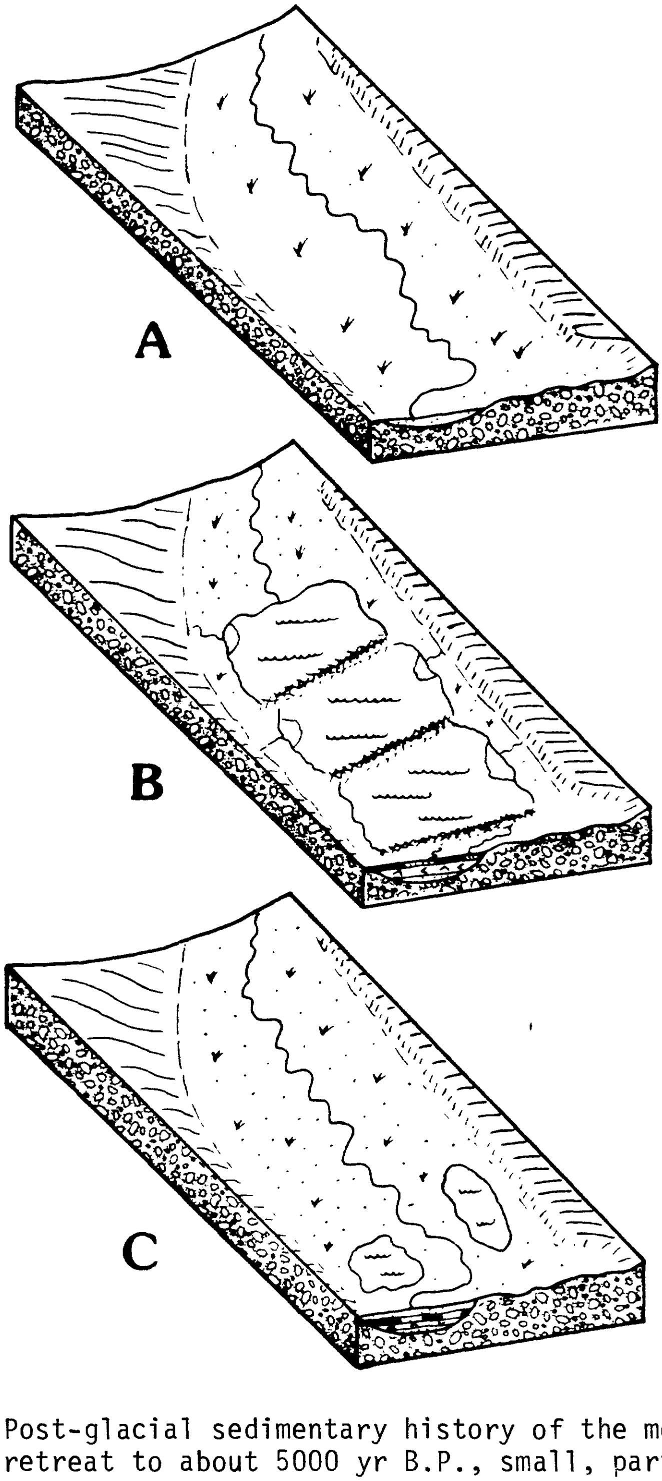

Figure 15. Post-glacial sedimentary history of the meadow mine. A. From time of ice retreat to about 5000 yr B.P., small, partly restricted (by kames), fluvial system flows through the meadow. B. At approximately 5000 yr B.P., beavers built one or more dams in the meadow, ponding drainage. C. Beaver ponds fill with sediment and fluvial drainage is reestablished. Diatomite accumulates in small floodplain ponds.

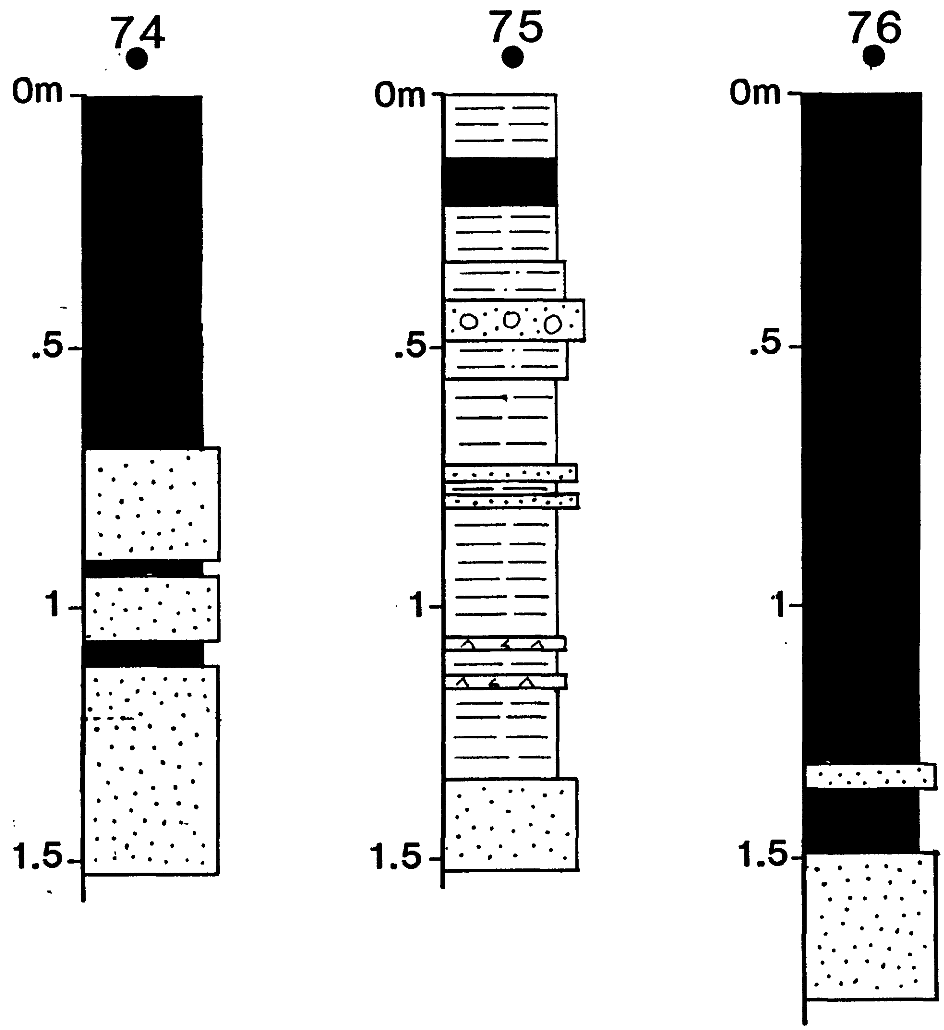

Figure 16. Stratigraphic data for the lower-valley complex of beaver ponds and dams. Legend is the same as in Figure 8; locations are shown in Figure 3.

the meadow mine was the broad glaciofluvial outwash plain in the downstream part of the valley.

If beavers first occupied this part of the valley at about 5000 yr B.P., then it has been a suitable site for beaver occupation for a considerable time period. This longevity is probably directly related to the role of upstream beaver dams and ponds as sediment traps. While meadow-mine beaver ponds silted up, downstream beaver ponds remained relatively free of clastic sediment and as a consequence are still viable.

URANIUM DISTRIBUTION

The organic-rich sediments of the valley floor contain anomalously high concentrations of uranium. Eleven stratigraphic horizons in a 110-cm core from a small bog (the government rock site) at the drainage divide (Fig. 3) have a mean uranium concentration ($\pm 1\sigma$) of 1641 ± 1381 ppm, a weighted average (based on the thickness of the sample interval) of 1948 ppm, and a range of 20 ppm to 4470 ppm. The mean organic matter content (± 1 , estimated from loss on ignition) in the eleven samples is 18.8 ± 17.8 percent, the weighted average is 26.1 percent, and the range is 3.7 percent to 53.1 percent. Samples with the highest and lowest uranium values contain 53.1 percent and 14.9 percent organic carbon, respectively.

Eighteen stratigraphic horizons in hole 6 at the spring pool site (Figs. 3, 6, 17) have a mean uranium concentration of 1243 ± 790 ppm, a weighted average of 1421 ppm, and a range of 141 ppm to 2790 ppm. The mean organic matter content for the core samples is 18.8 ± 17.8 percent, the weighted average is 26.1 percent, and the range is 3.72 percent to 53.09 percent. Samples with the highest and lowest uranium values contain 49.1 percent and 4.1 percent organic matter, respectively. Auger samples from hole 7 have yielded uranium values as high as 8960 ppm, and organic-rich samples in the upper 165 cm of this hole have a mean concentration of 7270 ppm. Units B and E contain the highest concentrations of uranium and organic matter.

Forty-three stratigraphic horizons from hole 25 and an adjacent hole 210 cm to the east (not shown on Fig. 8) in the upstream fluvial-dominated part of the meadow mine were also analyzed for uranium and organic matter. The mean uranium concentration is 265 ± 233 ppm, the weighted average is 232 ppm, and the range is 8.6 ppm (0.41 percent organic matter) to 1070 ppm (7.01 percent organic matter). The mean organic matter content in the core samples is 3.9 ± 3.5 percent, the weighted average is 3.9 percent, and the range is 0.41 percent to 14.6 percent. Uranium concentrations are considerably higher in the more organic-rich sediments (unit H) in the subsurface in the central and downstream part of the meadow (R. E. Miller, Joy Mining Company, oral commun., 1984).

CONTROLS ON URANIUM DISTRIBUTION

Surficial deposits in the valley of the north fork of Flodelle Creek have formed where uranium has precipitated from ground, surface, and spring waters in organic-rich, fine-grained sediments. The highest uranium values in samples from the spring pool and meadow mine are from the present surface, indicating that these deposits are presently forming. They have probably been continually forming since deglaciation about 13,000 years ago.

The Phillips Lake Granodiorite contains high concentrations of uranium

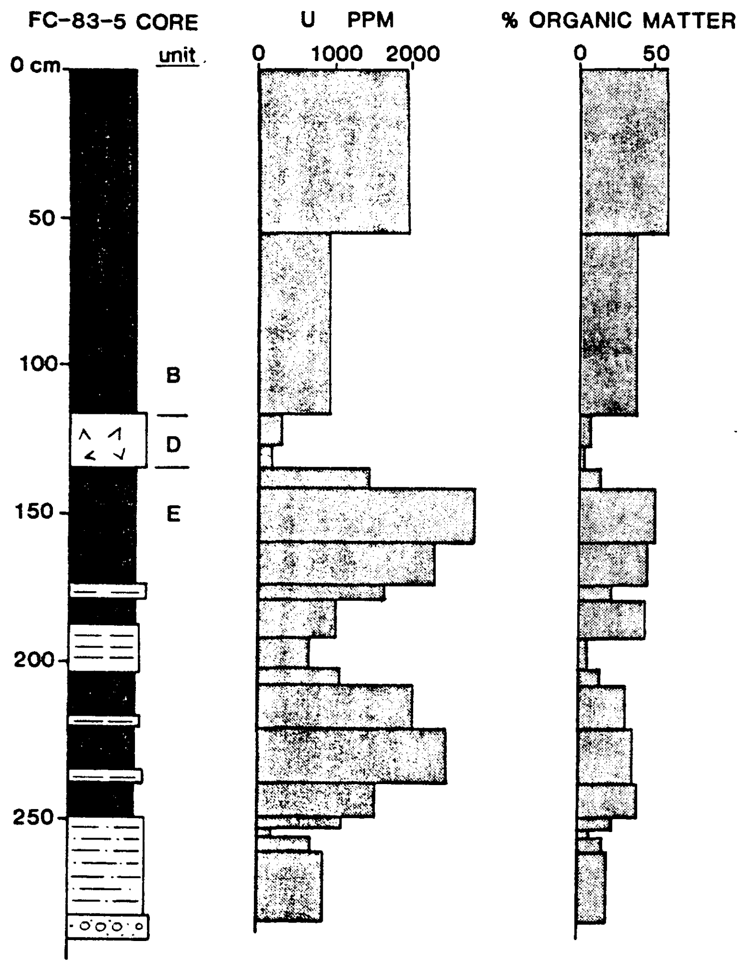

Figure 17. Diagram showing the stratigraphy, uranium concentration, and percent organic matter from core 6 at the spring pool site.

and has undoubtedly served as the uranium donor. Uranium is commonly leached from plutonic rocks to significant depths (Rosholt and others, 1973; Stuckless, 1979). Therefore, the longer a plutonic rock is at or near the surface, the more depleted in uranium it might become. If there was considerable glacial erosion of the bedrock in the drainage basin, then glaciation may have played an important control in development of surficial uranium deposits by eroding near-surface, uranium-depleted granitic rocks and subsequently exposing more uranium-rich rocks at or near to the surface in the leaching environment.

The occurrence of depositional environments containing abundant organic-rich sediments in the drainage basin was critical for concentration of the uranium leached from the Phillips Lake Granodiorite. Nahashima and others (1984) have shown that fixation of uranium in sediments by adsorption and ion exchange is facilitated by organic matter Organic matter may also provide food for sulfate-reducing bacteria which, in turn, may produce reduced sulfur species capable of reducing and fixing uranium and other metals in sediment. For 72 samples from the drainage basin, we obtained a correlation coefficient between uranium and organic matter of 0.86, the strongest correlation between uranium and other elements or components of the system that we noted.

The development of depositional environments suitable for the formation of surficial uranium deposits is also largely due to the glacial history of the drainage basin. Drainage at the spring pool became restricted when unconsolidated till was redeposited as a fan across the valley floor. By locally decreasing the stream gradient, this fan ponded drainage so that considerable fine-grained, organic-rich sediment was deposited and preserved. The broad flat valley floor at the meadow mine site and in the lower part of the valley probably formed by glaciofluvial sedimentation and erosion. These wide, low-gradient valley segments provided broad floodplains for small post-glacial streams and suitable sites for deposition and preservation of organic-rich floodplain sediments. Like the small fan at the spring pool, kames at the lower end of the meadow mine partly restricted drainage and provided a further impetus for deposition of organic-rich sediments.

The broad flat valley segments also provided favorable sites for beaver occupation, whose activities have also had major importance in creating environments suitable for formation of surficial uranium deposits. By damming the small post-glacial stream, beavers could pond a significant area and ensure themselves an adequate food supply. The most organic-rich sediments in and downstream from the meadow mine are associated with sedimentation in beaver ponds, and organic-rich sediments in the meadow mine are currently being extracted as uranium ore.

Glaciation and beaver dams have thus had great importance in the development of surficial uranium deposits in the north fork of Flodelle Creek drainage basin. Similar small drainage basins underalin by felsic to intermediate igneous rock are probably common in northeastern Washington and in other glaciated terranes. Based on the north fork of Flodelle Creek example, the occurrence of surficial uranium deposits in these similar drainage basins seems likely.

CONCLUSIONS

Relict glacial topography and beaver dams have strongly controlled the distribution of Holocene ponds and bogs in the north fork of Flodelle Creek drainage basin. These ponds have been sinks for abundant, fine-grained organic-rich sediment. Uranium that was leached from bedrock sources has precipitated in the organic-rich pond sediment, locally in economic quantities. Processes of pond formation have thus had major influence on the development of surficial uranium deposits in the north fork of Flodelle Creek. The case history provided by this study can be used as an aid in recognition and evaluation of surficial uranium deposits in other areas with similar geologic history.

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