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A Late Quaternary Chronology of Mass Wasting for a Small Valley in the Lemhi Mountains of Idaho

Abstract

Mapping of landforms and collection of relative-age data identified the type and age of late Quaternary deposits attributable to periods of cold climate in a small valley in the Lemhi Mountains. Mass wasting, rather than glaciation, characterized the Holocene geomorphic responses to decreasingly severe cold episodes. Pleistocene responses probably included both glaciation and development of periglacial slope movement over permafrost. Climatic changes were relatively synchronous throughout the Lemhi Mountains, but geomorphic responses differed within individual valleys.

Introduction

The last two decades have seen a remarkable expansion in our understanding of the chronology of glacial and mass-wasting periods in the Rocky Mountains. From the time of Richmond's (1965) classic paper outlining five Pleistocene and two Holocene glacial episodes in the Rockies to the present, research has expanded and refined the number and timing of glacial and cold climatic episodes. Table 1 presents a composite chronology for the Colorado and Wyoming Rocky Mountains, as drawn from a variety of works (Richmond 1965, Pierce *et al.* 1976, Madole 1980, Benedict 1981).

Research in the mountains of Idaho has also expanded our knowledge of the late Quaternary chronology. The Lemhi Mountains of east-central Idaho, approximately 160 km west of Yellowstone National Park, have been a focus of such work in recent years (Fig. 1). Building on the preliminary chronologies of Ruppel and Hait (1961) and Dort (1962), Knoll (1977) produced a detailed composite late Quaternary glacial and mass wasting chronology from four valleys in the Lemhi Mountains. His chronology contains one pre-Bull Lake, three Bull Lake, and nine Pinedale glacial advances. Knoll also documented five separate cold climatic pulses that occurred during the Neoglacial (the last 5000 years) on the basis of both glacial and mass wasting deposits. He correlated these five pulses with the three generally accepted Neoglacial stages of Wyoming and Colorado (Table 1). Recently, Winter (1982) further documented the latest Neoglacial stade through tree-ring analysis, indicating a major treeline retreat in the southern Lemhi Mountains 300 to 500 years BP (before present).

Geographic Setting and Background for the Present Study

The specific study site for the present paper is a short, 1.2 km long, unnamed valley on the eastern side of the central portion of the Lemhi Mountains. The valley is unofficially called the Hilltop Valley, after a mining claim near the valley head (Figs. 1 and 2).

The Hilltop Valley is much shorter than other major valleys in the Lemhi Mountains (Dort 1962, Knoll 1977). It is also relatively narrow, ranging in width from

260 to 300 m. The valley head is a poorly developed and/or preserved natural amphitheater at an elevation of approximately 2700 m above sea level. The base of a large terminal ridge that encloses the end of the valley is at an elevation of about 2350 m, providing a valley gradient of 291 m/km. This gradient is much steeper than in nearby valleys (Knoll 1977, Butler 1982).

The topoclimatic conditions of the Hilltop Valley are not as favorable for glaciation as those found in nearby valleys (Knoll 1977, Butler 1982). The Hilltop Valley is oriented almost exactly North 45° East, about 20° more easterly than an adjacent glaciated

TABLE 1. Comparison of the Composite Glacial Chronology for Colorado and Wyoming with Knoll's Chronology for the Lemhi Mountains of Idaho.

| | | Composite Chronology for the Colorado and Wyoming Rocky Mountains | Knoll's Composite Chronology for the Lemhi Mountains |
|-------------|---|---|---|
| HOLOCENE | Neoglaciation (5,000 BP-Present) | Arapaho (or Gannett) Peak Advance (350-100 BP) Audubon Advance (2,400-900 BP) Triple Lakes Advance (5,000-3,000 BP) | Stade 5 Stade 4 Stade 3 Stade 2 Stade 1 |
| | 10,000 BP-5,000 BP | Ptarmigan Advance (7,250-6,600 BP) Satanta Peak Advance (Approx. 10,000 BP) | No advances recorded |
| PLEISTOCENE | Pinedale Glaciation (35,000-10,000 BP) | 4 (No precise dating for these four advances) 3 2 1 | 9 8 7 (No precise dating for these nine advances) 6 5 4 3 2 1 |
| | Bull Lake Glaciation (Approx. 140,000 BP) | At least two advances | 3 (No precise dating for these three advances) 2 1 |
| | Pre-Bull Lake Glaciations (No firm dates) | Sacagawea Ridge Cedar Ridge Washakie Point | 1 (No precise dating or correlation available) |
| | | | |

valley. The headwall is poorly shaded as well, and its base is almost 200 m lower in elevation than the modestly glaciated valley immediately to the south (Butler 1982).

The Hilltop Valley headwall is composed of Ordovician Kinnikinic quartzite (Hait 1965). This bedrock is somewhat jointed and fractured, with snow accumulating in

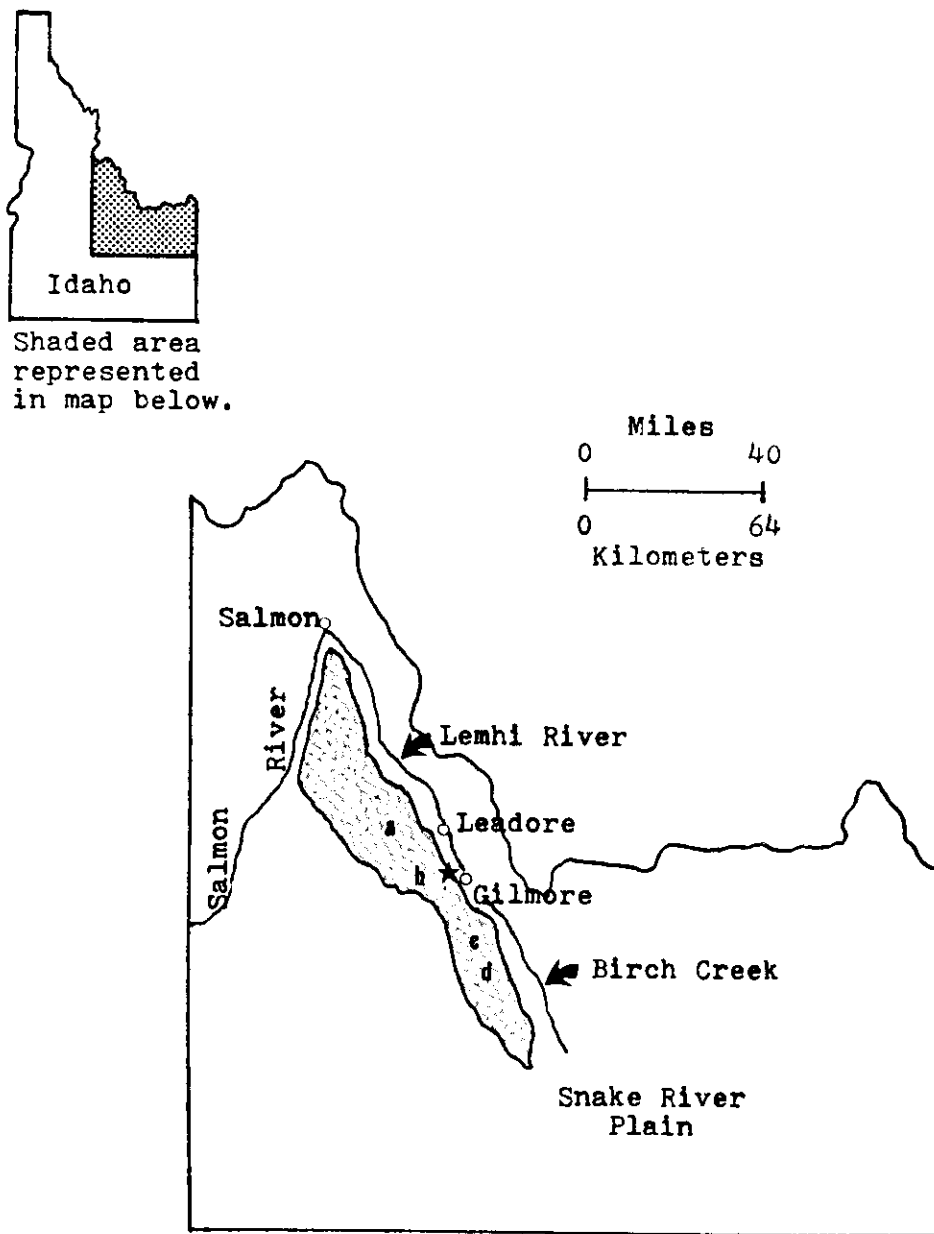


Figure 1. Location of the study area in Idaho. Shaded area in lower map represents the Lemhi Mountains. The star marks the location of the Hilltop Valley. Letters refer to major peaks in the Lemhi Mountains: a, Mogg Mountain; b, Flatiron Mountain; c, Bell Mountain; and d, Diamond Peak.

several large joints and chutes on the headwall. No faults or major structural features are shown for the valley by Hait.

Valley sidewalls are steep, in the range of 25-35°. Forest vegetation is thick on the southeastern valley sidewall. The northwestern (*i.e.*, southeastern-facing) sidewall vegetation reflects more xeric conditions, with a more open forest cover, sagebrush (*Artemisia* spp.), and grasses.

Prior references to the glacial and mass wasting history of this valley are extremely

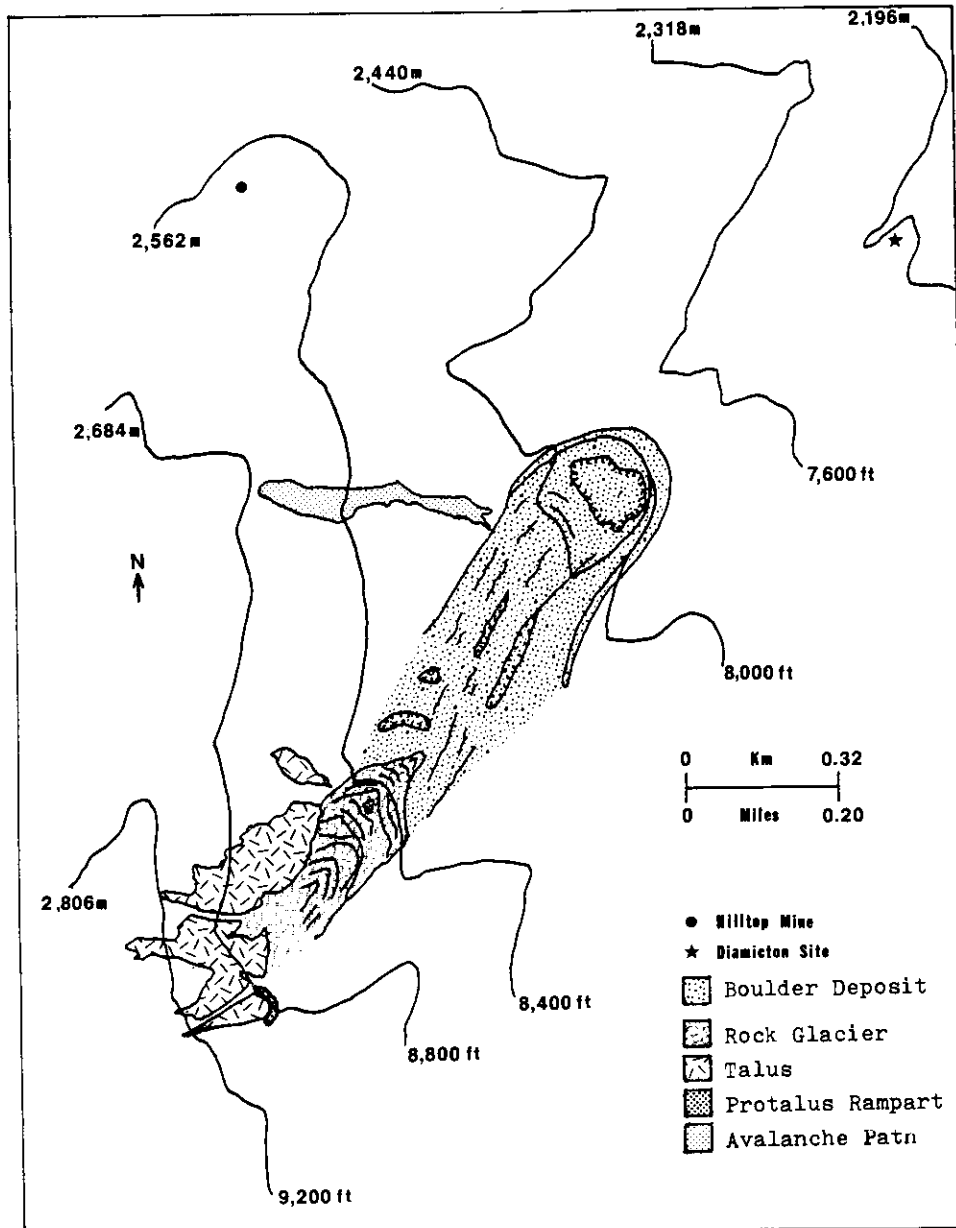


Figure 2. Generalized surficial deposits and landforms, Hilltop Valley, Lemhi Mountains, Idaho.

limited. In his preliminary aerial-photo reconnaissance, Dort (1962) classified the terminal ridge of the Hilltop Valley as "Pinedale moraine," and identified "Little Ice Age and Temple Lake deposits" on the valley floor just below the headwall. The U.S. Forest Service (1965) classified the entire valley as a "glacial trough land." The present study examines the deposits of this valley and describes the late Quaternary chronology of their development. Paleoenvironmental implications of this chronology are also presented.

The valley was chosen for two major reasons: 1) it is close to one of the four valleys studied by Knoll (1977), providing a basis for comparison of results; and 2) its apparent limited level of glaciation suggested that little destruction of deposits from earlier cold episodes had taken place (Dort 1977, iii).

Methodology

In order to determine the chronology of development of landforms attributable to late Quaternary cold episodes, it was first necessary to map their distribution and determine their origins. Field mapping of the landforms and close examinations of their surficial morphology accomplished these goals. Vertical exposures of diamictons were also studied in the field, where available. Data for several relative-age dating (RD) characteristics were also recorded at locations on the surface of the landforms in question. The distribution and origins of the mapped landforms and diamictons are presented in following sections. These discussions include age assignments and development of the late Quaternary chronology of mass wasting and paleoenvironmental change as determined from the mapped landforms (and diamictons) and their RD characteristics.

Description of the Hilltop Valley Boulder Deposit

The major depositional feature located in the Hilltop Valley is a large boulder deposit (Fig. 2). The deposit is a boulder-strewn, unstable mass of ridges, furrows, and large depressions contained behind a massive terminal (80 m high) and lateral ridge (65-70 m high) complex (the ridge referred to as Pinedale moraine by Dort (1962)). The average gradient on the surface of the boulder deposit is 233 m/km. This boulder deposit is interpreted as the remnant of an ice-cored rock glacier (Butler 1982), rather than as Pinedale moraine. It will be referred to as a boulder deposit to avoid confusion with a smaller rock glacier upvalley.

The crest of the terminal ridge of the boulder deposit is the most stable portion of the entire feature. The crestral width ranges from 4-6 m. Lithology (100% Kinnikinic quartzite), stability (relatively firm), and vegetation cover are uniform along the crest of the terminal and lateral ridge complex. Vegetation is a mature, open forest of Douglas-fir (*Pseudotsuga menziesii*) with trunks 1 m in diameter, and 25-30 m tall. Little understory exists, except for low *Juniperus* spp. bushes. Duff is thick in areas of heavier Douglas-fir coverage. Soil development along the crest of the terminal/lateral ridge complex is surprisingly poor. Two excavations on the crest revealed profiles that had, at best, an A2/C profile, with an A2 horizon of no more than a few centimeters depth. At one site on the eastern lateral ridge, the profile did not even exhibit a true A horizon. Rather, the profile had, in the strict sense, an O1/O2/C sequence. Duff content in the O horizons was emphasized by an organic matter content (determined by loss on ignition) of 66 percent.

A major depression exists within the boulder deposit just upvalley from the 80 m-high terminal ridge (Fig. 2). This depression is 30 m deep. The slopes leading into it are unstable and steep, with slope angles of 30° the norm.

The main body of the Hilltop Valley boulder deposit is a mass of jumbled boulders strewn about with little apparent pattern. The debris is coarse and subangular, with a pronounced lack of fines, except in low-lying areas or zones with low slope angles. Rocks in the deposit are large, ranging up to several meters on the a-axis. The deposit has an extremely high porosity attributable in part to the loose packing of the clasts. Lithology of the deposit is 100 percent Kinnikinic quartzite (based on counts of 100 boulders each at five different locations on the deposit).

In addition to the large depression immediately upvalley of the terminal ridge of the deposit, many more furrows (linear depressions) and rounded depressions occur on the surface. Many longitudinal furrows exist on the surface of the deposit, with only two transverse furrows. Ridges occur in the inter-furrow areas. The depth of the furrows (measured from the crest of surrounding ridges) ranges from 2 to 10 m. Some furrows have served as collection areas for fine sediments, and as such, support a vegetation cover, whereas the slopes of others are so steep as to preclude vegetation entirely.

Where vegetation exists on the surface of the boulder deposit, it is the same as that which occupies the crest of the terminal ridge, namely Douglas-fir trees and juniper bushes. Distribution of vegetation in furrow areas was commented on above. In general, ridge crests within the main body of the boulder deposit are stable and support some concentration of Douglas firs and/or junipers.

The Hilltop Valley Rock Glacier

Progressing upvalley from the Hilltop Valley boulder deposit, the next feature encountered is a much smaller, inactive rock glacier (probably formerly ice-cemented). The toe of the rock glacier is located at approximately 2550 m elevation. One hundred-twenty meters higher is the head of the rock glacier at the base of the amphitheater walls that form the head of the Hilltop Valley, a distance of 300 m (Fig. 2).

The toe of the rock glacier rises steeply above the Hilltop Valley boulder deposit at sharp slopes angles of 35-38°. There is an abrupt transition from the boulder deposit to the rock glacier, with a significant topographic rise of 5-8 m.

The rock glacier has surficial morphology typical for such a feature. Several transverse ridges and furrows that assist in recognizing rock glaciers occur on the surface of the Hilltop Valley rock glacier. Toward the southeastern down-valley end of the rock glacier, there is a hint of a longitudinal furrow, a characteristic also common to rock glaciers. Relative relief from the surface of the rock glacier to the bottom of the furrows varies, but is generally 3-4 m. The furrows range from 2-10 m in width. Ridge crests are up to 5 m wide.

Clasts on the surface of the rock glacier vary in size from less than 5 cm to over 1 m on the a-axis. Lithology, as determined by random counts of 30 rocks each at 5 locations, is 100 percent Kinnikinic quartzite.

Fine sediments have collected in the bottom of several of the furrow depressions. No soil is present on inter-furrow slopes or ridge crests, where unstable clasts and large interstices have prevented the accumulation of fines.

It is only within the furrow depressions that surface vegetation occurs on the rock

glacier. Small subalpine fir (*Abies lasiocarpa*) trees, low bushes, and alpine flowers are concentrated in these limited areas. Some small stabilizing patches of low bushes are also located on peripheries of the rock glacier and on low-angle slopes just above the bases of some of the transverse furrows.

One major transverse furrow divides the rock glacier into two distinct topographical components or lobes. This major furrow is 5 m deep and averages 10 m wide.

There is no distinct pit at the head of the rock glacier, a feature that characterizes some rock glaciers (Luckman and Crockett 1978). The rock glacier is contiguous with, and over-ridden by, surrounding talus slopes at the base of the valley headwall and northwestern sidewall. These characteristics suggest that the rock glacier was formerly ice-cemented, rather than ice-cored.

The Hilltop Valley Talus and Protalus Deposits

Talus deposits and protalus features are common in the central Lemhi Range (Knoll 1977). The Hilltop Valley is no exception, with talus covering the base of the valley headwall. A protalus deposit is located below the valley headwall and above the rock glacier.

The protalus deposit on the slope below the valley headwall is a protalus rampart. The rampart is approximately 80 m long, 2 m high, and 3 m wide; it is curved in plan view (Fig. 2). This form of protalus is what Knoll (1977) defined as a protalus loop rampart, subclass single loop.

Field examination of the protalus rampart revealed a coarse, bouldery, unstable landform with virtually no soil development along the rampart crest. Fines have accumulated at the base of the proximal slope of the rampart, allowing establishment of small (4-5 m high) subalpine fir trees. Lithology of the rampart is 100 percent Kinnikinic quartzite.

Talus covers the base of the headwall of the Hilltop Valley and accumulates in positions along the sides of the valley headwall. Morphologically the talus accumulates as cones and sheets, indicative of rockfall, rather than avalanche, origins (according to White (1967)).

The Hilltop Valley talus deposits consist of coarse blocks deposited with few fines. These characteristics also imply a rockfall origin (White 1967). Dead wood is located at the bases of some of the talus sheets, particularly on the northwest side of the headwall, suggesting that snow avalanches pass over the surface of the talus (from snow accumulated in chutes in the valley walls) and transports vegetative materials, but with little apparent geomorphic alteration.

The talus deposits may be divided into two main groups (one of which is shown in Table 2), on the basis of stability, vegetative cover, and percentage lichen cover. The first group, with up to 10 percent lichen cover and some vegetative development (small juniper bushes and subalpine fir), are barely stable to unstable, whereas the second group is extremely unstable, geomorphologically active, and lacking in vegetation or significant lichen cover.

Talus at the base of the valley headwall and northwestern sidewall over-rides the head and side of the rock glacier on the valley floor. A boulder ridge extends from the base of the northwestern sidewall talus toward, and merging into, the rock glacier. This ridge is also being over-ridden by fresh talus on the end at the base of the sidewall.

TABLE 2. Relative-age data for surficial deposits within the Hilltop Valley.

| Deposit/ Landform | Vertical Relief | Distal Slope Angle | Minimum Age as Determined through Tree-Ring Analysis | % Boulders Implanted (a) | Average Degree of Implantation (b) | % Lichen Cover | Stability of Footing |
|---------------------------------|---|---|--|-----------------------------|--|---|--|
| Boulder Deposit | 60-80 m | 33° | 450 years | Ranges from 0% to 100% | Ranges from 10% to 90% | 80-95% | Ranges from firm on terminal ridge to unstable within body of deposit. |
| Ice-cemented Rock Glacier | Varies, 8 m at toe | 35-38° | No Data | Less than 20% | 0% on surface 10-20% in furrows | 60-70% | Barely stable in furrows, barely stable to unstable on surface. |
| Protalus Rampart | 30-200 cm, highest on distal side | Not applicable for dating purposes | No Data | 0% | 0% | 30-45% | Unstable to very unstable and treacherous. |
| Tablis Deposits | Not applicable | Not applicable | No trees present | 0% | 0% | 0% on active talus, up to 10% on recently inactive talus | Very unstable and treacherous, constantly moving underfoot. |

(a) an estimation of how many boulders, in %, were at least partially implanted in a 2m x 3m transect on the surface of the deposit.

(b) determined by excavation of ten boulders greater than 0.3 m in diameter on the surface of the deposit.

Hilltop Valley Snow Avalanche Paths

As noted in the description of talus slopes above, snow avalanches occur on the walls surrounding the head of the Hilltop Valley. One other avalanche path is also located on a slope above the Hilltop Valley boulder deposit (Fig. 2).

Snow avalanches that occur within this avalanche path have cut a distinct swath through the mature Douglas fir forest on the northwestern valley sidewall. The path descends from an elevation of 2684 m to 2538 m. Vegetative conditions within the avalanche path attest to frequent avalanching, perhaps as often as every one to two years (Schaerer 1972).

Chronology of Development of Hilltop Valley Surficial Deposits

A lack of materials suitable for radiocarbon dating within the Hilltop Valley necessitated the use of RD techniques in order to establish periods of deposition or cessation of activity.

Figure 3 summarizes the age assignments of the surficial deposits/landforms in the Hilltop Valley based on the RD data presented in Table 2. A trend of decreasing areal coverage as the present is approached is apparent, a conclusion similar to one reached for surficial deposits in an adjacent valley (Butler 1982). This conclusion in turn implies a trend of decreasing severity of successive cold climatic episodes as the present is approached. The one exception to this conclusion would apparently be the areal extent of Audubon-aged deposits. However, it is likely that the talus deposits attributable to the Arapaho Peak stade have masked evidence of deposits assigned earlier ages, including deposits of Audubon age.

The Hilltop Valley boulder deposit RD characteristics suggest cessation of activity in the early Holocene. The ice cored rock glacier probably developed, however, during the last stade of Pinedale glaciation. Ice-cored rock glaciers are relatively insensitive to climatic changes due to their insulating cover of rubble (Luckman and Osborn 1979), so it is probable that stagnation of the late Pinedale Hilltop Valley rock glacier did not occur until the early Holocene, accounting for the boulder deposit's RD characteristics.

Acceptance of an ice-cemented origin for the smaller rock glacier in the valley permits direct correlation of the rock glacier development with local or regional climatic effects (*i.e.*, the Triple Lakes stade of Neoglaciation (Luckman and Osborn, 1979)). RD characteristics did not distinguish between the two lobes of this smaller rock glacier. However, the fact that two lobes and a large intervening transverse furrow exist on the surface of the rock glacier suggests two periods of movement. The second period of movement (represented by the upper lobe) did not entirely over-ride the lower lobe, implying: either 1) that the lower portion of the rock glacier formed during a more severe climatic period of the Triple Lakes stade than that which resulted in the upper, over-riding, lobe; or 2) inadequate material at the valley head during the period of the second advance prevented a complete over-ride of the lower lobe. Either interpretation accepts the division of the Triple Lakes period into two substades.

Diamicton Exposures Adjacent to the Hilltop Valley

The major geomorphic features within, and on the surrounding slopes of, the Hilltop Valley have been described. However, diamicton exposures of interest, which may shed light on late Quaternary paleo-environmental conditions, exist in immediately adjacent

areas. These exposures and paleoclimatic inferences drawn from them are presented below.

Hilltop Valley Diamicton Site

A bouldery diamicton is exposed in a cut located 750 m beyond the terminal ridge of the Hilltop Valley boulder deposit (Fig. 2). The exposure is rich in quartzite boulders

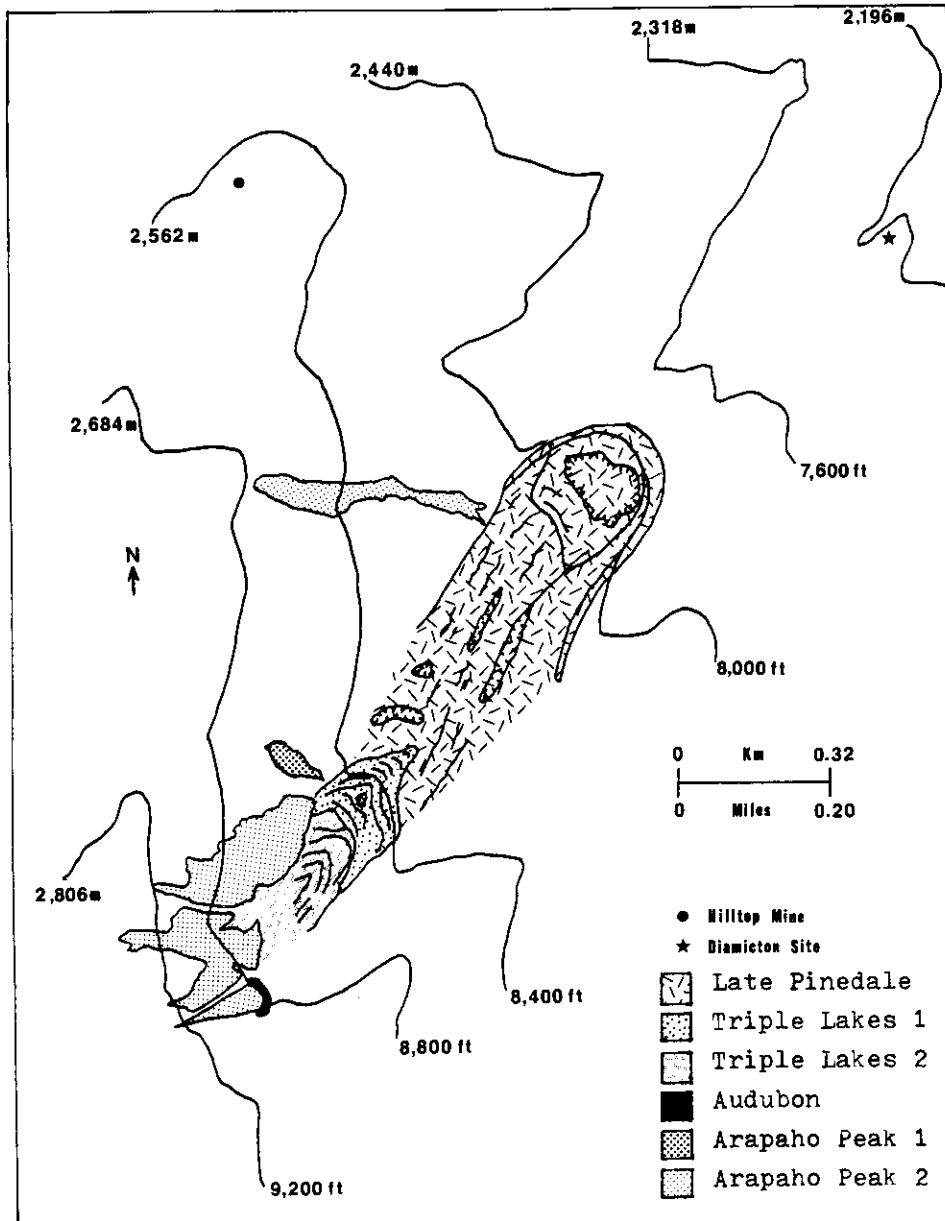


Figure 3. Age assignments of surficial deposits and landforms, Hilltop Valley, Lemhi Mountains, Idaho.

that often have thick white carbonate coatings on their undersides. There is no surficial expression or landform associated with the diamicton deposit.

The Kinnikinic quartzite lithology of the deposit supports a possible glacial origin. However, other processes which would adequately transport quartzite boulders to this location (such as massive landslides, sturzstroms, or rock glaciers) cannot be ruled out.

The thickness of carbonate coatings on the quartzite clasts suggests an old, pre-Bull Lake age for the diamicton. The smoothing of any former surficial expression of the deposit also suggests antiquity. A lack of datable material in the exposure prevents any definite placement of the deposit within a late Quaternary framework.

If the diamicton is attributable to glaciation, the location of the deposit well beyond terminal moraines would not be unusual in the Lemhi Range. Pre-Bull Lake erratics attributed to glaciation (identified by Knoll (1977)) extended much farther from the mountain front than the Hilltop Valley diamicton. Although no firm conclusions can be drawn from the diamicton, it is at least suggestive of pre-Pinedale and Bull Lake glaciation originating in the Hilltop Valley.

Hilltop Mine Site

An interesting stratigraphic sequence is exhibited in a bulldozer exposure adjacent to the Hilltop Mine on a spur of Portland Mountain (Fig. 2). The exposure is approximately 30 m long, and the units revealed extend the entire length of the cut. The slope into which the exposure was bulldozed is steep (27°).

A poorly-developed surface soil up to 15 cm in thickness overlies a diamicton layer consisting of elongated, subrounded, and crudely imbricated pebbles. This layer is 46 m thick and lies at an angle of 29° . The imbricated pebbles provide the unit with the illusion of motion, as if it were slowly moving, perhaps sliding, downslope.

Beneath the imbricated diamicton is a paleosol 5 cm thick; it is powdery and strongly carbonate in nature. Fine purplish-tinted rootlets are concentrated within the paleosol unit.

Under the powdery paleosol is another, even more crudely imbricated pebble unit 11-13 cm thick. The imbrication is more poorly developed and/or preserved than in the unit above the paleosol.

The strong-sloped appearance of both units of imbricated pebbles suggests some sort of periglacial downslope transport or creep, as if an entire unit of rocks had slid downslope over a frozen base. The sloped imbrication is certainly more suggestive of downslope sliding over a frozen surface than mere colluvial creep.

The paleosol in the exposure is strikingly similar to a Pinedale/Bull Lake paleosol described from a number of locations in an adjacent valley (Butler 1982). If the Hilltop Mine paleosol is correlative with that paleosol, as their physical characteristics suggest, the imbricated pebbles overlying the paleosol could be attributed to periglacial downslope creep/sliding during some portion of Pinedale time and the lower imbricated unit to a similar process during the Bull Lake period. With widespread glaciation in the Lemhi Range during Pinedale and Bull Lake times, it is probable that permafrost existed at higher elevations such as the Hilltop Mine Site.

Conclusions

The accuracy of the chronological assignments of deposits within the Hilltop Valley is

considered good, given the constraints of RD data. Accuracy of time assignments in periods earlier than the mid-Holocene is more questionable.

The lack of hard evidence for glaciation in the Hilltop Valley during the Holocene is one important feature of the chronology; another is the apparent lessening severity of Neoglacial stades as the present is approached. Decreasing severity is a trend common in many areas of the central Rocky Mountains (Benedict 1981).

The chronology for the Hilltop Valley and surrounding sites is simpler than the composite chronology developed by Knoll (1977). Even though the Hilltop Valley chronology is less complicated than that derived by Knoll, certain similarities between the two are apparent. For example, both chronologies share a similar pattern during the Neoglacial, although the geomorphic responses to the cold climatic conditions of that period varied somewhat. Two periods of Triple Lakes activity were apparent in the Hilltop Valley, whereas only one glacial period was identified in an adjacent glaciated valley to the south (Butler 1982). It is possible that the presumably milder climate of the Hilltop Valley could not support continuous periglacial conditions and resultant rock glacier development during the Triple Lakes period. Protected and favorably oriented valleys in the Lemhi Mountains may have been able to sustain one complete period of glaciation stretching through the time covered by two periods of rock glacial activity in the Hilltop Valley (and Colorado Front Range; Benedict (1981)). The Audubon and Arapaho Peak stades in the Hilltop Valley and Knoll's valleys produced climatic conditions and geomorphic responses of striking similarity.

Little is known about the Pleistocene climatic events and geomorphic responses in the Hilltop Valley, although diamicton deposits are suggestive of a complex history. More events probably occurred in that valley than show up in the geomorphic record, but how such hypothetical events would match with those described by Knoll (1977) is not known. Presumably, the events in the valleys would match well, such as occurs with the record of the adjacent glaciated valley and the study valleys several kilometers to the south described by Knoll. Late Quaternary climatic episodes and changes were evidently regional in nature in the Lemhi Mountains, although the form and intensity of geomorphic and paleoenvironmental responses varied within individual valleys.

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Literature Cited

- Benedict, J. B. 1981. *The Fourth of July Valley: Glacial Geology and Archeology of the Timberline Ecotone*. Research Report No. 2, Center for Mountain Archeology, Ward, Colorado.
- Butler, D. R. 1982. *Late Quaternary Glaciation and Paleoenvironmental Changes in Adjacent Valleys, Lemhi Mountains, Idaho*. Unpub. Ph.D. thesis, Univ. of Kansas.

- Dort, W. Jr. 1962. Multiple glaciation of southern Lemhi Mountains, Idaho: preliminary reconnaissance report. *Tebiwa* 5: 2-17.
- . 1977. Foreword, in: *Chronology of Alpine Glacier Stillstands, East-Central Lemhi Range, Idaho*, by Kenneth M. Knoll, Idaho State Univ. Museum of Natural History, Pocatello.
- Hait, M. H., Jr. 1965. *Structure of the Gilmore Area, Lemhi Range, Idaho*. Unpub. Ph.D. thesis, Pennsylvania State Univ.
- Knoll, K. 1977. *Chronology of Alpine Glacier Stillstands, East-Central Lemhi Range, Idaho*. Special Publication, Idaho State Museum of Natural History, Pocatello.
- Luckman, B. H., and K. J. Crockett. 1978. Distribution and characteristics of rock glaciers in the southern part of Jasper National Park, Alberta. *Canadian Journal of Earth Sciences* 15: 540-550.
- , and G. D. Osborn. 1979. Holocene glacier fluctuations in the middle Canadian Rocky Mountains. *Quaternary Research* 11: 52-77.
- Madole, R. F. 1980. Time of Pinedale deglaciation in north-central Colorado: further considerations. *Geology* 8: 118-122.
- Pierce, K. L., J. D. Obradovich, and I. Friedman, 1976. Obsidian hydration dating and correlation of Bull Lake and Pinedale Glaciations near West Yellowstone, Montana. *Geological Society of America Bulletin* 87: 703-710.
- Richmond, G. M. 1965. Glaciation of the Rocky Mountains in: *The Quaternary of the United States*, (H. E. Wright, Jr., and D. G. Frey, eds.), Princeton Univ., Princeton.
- Ruppel, E. T., and M. H. Hait, Jr. 1961. Pleistocene geology of the central part of the Lemhi Range, Idaho. *U.S.G.S. Professional Paper* 424-B.
- Schaerer, P. A. 1972. Terrain and vegetation of snow avalanche sites at Rogers Pass, British Columbia, in: *Mountain Geomorphology*, (O. Slaymaker and H. J. McPherson, eds.), Tantalus Research Ltd., Vancouver.
- U.S. Forest Service. 1965. *Land Type Association Map*, Salmon National Forest, Idaho. U.S. Forest Service, Ogden, Utah.
- White, S. E. 1967. Rockfall, alluvial, and avalanche talus in the Colorado Front Range. *Geological Society of America Special Paper* No. 115.
- Winter, M. H. 1982. Upper treeline fluctuation in the Lemhi Range, southeastern Idaho. *AAG Program Abstracts*, Association of American Geographers 78th Annual Meeting, San Antonio, Texas.

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