Glaciation of the Pioneer Mountains: A Proposed Model for Idaho

by

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ABSTRACT

The glacial deposits of three basins in the Pioneer Mountains, central Idaho, have been mapped, and the glacial stratigraphy and history have been determined from those deposits. These three basins, locally known as the Copper Basin, Wildhorse Canyon, and the North Fork drainage, constitute the headwaters of the Big Lost River. Within each basin, two major episodes of glacial advance can be differentiated by relative-dating (RD) criteria, including soil properties and moraine morphology. Second-order events within each glacial advance are subdivided on the basis of moraine position, geometry, and terrace relationships.

To avoid unwarranted long-range correlations with the established Rocky Mountain chronology (Pinedale-Bull Lake) and also to avoid conflicts with the American Commission on Stratigraphic Nomenclature, an informal chronology has been established for each basin, where each RD-separable package of deposits is assigned to an “advance” with local informal names, and where second-order “events” within each “advance” are designated by Roman numerals. To facilitate communication, these “advances” are then correlated to regional “glaciations.” At this time, two major, well-documented glaciations are recognized and informally named in the Pioneer Mountains: the Potholes glaciation (younger) and the Copper Basin glaciation (older). Elevated gravels of assumed glacial origin provide evidence for a third, yet older, glaciation herein named the “Pioneer glaciation.” Additional areas in central Idaho have been tentatively correlated to this glacial model.

Reconstruction of ice deployment shows that glaciation was extensive during the Copper Basin glaciation, when major lobes (herein named the “Copper Basin Lobe,” the “Wildhorse Canyon Lobe,” and the “North Fork Lobe”) developed in each drainage basin. Ice-dammed lakes developed in the Copper Basin Flats and in the canyon of the East Fork of the Big Lost River (herein named “Glacial Lake East Fork”). Catastrophic drainage of Glacial Lake East Fork is documented by the presence of flood-transported boulders well down-canyon from the ice dam.

Ice deployment during the Potholes glaciation was similar but less extensive than during the Copper Basin glaciation. The Copper Basin and Wildhorse Canyon Lobes re-formed, but the three valley glaciers in the North Fork drainage did not coalesce to reconstitute the North Fork Lobe. Glacial Lake East Fork was dammed again, and again drained catastrophically. Deglaciation during the Potholes glaciation featured the progressive retreat of the ice lobes, the breakup into individual valley glaciers, and the readvance of individual glaciers. No moraines younger than the Potholes glaciation have been mapped.

INTRODUCTION

This paper reviews the results of seven years of research on the glacial history and deposits of the Pioneer Mountains of central Idaho (Figure 1).
Detailed mapping, relative age dating, pedologic investigations, provenance analysis, and theoretical glacial reconstructions have been employed to develop a local stratigraphy based on relative-dating (RD) techniques (Birkeland and others, 1979). A stratigraphic model, herein called the "Idaho Glacial Model," is proposed. This model further extends the "Rocky Mountain Glacial Model" of Mears (1974) yet remains independent and dynamic by means of a separate, informal, stratigraphic nomenclature. As the areal extent of detailed investigation grows, the model can be extended, expanded, and correlated with those generated in adjacent areas of the Rocky Mountains.

LOCATION AND BEDROCK GEOLOGY

The Pioneer Mountains and their northeastern extension, the Boulder Mountains, are located in central Idaho, north of the Snake River Plain and east of the town of Mackay. The study area includes about 400 square kilometers on the northern side of the Pioneer Mountain divide in the glaciated headwaters of the Big Lost River. For logistic purposes, three separate but adjacent areas were mapped individually (Figure 1). These areas are known locally as the Copper Basin, Wildhorse Canyon, and the North Fork drainage.

The geomorphologic setting of the area, as evidenced by the high relief, has been greatly influenced by Quaternary glacial and fluvial activity. Most streams in glaciated valleys are underfit, and uplands display classic Alpine-type glaciated features including cols, aretes, horns, and cirques. Hyndman Peak, altitude 3,681 meters, is the highest point in the study area.

The Pioneer Mountains consist structurally of two north-trending elongated domes. These domes are cored by autochthonous Precambrian metamorphic units surrounded by a number of allochthonous, upper Paleozoic elastic units which were emplaced by thrust faulting (Dover, 1966, 1969). During the formation of the Idaho batholith (Cretaceous), small "satellite" intrusive bodies were emplaced in the western Pioneer Mountains. Stratigraphically overlying all of these units are the Challis Volcanics of Tertiary age. These volcanic rocks, consisting of interbedded lava and tuffaceous units, probably blanketed the entire region at one time, but uplift and erosion has resulted in the exposure of underlying units. Tertiary through Quaternary age block faulting is believed to be the cause of this uplift and the present relief (Umpleby and others, 1930; Dover, 1966, 1969).

PREVIOUS WORK

Umpleby and others (1930) and Nelson and Ross (1969) were the first researchers to map and subdivide glacial deposits in the Pioneer Mountains. More recently, Dover (1966, 1969) and Dover and others (1976) mapped and described the surficial deposits as part of a detailed investigation of the stratigraphy and structure of the area.

Mapping by students from Lehigh University has resulted in seven master's theses. These include mapping and provenance analysis in the Copper Basin (Wigley, 1976; Pasquini, 1976), Wildhorse Canyon (Stewart, 1977; Brugger, in preparation), North Fork drainage (Cotter, 1980; Repsher, 1980), and provenance analysis of glaciofluvial terraces (Pankos, in preparation).

In each of the three glacial basins of the northern Pioneer Mountains, glacial and glaciofluvial deposits were mapped and differentiated by employing relative-dating techniques that have been used previously in the Rocky Mountains (Birkeland and others, 1979). In addition, models of ice deployment were developed and reported by Evenson and others (1979), Repsher and others (1980), and Brugger (in preparation).

RELATIVE-DATING (RD) TECHNIQUES

The lack of organic matter suitable for radiocarbon dating and of datable tephras within the glacial deposits has forced us to resort to the application of semiquantitative relative-dating (RD) techniques to subdivide the glacial deposits of the area. Relative dating is based on the premise that weathering parameters are time dependent and therefore can be used to distinguish episodes of deposition (Burke and Birkeland, 1979). As succinctly demonstrated by Burke and Birkeland (1979), a multiparameter approach to relative dating increases the reliability of local till subdivisions and increases the chances of obtaining criteria useful for regional correlation. The parameters utilized for relative dating in the Pioneer Mountains include moraine morphology (number and freshness of ice-disintegration hollows, preservation of original morainic form, and degree of secondary dissection), extent of glaciation downvalley (older moraines are
downvalley or "outside" younger deposits), spatial relationships of moraines and glaciofluvial terraces (terraces are graded to a moraine of the same age and dissect older moraines and terraces), and soil properties (color, structure, texture, carbonate concentrations, clay mineralogy, and soil chemistry).

Relative-dating techniques have been used throughout the Rocky Mountains by numerous researchers (for example, Richmond, 1948, 1965, 1976; Moss, 1949, 1951a, 1951b; Holmes and Moss, 1955; Birkeland, 1964, 1973; Crandell, 1967; Carroll, 1974; Mahaney, 1974; Pierce and others, 1976; Evenson and others, 1979) and have proven extremely useful, on a local level, for the subdivision of glacial deposits. There are, however, problems associated with the formal naming of glacial deposits on the basis of physical features resulting from postdepositional modification (relative dating). As pointed out by Birkeland and others (1979), the problem arises because the "Code of Stratigraphic Nomenclature" currently makes no provision for defining glacial units on the basis of multiple, relative-dating parameters.

The American Commission on Stratigraphic Nomenclature (1970) has approved a variety of classifications (that is, time-, rock-, and soil-stratigraphic units) for the distinction and correlation of Quaternary deposits, but none of them embraces the multiple parameters used in relative-age dating. In each of the code-approved classifications an individually defined parameter must be used to delimit a stratigraphic unit, whereas relative dating relies on the application of multiple parameters which are utilized in other stratigraphic systems. Our use of multiple, relative-dating techniques (for example, both soil and morphologic features) must therefore result in a mixed or "hybrid" stratigraphic classification (Birkeland and others, 1979) not formally recognized by the Stratigraphic Code. However, because RD data does not generate a code-approved stratigraphic classification does not mean that RD-based units cannot be named on an informal or even formal basis (see Burke and Birkeland, 1979). It is important, however, that care be taken to avoid the proliferation of even informal stratigraphic nomenclature. As discussed by Birkeland and others (1979) and Burke and Birkeland (1979), only first-order events (Porter, 1971) are worthy of even informal names.

Following the suggestion of Birkeland and others (1979), we now advocate the use of RD-based units for the glacial deposits of the Pioneer Mountains. Multiple relative-dating techniques have been used in each of the three basins (Copper Basin, Wildhorse Canyon, and North Fork) in the Pioneer Mountains, and in each area different techniques have been shown to be of varying effectiveness in the differentiation of glacial deposits. The RD units developed within separate drainages were then assigned their own informal stratigraphic names. We feel this facilitates communication, avoids conflict with the Stratigraphic Code, and allows correlation between individual basins; however this does not imply age equivalence (as is the case when the same term is extended from basin to basin) where it is not warranted or intended.

STRATIGRAPHIC NOMENCLATURE

The problems associated with stratigraphic nomenclature of glacial deposits in the Rocky Mountains have existed since Blackwelder (1915) used the same terms in a morpho-, time-, and climate-stratigraphic sense (for example, Pinedale moraine or drift, Pinedale epoch, and Pinedale Glacial stage). Since then, researchers in the Rocky Mountains have generally taken two approaches when naming glacial deposits: either the same stratigraphic names (that is, Pinedale) are used over a large area, or new formal names for stratigraphic units are designated for every drainage basin. As Birkeland and others (1979) have stated, the problem with the first approach is that the use of the same name implies (however inadvertently) correlations which are often not substantiated. On the other hand, the use of new formal terms results in both an exorbitant number of terms and confusion for those who are not familiar with the area.

To avoid this problem, Birkeland and others (1979) have suggested using letter designations to differentiate stades or glacial events ("first-order events," for example, Crandell, 1967). We do not feel that letter or number designations are adequate for the delineation of first-order events with obvious morphological and other RD differences as those found throughout the Pioneer Mountains. For example, neither communication nor convenience is served by referring to "Advance A of Wildhorse Canyon" or "Advance B of the Copper Basin." The use of letters is clumsy and stratigraphically invalid, and it implies some correlation. We do agree, however, with this method for identifying second-order depositional episodes (events) within first-order events (advances) and have used a variant of this method (that is, North Fork I, North Fork II, and so on) in the Pioneer Mountains (Wigley and others, 1978; Cotter, 1980). At the same time, we do not favor the continued use and extension of the terms "Pinedale" and "Bull Lake" as this implies
correlation with the type areas of these deposits in the Wind River Range and with other deposits to which these names have been applied.

As our work in the Pioneer Mountains continues it is becoming apparent that an independent, simple, rational classification of relative-dating (RD) defined deposits is required for local and regional correlation. In each of the drainages we have studied, detailed mapping of glacial and glacial-fluvial deposits resulted in the differentiation of two first-order glacial events (and probable evidence of a third) based on the clear separation of deposits through the relative-dating techniques previously discussed. In the past, we (Wigley and others, 1978; Evenson and others, 1979) and others (Nelson and Ross, 1969) have referred to deposits of these first-order events as Pinedale (younger) and Bull Lake (older). Older deposits of assumed glacial origin were also recognized and simply called "Pre-Bull Lake" to indicate antiquity. This system, however, is unacceptable for the reasons already discussed. The nomenclature system we currently favor is the establishment of a set of informal stratigraphic terms for each of the RD differentiable deposits (mapped as moraines and terraces) within a given (local) drainage. The terms till and gravel are avoided because these are rock stratigraphic terms. Mapping of these deposits delimits the first-order glacial events which we call "advances" (that is, Wildhorse Canyon advance, Devil's Bedstead advance, North Fork advance, and the like). Second-order episodes (which we call "events") within these advances are designated by Roman numerals appended to the advance name (that is, North Fork I, North Fork II, and so on) after the suggestion of Birkeland and others (1979). This system yields independent, informal stratigraphic units which can then be correlated with local and regional stratigraphic units. The advantage of this system is that RD-based units can be correlated without the undesirable extension of a stratigraphic term over large areas. If errors in correlation are later detected, the correlation and not the stratigraphic name can be simply and easily changed. This system of naming units and subsequent correlation is an accepted geologic practice which allows the concomitant development of stratigraphic units and unambiguous correlation. The system is flexible and can evolve as new information becomes available.

Admittedly, this system results in a proliferation of stratigraphic terms confusing to persons not thoroughly familiar with the literature of the area. To solve this problem and to aid in communication on a regional basis (within central Idaho), we propose the establishment of regional terms (glaciations) to which local informal units can be tentatively correlated. These regional terms will provide a system, to which local stratigraphies within central Idaho can be correlated, facilitating communication yet avoiding the possible overextension of the terms utilized in the Rocky Mountain Glacial Model. The terms which we propose for this purpose are Potholes glaciation (youngest), Copper Basin glaciation, and Pioneer glaciation (oldest). Using this system it is possible to name advances, subdivide events, and correlate units locally defined by RD criteria and simultaneously have a regional set of terms to which all advances may be correlated (glaciations). Glaciations, advances, and events in turn may then be correlated with other chronologies, such as those used in the Cascade Range, the Central Rocky Mountains, and the midcontinent.

IDAHO GLACIAL MODEL

Table I summarizes the nomenclature we now use for the three drainages we have studied in detail in central Idaho. In addition, it presents our correlation of local units with each other and with the Idaho Glacial Model. The terminology for the North Fork drainage follows that proposed by Cotter (1980). The nomenclature for Wildhorse Canyon and the Copper Basin is new, as is that proposed for regional use within central Idaho.

As shown on Table I, the Idaho Glacial Model recognizes and names three periods (glaciations) of glacial activity. They are called "Potholes glaciation" (youngest), Copper Basin glaciation, and Pioneer glaciation (oldest). The nomenclature for the Idaho Glacial Model is based on deposits in the Copper

Table I. Nomenclature used in the Idaho Glacial Model and correlation with local stratigraphies developed for individual basins.
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Basin where the characteristics of each of the deposits are well displayed. We will begin our discussion of the model by defining the physical characteristics of the deposits of each glaciation, beginning with the youngest.

POTHOLES GLACIATION

Moraines assigned to the Potholes glaciation are easily recognized by their fresh surface morphology. They are sharp crested and kettled and preserve ice-disintegration features that often contain water (Figure 2). Surface-boulder frequencies are very high, and boulders occasionally show ice-scour features. Soils developed on deposits of the Potholes glaciation are weakly developed (Wigley, 1976; Stewart, 1977; and Cotter, 1980) and lack appreciable calcium carbonate (Cca) buildup. The deposits correlated with the Potholes glaciation include those assigned to the North Fork advance by Cotter (1980) in the North Fork drainage and those assigned to the Pinedale glaciation by Stewart (1977) in Wildhorse Canyon and by Wigley (1976) in the Copper Basin. The deposits called “Pinedale” by Stewart (1977) and Wigley (1976) are herein informally renamed “Wildhorse Canyon advance” and “Road Creek advance,” respectively (Table 1). An informal type locality for the deposits of the Potholes glaciation is here designated as the moraine mapped as “Pt-1” by Wigley (1976) on the west side of the Copper Basin in the area of Road Creek (Figure 2).

COPPER BASIN GLACIATION

Moraines assigned to the Copper Basin glaciation are the oldest well-preserved glacial deposits in the study area. Generally, moraines of the Copper Basin glaciation extend 0.5 to 1.0 kilometer further down valley than those of the Potholes glaciation. Moraines of the Copper Basin glaciation are subdued, bulky, and well dissected by tributary streams. Moraine surfaces are irregular but mature in appearance, having filled or breached surface depressions (Figure 2). Surface-boulder frequencies are low to moderate, characterized by scattered, fractured large boulders. Boulder surfaces are well pitted, removing all evidence of ice-scour features. Soils developed on tills of the Copper Basin glaciation are weakly developed, but commonly have a well-developed calcium carbonate buildup (Cca-horizon) at depth (Wigley, 1976; Stewart, 1977; Wigley and others, 1978; Cotter, 1980).

The deposits assigned to the Copper Basin glaciation include those assigned to the Kane advance by Cotter (1980) in the North Fork drainage and those assigned to the Bull Lake glaciation by Stewart (1977) in the Wildhorse Canyon and by Wigley (1976) in the Copper Basin. The deposits called “Bull Lake” by Stewart (1977) and Wigley (1976) are herein informally renamed “Devil’s Bedstead advance” and “Ramey Creek advance” in Wildhorse Canyon and Copper Basin, respectively (Table 1). An informal type locality for the deposits of the Copper Basin glaciation is here designated as the moraine mapped as “BT” by Wigley (1976) on the west side of the Copper Basin in the area of Ramey Creek (Figure 2).

PIioneer GLACIATION

The term “Pioneer glaciation” is here used to
include all deposits of assumed glacial origin older than the deposits of the Copper Basin glaciation. Because the origin, age, and correlation of numerous, isolated deposits within the Pioneer Range and elsewhere in central Idaho are difficult to document, we show these terms with question marks on Table 1. The Pioneer glaciation provides an all-inclusive regional term for this small, but important, group of deposits. In addition, the inclusion of the poorly documented Pioneer glaciation in the Idaho Glacial Model insures that the model has the capacity to accommodate additional glacial deposits older than the Copper Basin glaciation.

Deposits of the Pioneer glaciation are characterized by their elevated position, degree of dissection, and extensive weathering, all of which indicate their antiquity. Because of the isolated distribution, limited extent, and unknown origin of the deposits of the Pioneer glaciation, no detailed description or type area is given for these deposits. In this paper we simply wish to give informal local names to the two deposits, previously mapped as Pre-Bull Lake by Wigley (1976) and Stewart (1977). Herein, we propose the informal names Bellas Canyon advance and Pole Creek advance for the deposits mapped as Pre-Bull Lake by Wigley (1976) and Stewart (1977) in the Copper Basin and Wildhorse Canyon, respectively (Table 1). Deposits of the Pioneer glaciation were not recognized in the North Fork drainage, and subdivision (into events) of the Bellas Canyon and Pole Creek advances is not possible.

COPPER BASIN GLACIATION

Deposits of the Copper Basin glaciation are the oldest well-preserved deposits in the area. These deposits consist of both terraces and moraines. As described previously, moraines of the Copper Basin glaciation are morphologically subdued and quite weathered. Based on morphology alone, moraines within this glaciation cannot be differentiated from one another; however, two distinct glaciofluvial terrace levels provide evidence of at least two separate advances during the Copper Basin glaciation. Moraine geometry suggests that ice deployment was similar during both the Potholes and Copper Basin glaciations, but the extent of ice advance was greater during the Copper Basin glaciation.

Three distinct sources of ice were present in the Copper Basin during the Ramey Creek advance (correlated to the Copper Basin glaciation). An intermontane piedmont complex (the Copper Basin Lobe, Figure 3) was fed from Lake, Muldoon, and Starhope Canyons to the south of the basin and from several small canyons to the west of the basin. The steep topography on the west side of the basin and the constricted valley of the East Fork of the Big Lost River to the northwest caused the ice to expand eastward onto the area locally known as Copper Basin Flats and upcanyon into the lower reaches of Corral Creek.

A second area of ice accumulation in the Copper Basin was located east of the piedmont complex, in Anderson, Smelter, Steve, Charcoal, and Coal Canyons. The glacial history of these drainages consists wholly of isolated valley glaciers.

The third area of ice accumulation and outflow was in Corral Creek (the Corral Creek Lobe), a southwest-oriented valley. Ice advance was restricted by the unfavorable orientation of the valley, but during the Ramey Creek advance, ice from the Copper Basin Lobe and from the Corral Creek Lobe met, as documented by provenance data (Evenson and others, 1979). This confluence of ice dammed a large ice marginal lake (Figure 3) in the Copper Basin Flats as shown by thick lake clay underlying the flats.

In Wildhorse Canyon and the North Fork drainage, the geometry of Devil's Bedstead and Kane advance moraines indicates more extensive glaciation
than during the ensuing Wildhorse Canyon and North Fork advances, but at no time did the glaciers expand beyond the confines of the valley walls. Glaciers in these drainages are much narrower due to the confining topography.

In the drainage of Wildhorse Creek, the three principal trunk glaciers from Wildhorse, Fall, and Left Fork Canyons coalesced to form the Wildhorse Canyon Lobe that flowed northward into the East Fork Canyon to deposit moraines of the Devil's Bedstead advance (Figure 3). The occupation of this portion of East Fork Canyon occurred numerous times during the Pleistocene, and each time it resulted in the damming of westward flowing drainage from the Copper Basin and in the forming of a lake (Evenson and others, 1979; Stewart, 1977). This lake is herein named “Glacial Lake East Fork” (Figure 3). Although individual lake levels cannot be distinguished, ice-rafted boulders and deltaic gravels well above the present canyon floor indicate lake depths of up to 120 meters. Because this lake was dammed by an active ice margin, minor retreats of the terminus of the Wildhorse Canyon Lobe resulted in rapid or catastrophic drainage of the lake waters. Large erratic boulders located well beyond the extent of glaciation, which caused early researchers some confusion (Umpleby and others, 1930, Figure 4), are presently believed to have been deposited by jokulhlaup activity. Lakes were dammed in the East Fork Canyon not only during the Devil's Bedstead advance (Copper Basin glaciation correlative) but also during the Wildhorse Canyon advance (Potholes glaciation correlative).

In the North Fork drainage only scattered remnants of Kane advance moraines (Copper Basin glaciation) are preserved. Provenance data (Cotter, 1980; Repsher, 1980) suggest that the three principal trunk glaciers originating in North Fork, Summit, and Kane Canyons coalesced and flowed northwest as a complex valley glacier. The geometry of the younger North Fork advance moraines shows that this coalescence (to form the North Fork Lobe) occurred only during the Copper Basin glaciation (Figure 3).

POTHOLES GLACIATION

Moraines of the Potholes glaciation are morphologically fresh and little weathered. Although no absolute proof can be offered in the Pioneer Mountains, the Potholes glaciation correlatives (Road Creek advance, Wildhorse Canyon advance, and North Fork advance) are assumed to represent a major climatically controlled, widespread glacial event that was temporally distinct from the Copper Basin glaciation correlatives. This belief is based on the marked contrast in relative-dating parameters exhibited by deposits assigned to the Copper Basin and Potholes glaciations.

Moraines assigned to the Potholes glaciation are numerous, and all are located upcanyon from moraines of the Copper Basin glaciation, documenting that glaciation was less extensive during the Potholes glaciation. Well-developed moraines and paired terraces document four distinct depositional events during the Potholes glaciation throughout the Pioneer Mountains (Table 1). Moraines of this glaciation, although indistinguishable from each other on the basis of morphological or weathering characteristics, can be differentiated on the basis of the basis of downvalley position and their relationship to terrace levels. Several moraines were deposited by readvances, as shown by provenance data, cross-cutting relationships, and moraine geometry (Evenson and others, 1979; Brugger, in preparation, but it is unknown whether most moraines represent a single, continuous deglaciation or a series of retreat and advance events to successive upvalley ice-margin positions.

Moss (1974) has discussed the relationship between glaciofluvial terraces and moraines in Wyoming. He found a genetic relationship between moraine positions and terrace levels graded to them, and he has implied synchronicity of glaciofluvial terrace deposition and associated moraine construction. In the Pioneer Mountains, the terrace gravels are assumed to be glaciofluvial in origin and formed during periods of glacial advance or stillstand. Conversely, downcutting and the attainment of a new terrace level is assumed to be associated with deglaciation and interglacial conditions. Terrace levels were therefore extremely useful in differentiating moraines of the Potholes glaciation and in correlating events from basin to basin.

Four separate moraine complexes of the Potholes glaciation are correlated throughout the Pioneer Mountains. Moraines of the Road Creek I, Wildhorse Canyon I, and North Fork I events (considered as terminal moraines of the Potholes glaciation) are located furthest downvalley but are associated with outwash gravels only in the Copper Basin Flats. No terraces of this advance are preserved in the constricted valleys of Wildhorse Canyon or the North Fork drainage, which served as the only drainage path for meltwater. The existence of Glacial Lake East Fork, between Wildhorse Canyon and the Copper Basin (Figure 4), precluded the formation of a terrace graded to the Road Creek I moraines of the Copper Basin. Downstream from the Wildhorse Canyon I and North Fork I moraines, the Big Lost River Canyon is narrow; consequently
later terrace-forming events and jökulhlaups from the lake dammed in the East Fork could easily remove or bury all traces of the earlier terraces.

The highest continuous terrace in the Pioneer Mountains cuts through the outermost (oldest) moraines (Road Creek I, Wildhorse Canyon I, and North Fork I) correlated with the Potholes glaciation and grades to moraines farther upvalley. The moraines that grade into this upper terrace are assigned to the Road Creek II, Wildhorse Canyon II, and North Fork II events, and as these moraines all grade to the same terrace level, they can be conclusively correlated. In the same manner, moraines further upvalley that grade to a lower terrace which developed in all three drainage basins are assigned to the Road Creek III, Wildhorse Canyon III, and North Fork III events and are also explicitly correlated.

All moraines upvalley from those graded to the lower continuous terrace are arbitrarily assigned to the Road Creek IV, Wildhorse Canyon IV, and North Fork IV events. These moraines are restricted to the individual source canyons and are associated with limited terraces that cannot be traced continuously between adjacent canyons. No exact correlation of these deposits is possible. It is likely that some moraines were formed after ice had disappeared from lower cirques.

In the Pioneer Mountains, ice deployment in the advances correlated with the Potholes glaciation was similar to ice deployment during the Copper Basin glaciation, but less extensive. In the North Fork drainage, North Fork I ice margins of the three principal valley glaciers (Figure 4) were located about 1 kilometer upvalley from the inferred Kane advance terminus (Figure 3). The three trunk glaciers did not coalesce, but they were in contact with each other, as shown by moraine geometry (Cotter, 1980) and provenance data (Repsher, 1980).

In the Wildhorse Canyon area (Figure 4), ice again expanded into the canyon of the East Fork of the Big Lost River during the Wildhorse Canyon I event, again impounding Glacial Lake East Fork by damming drainage from the Copper Basin. The depth and extent of the lake which formed during this time was probably similar to the lake which existed during the Devil's Bedstead advance; however, the lack of well-developed strandlines prevents an accurate reconstruction of the varying lake stands. The frequency of jökulhlaup activity probably reached its peak during the Wildhorse Canyon I advance, as only minor fluctuations in ice margin position would be required to initiate impoundment and release of the waters of Glacial Lake East Fork.

In the Copper Basin, a large intermontane piedmont lobe—the Copper Basin Lobe—fed by catchment areas to the south and west again formed during the Road Creek I event (Figure 4). The geometry of Road Creek I moraines shows that ice did not extend very far northwestward into the East Fork Canyon, nor did the piedmont lobe spread eastward onto the Copper Basin Flats. It was during the Road Creek I that the moraine locally known as "the Potholes" was deposited. This moraine (Figure 2) succinctly illustrates the morphologic characteristics of the moraines of the Potholes glaciation.

Local glaciers developed in Coal, Charcoal, Steve, Smelter, and Anderson Canyons to the east of the piedmont lobe. The glacial history of these canyons during the Road Creek advance (Potholes glaciation) is similar to the history during the Ramey Creek advance (Copper Basin glaciation) and consists solely of isolated valley glaciation. The record of deposits in most of the canyons is incomplete, but it is well displayed in Anderson Canyon. An isolated glacier also existed in Corral Creek, but it did not meet ice moving upvalley from the piedmont lobe as it did during the Ramey Creek advance.

Moraines assigned to the North Fork II, Wildhorse Canyon II, and Road Creek II events can be correlated on the basis of their association with the upper continuous terrace, as discussed earlier. During this advance, ice margins were located farther upvalley than during earlier advances, but the pattern of ice deployment was similar (Figure 5). In the North Fork drainage, none of the three trunk glaciers were in contact. In Wildhorse Canyon, ice did extend to the East Fork Canyon, but there is little evidence that drainage from the Copper Basin was dammed. In the Copper Basin, the Copper Basin Lobe still existed, but it was not as large in areal extent or in volume as it had been during previous advances.

Ice continued to retreat and then may have readvanced during the North Fork III, Wildhorse Canyon III, and Road Creek III events. Ice deployment was relatively unchanged in the North Fork drainage but radically different in the other two basins (Figure 6). The glacier occupying Wildhorse Canyon had split into at least two separate glaciers, leaving Wildhorse Canyon III moraines at the junction of Wildhorse Creek and Fall Creek and at the mouth of Left Fork Creek.

Provenance data and moraine geometry (Brugger, in preparation) reveal that ice from the upper reaches of Wildhorse Creek expanded into lower Fall Creek Canyon, suggesting that the Wildhorse Canyon III event may have been a readvance.

The piedmont lobe in the Copper Basin had split into six individual glaciers by the time the Road Creek III moraines had been formed. Moraine cross-cutting relationships and provenance data suggest
that ice from Lake Creek and perhaps Broad Canyon readvanced and crossed the main drainage channel (Pasquini, 1976; Evenson and others, 1979). There is no evidence whether the remaining glaciers readvanced or simply melted back to their Road Creek III positions.

Moraines assigned to the North Fork IV, Wildhorse Canyon IV, and Road Creek IV events are restricted to the source canyons and cannot be reliably correlated. The record of glaciation during these advances is probably incomplete, as no moraines are preserved in some major canyons, while abundant moraines are preserved in adjacent canyons. It is believed that the duration and timing of the deposition of these late moraines may have varied from valley to valley. Therefore, the correlation of these moraines must be considered tenuous at best.

**YOUNGER DEPOSITION EVENTS**

Deposits younger than the Potholes glaciation in the Pioneer Mountains appear to consist entirely of alluvium, alluvial fan, rock slide, talus, and rock-glacier deposits. We currently recognize no moraines younger than the Potholes glaciation. At this time, insufficient evidence exists to subdivide the depositional events younger than the Potholes glaciation; therefore, we make no attempt to do so.

**CORRELATION OF OTHER STUDY AREAS WITH THE IDAHO GLACIAL MODEL**

Glacial deposits have been mapped in detail in...
only a small portion of central Idaho. Early researchers focused primarily on bedrock geology and economic deposits; consequently, surficial geology was mapped only when necessary. Descriptions of moraine morphology are brief, and when correlations were made, they were to the Midwest chronology, such as Wisconsinan or Nebraskan. Several researchers, however, have completed projects in central Idaho during the past thirty years using the nomenclature of the Rocky Mountain Glacial Model (Mears, 1974) with some modification. These chronologies are here reviewed and tentatively correlated with the Idaho Glacial Model (Table 2). We recognize that these correlations are tentative at best and that they will require a great deal of detailed work to substantiate them.

Williams (1961) mapped deposits in the southern part of the Stanley Basin and adjacent highlands. He describes deposits of four separate ages: Pre-Bull Lake till found in isolated patches on ridge crests east and north of the basin, Bull Lake and Pinedale moraines on the floor of the basin, and Neoglacial rock glaciers in the cirques of the Sawtooth Mountains. On the basis of Williams' description of the units and reconnaissance investigations during two field seasons, we suggest a correlation of Williams' Pinedale and Bull Lake glaciations with the Potholes glaciation and Copper Basin glaciation, respectively, of the Idaho Glacial Model (Table 2).

In a similar study, Schmidt and Mackin (1970) also mapped Pinedale and Bull Lake moraines in Bear Valley and the surrounding area. Published descriptions and reconnaissance investigations also suggest correlations between Pinedale and our Potholes glaciation and between Bull Lake and our Copper Basin glaciation (Table 2).

Knoll (1977) made a detailed study of deposits in four small canyons in the Lemhi Mountains, north of our study area. He correlated his deposits with the Rocky Mountain Glacial Model. He also attempted to subdivide second-order events (stadials) and correlate these with the stades in the Rocky Mountain Glacial Model. Knoll found one to three stadials in one stade of Sacagawea Ridge, two to three stadials in two to three stadials of Bull Lake, nine stadials in three stadials of Pinedale, and five stadials in three stadials of Neoglacial events. From published descriptions we suggest a correlation between the Pinedale of Knoll and our Potholes glaciation and between his Bull Lake and our Copper Basin glaciation. No correlation can be made between his second-order events and the second-order events of the Pioneer Mountains (for example, Wildhorse Canyon II), because the number of events may vary depending on the definition each researcher uses and also on the number of events actually preserved in each canyon. Knoll's Sacagawea Ridge has no exact match in the Pioneer Mountains, as no moraines older than those correlated to the Copper Basin glaciation have been found. At this time, the moraines Knoll mapped as Sacagawea Ridge and the Pre-Bull Lake till that Williams (1961) describes are correlated with our Pioneer glaciation.

The remaining area in central Idaho that has been studied in detail is the area near McCall at the north end of Long Valley. The original mapping was done by Schmidt and Mackin (1970). They found evidence for four distinct ages of deposits: a Pre-Bull Lake moraine, Bull Lake and Pinedale moraines, and a Neoglacial rock glacier. They did not divide each group of deposits into second-order events, although reconnaissance data suggest that this is possible. Their stratigraphy has been modified by Colman and Pierce (1981) who defined an additional advance between the Pinedale and Bull Lake moraines on the basis of the thickness of basalt weathering rinds. By making a correlation between the Bull Lake of the McCall area and the Bull Lake moraines of the West Yellowstone Basin, which are dated by obsidian hydration (Pierce and others, 1976), to calibrate their basalt-weathering curve, Colman and Pierce obtained approximate dates of 20,000 years for the Pinedale moraines, 60,000 years for the intermediate moraines, and 140,000 years for the Bull Lake moraines. The oldest moraine could not be dated by this method. They estimated a 10 to 20 percent error in their ages due to error limits on the weathering-rind-thickness data.

Based on the published descriptions of the Long Valley units and also on reconnaissance mapping, we would correlate the Pinedale moraines with our Potholes glaciation, and the Bull Lake moraines

### Table 2. Correlation of time stratigraphic chronologies used in Idaho with the Idaho Glacial Model.

<table>
<thead>
<tr>
<th>Idaho Glacial Model</th>
<th>Stanley Basin</th>
<th>Bear Valley</th>
<th>Lemhi Mountains</th>
<th>Long Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Bull Lake</td>
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<td></td>
</tr>
<tr>
<td>Pinedale</td>
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<tr>
<td>Copper Basin</td>
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</tr>
<tr>
<td>Potholes</td>
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<tr>
<td>Pioneer</td>
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</tbody>
</table>

*Note: Table adapted for clarity and to fit the context.*

...
with our Copper Basin glaciation. No known analog of the intermediate moraines exists in the Pioneer Mountains, and no correlation can be made. On the basis of surface morphology, the intermediate moraine is similar to the Bull Lake moraines and may thus be correlated with the Copper Basin glaciation. Alternatively, the intermediate moraine may represent a separate glaciation not as extensive as the Potholes glaciation and thus not preserved in the Pioneer Mountains. Further study will be needed to resolve the status of the intermediate moraine.

CONCLUSIONS

The drainages of the northern Pioneer Mountains have been modified by at least two and perhaps three episodes of glaciation. The two younger, well-documented glaciations are represented by multiple moraine complexes. These moraines have been differentiated by relative-age dating techniques (moraine morphology, pedogenic characteristics, extent of glaciation, and terrace associations) and have been grouped into two informal units: the Potholes glaciation (younger) and the Copper Basin glaciation (older). Isolated high gravels of assumed glacial origin are assigned to the Pioneer glaciation (oldest). Accurate correlation between basins, combined with provenance and moraine geometry, has allowed reconstruction of modes of ice-deployment of two principal glacial episodes (Potholes and Copper Basin glaciation) and also resulted in the development of a detailed deglaciation chronology of the Potholes glaciation within the Pioneer Mountains.

The relative-age stratigraphic nomenclature developed for this study provides a regional standard (the Idaho Glacial Model) to which local stratigraphies may be compared and correlated. As the Idaho Glacial Model continues to be extended it can be correlated to other regional stratigraphies. The Rocky Mountain Glacial Model (Mears, 1974) may then be expanded to include these intra-correlated regional stratigraphies without over-extending the terms Pinedale and Bull Lake. It is not possible, at this time, to correlate deposits in this study area with the stratigraphic units of the Rocky Mountain Glacial Model at their type localities in the Wind River Range, Wyoming. However, deposits of the two advances mapped in the Pioneer Mountains (Potholes and Copper Basin glaciations) have been accurately correlated from basin to basin in the Pioneer Mountains and have been tentatively correlated with other regions of Idaho.

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