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The Glacial Geology of the North Fork of the Big Lost River, Custer County, Idaho: A Pedologic Approach.

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The Glacial Geology of the North Fork
of the Big Lost River,
Custer County, Idaho: A Pedologic Approach

by

James F. P. Cotter

A Thesis
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Dec 12, 1980
(date)

Professor in Charge

Chairman of Department

DEDICATION

This study is dedicated to my parents, Dr. and Mrs. C. Francis Cotter, in thanks for the many years they have lovingly and patiently encouraged me during my education.

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation to Dr. Edward B. Evenson, Dr. Bobb Carson, and Dr. James Parks for their guidance and sound advice during the past years. Special thanks is also due to Dr. Torre Vorren, Mr. Keith Brugger, Mr. Jack Ridge, and Mr. James Henry Zigmont for invaluable discussion of several issues that were to some degree controversial. Invaluable field assistance was supplied by Mr. Frank Neher, Jack Ridge, Fred Haines, Vince Petrobon, and George Thomas; to these people I extend my deepest thanks.

My family, the Politi's and the Cotter's, provided unending and untiring support during the period of this study, and for this, I thank them all warmly, with my love. It is to my wife, Adele, however, that I extend my greatest thanks; for the patient, kind, and understanding love and support she has given me. Without her, this study would never have been completed.

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ABSTRACT

The drainage of the North Fork of the Big Lost River includes three principal trunk streams and their tributaries in the Pioneer and Boulder Mountains of south-central Idaho. The study area (275 km^2) forms a large portion of the drainage of the Big Lost River and is located approximately 68 km north of the Snake River Plain.

Deposits of two extensive glaciations, and one period of restricted glacier advance (or periglacial activity), have been mapped and tentatively correlated within the area. A relative age stratigraphy and stratigraphic nomenclature (Birkeland, et al., 1979) unique to this area was developed and informally used for this study. The two periods of glacial activity were designated; the "Kane Advance" and the "North Fork Advance". A younger phase, largely a period of periglacial activity, was described and designated "Neoglacial". Although direct correlation has not been accomplished, these deposits are probably correlatives of the deposit, assigned to the "Bull Lake", "Pinedale", and "Neoglacial" glaciations in adjoining areas of the Pioneer Mountains. It is impossible at this time to correlate the deposits in the Pioneer Mountains with deposits in the Wind River Range, Wyoming; but by applying the methods and stratigraphic constraints used elsewhere in the Rocky Mountains, the Rocky Mountain Glacial Model has been further extended to this region of Idaho.

Field relationships of Kane Advance and North Fork Advance deposits demonstrate that the differentiation of terminal moraines can be accurately accomplished by using morphologic and pedologic (qualitative) parameters. Recessional moraines of a single glaciation can be differentiated by association with glaciofluvial terraces and by glaciation extent rather than morphologic parameters.

Pebble lithology provenance studies aided in the reconstruction of the geometry of the three mutually independent trunk glaciers that existed in the area. During the Kane Advance, these three ice streams coalesced to form one composite valley glacier. During the North Fork Advance, the maximum extent of glaciation was considerably less, and only the termini of two of the ice bodies contacted each other.

Soil analysis has shown that clay mineral alterations are occuring in soils in tills of both advances, although clay mineral variation showed no consistant variation with either depth or age. It is possible that cryoturbation and/or solifluction during cooler (Neoglacial?) periods subsequent to the deposition of the moraines studies, resulted in the "erasing" of previously formed alteration products. It is also possible, however, that climatic conditions were such that pedogenesis did not occur until after all moraines were deposited, or that soils have reached a "terminal grade" of development. Until other quantifiable pedogenic parameters have been studied, regional correlations of glacial deposits of the Pioneer Mountains will be difficult.

INTRODUCTION

Objectives

This project was designed to continue the mapping of glacial and surficial deposits in the drainage of the Big Lost River in south-central Idaho. The study area includes those areas drained by the North Fork of the Big Lost River. Deposits in the area afforded an excellent opportunity to extend the glacial model of the Pioneer Mountains as developed by Wigley, et al. (1978), Evenson, et al. (1979), Stewart (1977), Wigley (1976), and Pasquini (1976) to an adjacent, yet separate, area. The field and laboratory studies by Lehigh University faculty and students on glacial deposits in the Big Lost River watershed has led to a greater understanding of Alpine-type glaciation in the Idaho Rocky Mountains, and a more accurate model of the relative chronology and provenance of glacial deposits in the Pioneer Mountains.

This study consisted of two phases. The first phase included eight weeks of field mapping and sampling. The second phase of the study included laboratory analysis of soil clay mineralogy and pebble lithologies in an attempt to determine: a) relative age of the various morainic deposits; and b) provenance of deposits and the flow direction of the ice stream which deposited them.

Location and Geomorphic Environment

The study area includes approximately 275 sq. km in the Pioneer Mountains of Custer County, Idaho (Figure 1). The confluence of Summit Creek and the North Fork of the Big Lost River is some 53 km south-southwest of Mackay, Idaho and 30 km north-northeast of Ketchum, Idaho.

The two major trunk streams in the study area are the North Fork of the Big Lost River and Summit Creek (Figure 2). Summit Creek drains northeastward from the divide that separates the Trail Creek and Big Lost River water sheds (Figures 1 and 2). Glaciated valleys tributary to Summit Creek include: Park Creek, Little and Big Falls Creeks, Phi Kappa Creek, and Kane Creek Canyons, and two unnamed canyons (Figure 2). Although there are many streams tributary to the North Fork of the Big Lost River, only Corral Creek, Miller Creek, Squibb Creek, and Bear Creek Canyons (Figure 2) have been glaciated. This is due to the northwestward decrease of summit altitudes and the greater frequency of south facing zones of accumulation (Plate 1).

The geomorphologic setting of the study area has been greatly influenced by Quaternary fluvial and glacial activity. Streams in glaciated valleys are often underfit and uplands display classic Alpine-type glaciation features such as cols, aretes, horns, and cirques. Elevations in the study area range from 2,360 m along the North Fork, in the northeast corner of the area, to 3955 m above Kane Canyon.

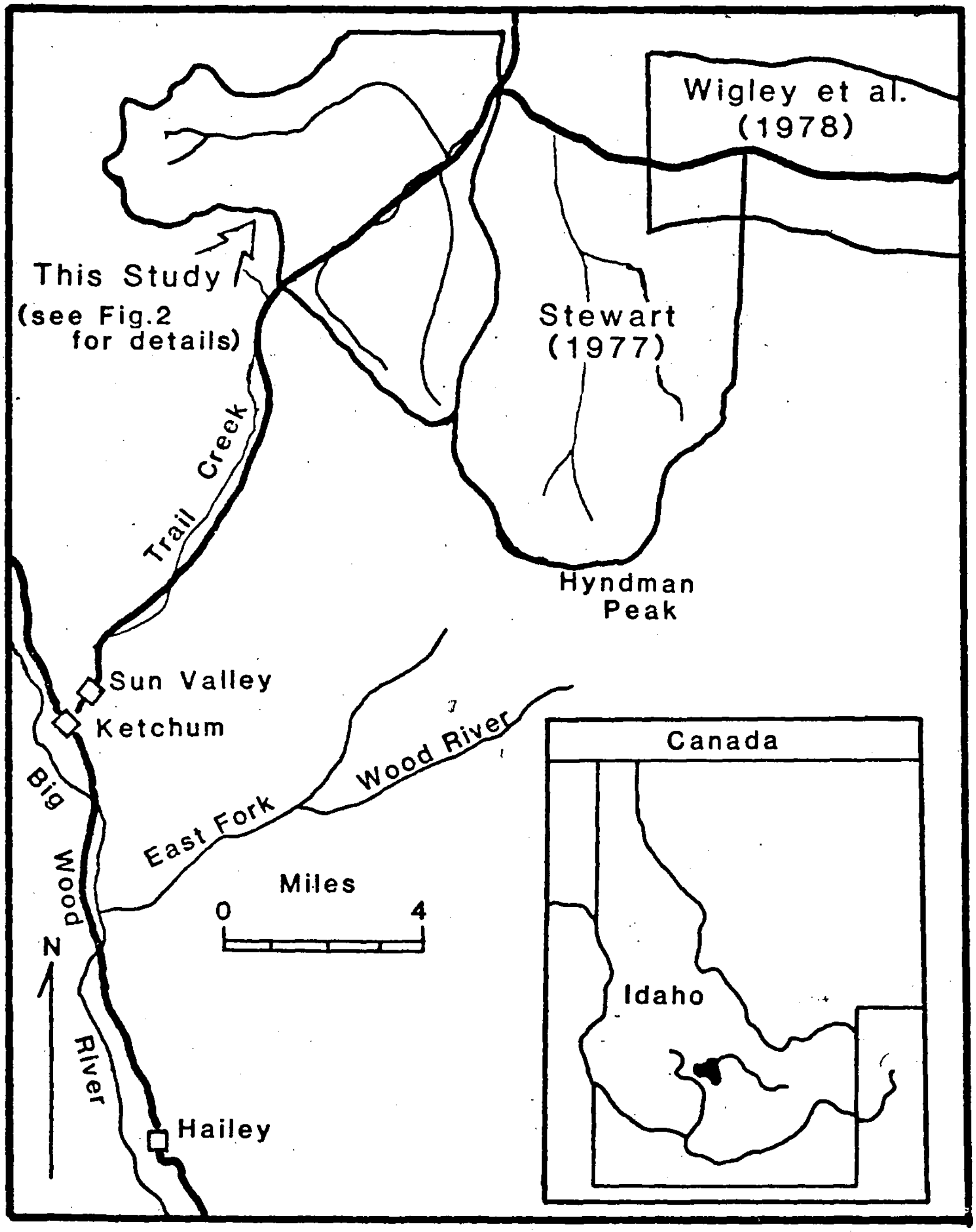


Figure 1. Location map of the study area. Also shown are other investigations in the area by Lehigh University faculty and staff.

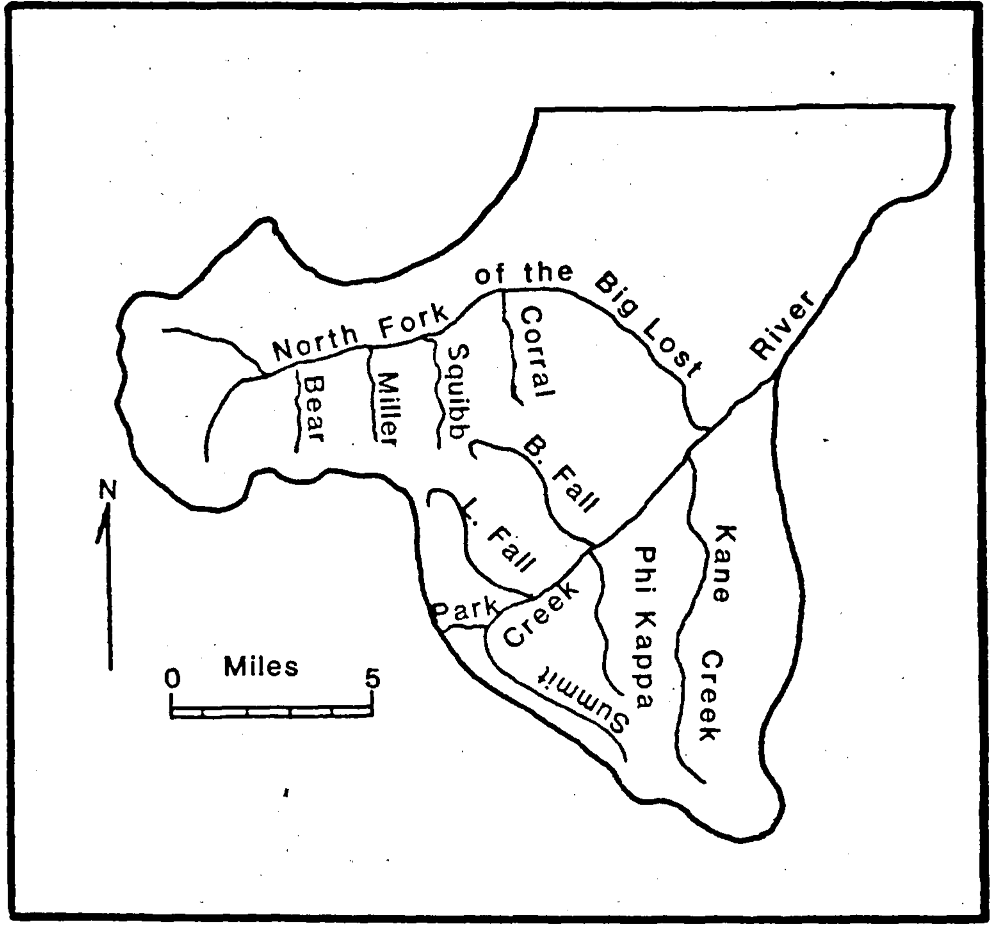


Figure 2. Major glaciated drainages of the study area (see Figure 1 for location).

Although glaciation has influenced topographic relief (1600 m), the origin of the rugged topography of the Pioneer and Boulder Mountains has not been resolved (Dover, 1969). Umpleby, et al. (1930) have suggested high angle faulting as the cause, specifically Tertiary to Quaternary block faulting; pointing out the importance of structural control of drainage.

Bedrock Geology

The study area is underlain by an extremely diverse bedrock geology, characterized by complex structural elements and numerous lithologies of varying ages. Most of the bedrock lithologies are represented by clasts of varying sizes in glacial deposits. Due to the complex nature of the geology, part of the field work for this project was dedicated to the familiarization with exposed lithologies for provenance studies.

Generalized bedrock geology of the study area is presented in Figure 3 according to lithology rather than individual formations. For clarity, all lithologies in the area have been grouped into four lithologic types, distinguished readily in the field. "Lithology M" consists of all crystalline Precambrian units (including the Wildhorse Migmatite Gneiss Complex) as well as the East Fork and Hyndman Peak Formations. "Lithology I" consists of Cretaceous quartz monzinite intrusives "Lithology C" groups the carbonate/clastic lithologies of the Copper Basin Group. "Lithology V" consists of rocks assigned to the Challis Volcanics. The follow-

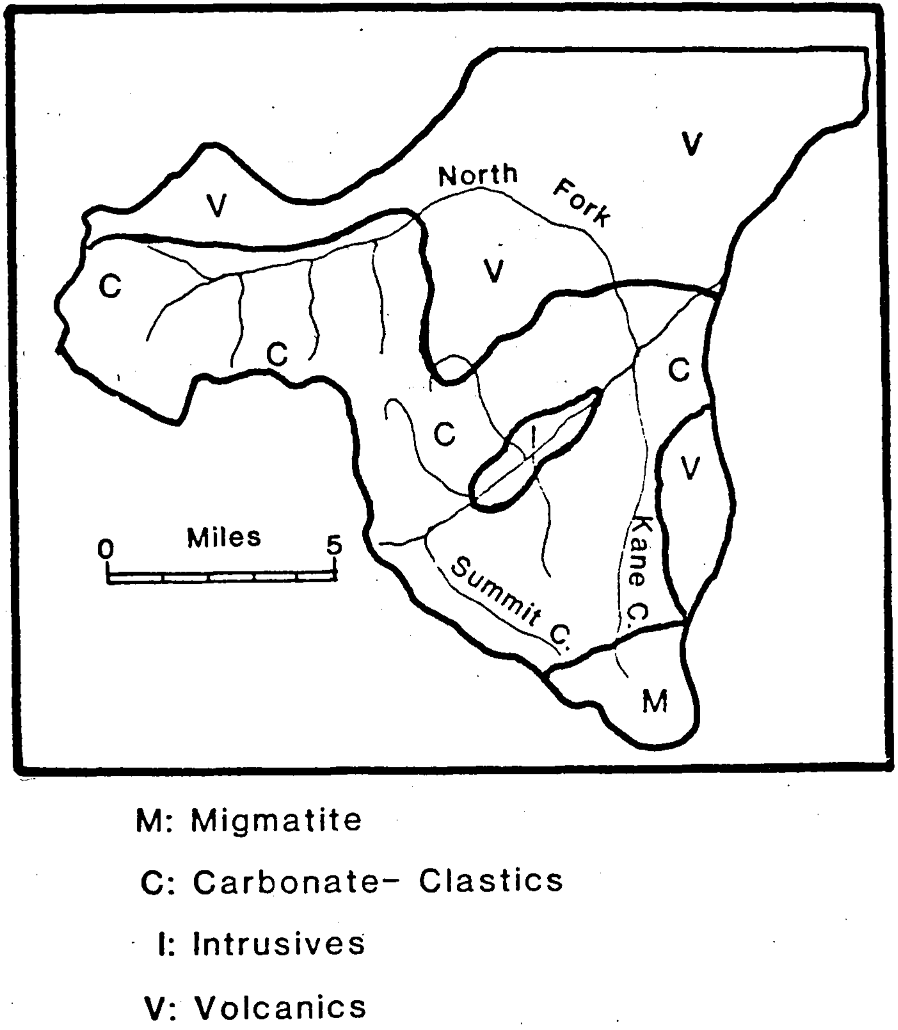


Figure 3. Generalized bedrock geology of the North Fork of the Big Lost River; modified from Umpleby, et al. (1930) and Dover (1966, 1969). Individual rock-stratigraphic units have been grouped together on the basis of gross lithology. Migmatite - Wildhorse Canyon Migmatite Gneiss Complex, Hyndman Peak Formation and East Fork Formation; Carbonate-Clastic - Copper Basin Group; Intrusive - Cretaceous Quartz Monzonite; Volcanic - Challis Volcanics.

ing description of bedrock geology is modified from Umpleby, et al. (1930) and Dover (1966, 1969).

The Pioneer Mountains are cored by two north trending domes consisting of autochthonous Precambrian units bounded by allocthonous Paleozoic sedimentary units. The smaller of these two domes underlies a portion of the study area (Lithology M, Figure 3). The two domes differ slightly in trend and divergence of foliation and lithologic layering. The significance of the variance of these trends is not presently understood (Dover, 1969). The major structural trends in the Precambrian units were developed during the formation of the domes.

The Precambrian units that make up the core of the two Pioneer Mountain domes have been grouped as the Wildhorse Canyon Gneiss Complex. Dover (1969) has described this formation as a migmatite, or a "mixed rock", containing both metamorphic and granitic layers. According to Dover (1969), the migmatitic complex is the result of the regional dynamic metamorphism of a thick succession of quartzitic sedimentary units which were cut by dikes and sills that have been converted to orthoamphibolites. Intimately mixed with the migmatite units are partially metamorphosed granitic intrusions that were injected during a syn- or post-metamorphic event.

Overlying the Migmatite Complex are metasedimentary deposits of latest Precambrian and earliest Paleozoic age; the East Fork and the Hyndman Peak Formations (included in Lithology M, Figure 3). Also autochthonous, these crystalline deposits are impure argillaceous, quartzitic dolomites (Hyndman Peak) and limestones and quartz samdstones (East Fork) that have undergone a single, regional synkinematic metamorphism, possibly post-Ordovician in age.

Surrounding the autochthonous crystalline cores of the Pioneer Mountain domes is a series of weakly metamorphosed allochthonous upper Paleozoic units known as the Copper Basin Group ("Lithology C", Figure 3); the emplacement of which post-dates metamorphism (Dover, 1969). These eugeosynclinal carbonate and clastic lithologies were deposited in association with alternating periods of quiesence and uplift attributed to the Antler Orogeny (Nelson and Ross, 1969).

During the Cretaceous, synorogenic intrusives ranging in composition from granodiorite to quartz monzonite were emplaced ("Lithology I", Figure 3). These intrusives are generally coarse grained, with some gneissic structure. Porphyritic phases of the intrusives are dominated by potassium feldspar and quartz megacrysts. Dover (1969) suggests the intrusives represent "satellites" of the Idaho Batholith (the emplacement of which is associated with the Laramide Revolution).

The post-orogenic period in this area is represented principally by volcanics. Quartz monzonites were emplaced in Big Fall and Summit Creeks, and Tertiary (Miocene?) aged plutonics were emplaced along Ryan Peak in association with the Challis Volcanics.

The Challis Volcanics overlie all other stratigraphic units in the area and consist of interbedded lava and tuffaceous units (Lithology V; Figure 3). The flows of the Challis Volcanics undoubtably blanketed the area during the Tertiary, with subsequent uplift and erosion resulting in the exposure of older units. The extent of this uplifting (block faulting), however, is unknown.

PREVIOUS WORK

Rocky Mountain Region

Alpine glaciation was widespread in the Rocky Mountains during the Quaternary from Canada to New Mexico. Although locally small ice caps formed, valley glaciers predominated. As a result, Quaternary deposits are characterized by valley and intermontaine glacial and glaciofluvial units which are isolated geographically from deposits outside of their respective basins.

The systematic examination of Quaternary deposits in the Rocky Mountains began with Blackwelder (1915) in the Wind River Range of Wyoming. The differentiation of three distinct drifts: the Buffalo (oldest), the Bull Lake, and the Pinedale, by Blackwelder, is considered to be the beginning of the evolution of the "Rocky Mountain Model" as described by Mears (1974). The Rocky Mountain Model, in effect, consists of the stratigraphic foundations established by early workers in the Wind River region (Blackwelder, 1915; Richmond, 1948; Moss, 1949, 1951a,b; Holmes and Moss, 1955) which have been subsequently modified and applied to deposits elsewhere in the Rocky Mountains. The model remains dynamic and functional, though hindered by the lack of absolute dates and reliable correlation mechanisms. The evolution of the Rocky Mountain Model shall briefly be described here.

TABLE 1. Stratigraphic Nomenclature of the Rocky Mountain Model, this study and the studies of Stewart (1977) and Wigley (1976).

Age Years B. P. (Not to scale)	Rocky Mountain Glacial Model		This Study		Stewart (1977) Wigley (1976)	
300-100	Gannet Peak	Neoglacial	Neoglacial	Undifferentiated	Neoglacial	Undifferentiated
1850-950	Audobon					
5000-3000	Triple Lakes					
11,000	Late Stade	Pinedale	North Fork Advance	IV	Pinedale Glaciation	IV
	Middle Stade			III		III
				II		II
>30,000	Early Stade			I		I
85,000	Late Stade	Bull Lake	Kane Advance	Undifferentiated	Bull Lake Glaciation	II
	Non Glacial Interval					
125,000	Early Stade					I
250,000	Sacagawea Ridge	Pre-Bull Lake	Pre-Kane Advance (Not Recognized)		Pre-Bull Lake Glaciation	Undifferentiated
750,000	Cedar Ridge					
1,500,000	Washakie Point					

Pre-Bull Lake or "Buffalo" Glaciation

Following the work of Blackwelder, subsequent work in the Wind River Range by Richmond (1948), Moss (1949, 1951a,b), and Holmes and Moss (1955) revealed that the events that Blackwelder had described were far more complex than he had envisioned. However, the work of Blackwelder has been accepted, in part, as a regional standard (Richmond, 1960b, 1965).

Blackwelder (1915) originally designated what he considered to be the oldest Quaternary deposits in the Wind River Range as "Buffalo" stage, and suggested that these deposits represented one distinct episode of glaciation. Although other workers (Ross, 1929; Atwood, 1937; Moss, 1949, 1951a,b; and Horberg, 1954) recognized "old" drifts which they believed to be correlatives of Buffalo deposits, the ambiguities of both the age and long distance correlation resulted in the slow abandonment of the term "Buffalo Drift". The type locality of Buffalo till is now believed to represent more than one episode of glaciation, all of which are considered to be of Pinedale age (Richmond, 1957, 1962a, 1964b). Currently, the oldest deposits in most areas are simply called: Pre-Bull Lake or Early Pleistocene.

Richmond (1957, 1962a, 1964b) has named and described three Pre-Bull Lake events in the Wind River Range: the Washakie Point (oldest), the Cedar Ridge, and the Sacagawea Ridge Glaciations (Table 1). Deposition of till along drainage lines quite different from those of today has led to the assumption that the oldest two Pre-Bull Lake glaciations (Washakie Point and Cedar Ridge) occurred prior to the downcutting of major streams and therefore pre-date the formation of the canyons characteristic of the Rocky Mountains (Richmond, 1976). Subsequent glacial and glaciofluvial activity, however, has greatly modified "pre-canyon" Pre-Bull Lake deposits.

In general, Pre-Bull Lake deposits are characterized by dissection and alteration due to extended exposure to weathering and erosion. There are few vestiges of glacial topography on any of these deposits. The dissected nature and lack of morainic morphology, make the mapping and correlation of Pre-Bull Lake deposits difficult.

Pre-Bull Lake tills are sheet-like in form, have smooth surfaces, and have few surface boulders exposed on till deposits (Richmond, 1957). All Pre-Bull Lake tills lack striated boulders and contain high percentages of ghost boulders. Pre-Bull Lake tills are more compact and contain higher percentages of clay and silt than younger deposits (Richmond, 1965).

In the Pioneer Mountains, both Stewart (1977) and Wigley (1976) have recognized deposits of Pre-Bull Lake Glaciations. As in other areas of the Rocky Mountains, identification of these Pre-Bull Lake events is based primarily on elevated gravels and terrace levels high above present stream levels.

Bull Lake Glaciation

The Bull Lake Glaciation has classically been interpreted as the first of the "Wisconsinan" advances in the Rocky Mountains (Table 1). Two Bull Lake episodes have been recognized in the Wind River Range (Richmond, 1948; Moss, 1951a,b; and Holmes and Moss, 1955). Deposits of these two events have been differentiated primarily on the basis of relative age criteria, though some absolute dates exist (Table 1).

Throughout the Rocky Mountains, Bull Lake age moraines are fairly well preserved, and, together with Pinedale age moraines, dominate the constructional morphology of glaciated valleys (Modale, 1976). Bull Lake moraine complexes generally have intermediate (in relation to Pre-Bull Lake and Pinedale deposits) weathering characteristics (Holmes and Moss, 1955). Bull Lake tills are more weathered than tills of Pinedale age, and contain higher percentages of clays and silts. Within tills, clasts are usually fresh, but some have weathering rinds and are, in part, rotted. Striations are only preserved on the under side of surface boulders. Bull Lake moraines retain a softened form of their original topography and are notably dissected and lack undrained hollows. Kettles, though present on Bull Lake morianes, are often filled with fluvial or eolian deposits (Knoll, 1973).

The extent of the Bull Lake Glaciation events vary from place to place. Generally, Bull Lake Early Stade deposits extend further downstream, with deposits of subsequent glaciations found successively up valley. The differentiation of Early and Late Stade Bull Lake deposits in the Pioneer Mountains has been based principally on down valley extent (Stewart, 1977; Wigley, 1976).

The absolute age of Bull Lake deposits is problematic. Richmond (1972) believes the Bull Lake Early Stade of the Wind River Range occurred between 125,000 and 105,000 yrs. B.P. and the Late Stade occurred between 105,000 and 85,000 yrs. B.P. Pierce, Obradivich, and Friedman (1976), using obsidian hydration data and radiometric dating of associated volcanics in Yellowstone, date the upper boundary of the Late Stade at 140,000 yrs. B.P., which is an Illinoian age (or pre-Sangamon soil) (Table 1) in the terminology of the Midcontinent (Willman and Frye, 1970). The interval separating Late and Early Stades of the Bull Lake Glaciation is also somewhat problematic. In instances where Late Stade and Early Stade Bull Lake tills are superposed, rates of soil formation indicate the Bull Lake Interstadial was approximately equal in duration to the Bull Lake - Pinedale Interglacial (Richmond, 1965); hence, Richmond (1965) designated this period of time a "non-glacial interval" (Table 1).

Pinedale Glaciation

In most of the glaciated valleys of the Rocky Mountains, deposits of the Pinedale Glaciation make up a large percentage of the Quaternary deposits. Pinedale moraines are well preserved, irregular, steep sloped, and very bouldery. Pinedale moraines are also characterized by a poorly integrated drainage and the absence of dissection by fluvial processes subsequent to deposition; as a result of this, many kettles still contain ponds.

Often, Pinedale terminal moraines are found upvalley from those of the Bull Lake Glaciation, though in some cases, older moraines have been breached by advancing Pinedale ice (Madole, 1976). Pinedale tills are less weathered than Bull Lake tills, and till clasts are usually fresh and have well preserved striae (Knoll, 1973; Moss, 1951a).

The Pinedale Glaciation is represented by multiple moraine complexes reflecting a "complex glaciation", consisting of multiple advance and retreat couplets, or a number of pulsations during retreat from Pinedale Maximum. Richmond has divided the Pinedale Glaciation into three stades in the Wind River Range, but up to eight distinct Pinedale moraines have been recognized in individual valleys elsewhere in the Rocky Mountains (Knoll, 1973).

The multiple character of Pinedale moraines has inhibited correlation of Pinedale events from region to region. Recent radiometric studies (Table 1), however, have established that the Pinedale Glaciation had begun by 30,000 yrs. B.P. and ended by 11,000 yrs. B.P. (Richmond, 1976; Pierce, et al., 1976; Nelson, et al., 1979; and Madole, 1980). Madole (1972) believes that no major interval of time separated successive depositional events of Pinedale age.

Neoglaciation

In addition to numerous Pinedale terminal and recessional moraines recognized in individual valleys, a distinct late- or post-Pinedale deposit has been recognized in the Wind River Range (Moss, 1951a) and in the Colorado Front Range (Benedict, 1973; Mahaney, 1972). Moss (1951a) originally described and named the Temple Lake moraine, which he considered to be of late-Pinedale age. Later, Richmond (1957, 1965) suggested that the Temple Lake moraine was deposited following the altithermal, or during Neoglaciation. Subsequent work by Benedict (1967, 1968, 1973), Birkeland and Miller (1973), Madole (1972), and Mahaney (1972) in the Colorado Front Range has led to the establishment of the Santanta Peak moraine as a late-Pinedale deposit. The Santanta Peak moraine has since been correlated to the Temple Lake moraine of Moss (1951a) by Madole (1972) and Currey (1974).

Neoglacial deposits ("little ice age" of Matthes, 1939) were originally described by Moss (1951a), and were defined as those deposits younger than the "climatic optimum" or altithermal. The problem of subdividing Neoglacial deposits evolved with the "Temple Lake Problem"; it has only been since the work of Benedict (1967, 1968, 1973), Madole (1972, 1976), Mahaney (1972), and

Mahaney and Fahey (1976) in the Colorado Front Range that the Noeglacial history of the Rocky Mountains has been accurately dated and reinterpreted. Through the use of lichenometry, the Neoglacial has been divided into three advances: the Triple Lakes (oldest; Benedict, 1973), the Audobon (Madole, 1972), and the Arrapaho Peak (youngest; Benedict, 1973) (Table 1).

Pioneer Mountains and Adjacent Regions

Previous investigations of glacial deposits in the study area are extremely limited. Prior to this study, only Umpleby, et al. (1930), Dover (1966, 1969), and Dover, et al. (1979) recognized and mapped Quaternary deposits within the North Fork drainage; and no attempt was made to differentiate the deposits according to age. East of the study area, within the drainage of the East Fork of the Big Lost River (Figure 1), glacial deposits of different ages are reported by Nelson and Ross (1969), Wigley (1976), Otto (1976), Stewart (1977), and Wigley, et al. (1978).

Nelson and Ross (1969) originally differentiated deposits of two ages (Bull Lake and Pinedale) in the Copper Basin (Figure 1) on the basis of morphostratigraphy. Wigley (1976) and Stewart (1977) (Figure 1), in detailed studies of glacial deposits of the Copper Basin and Wildhorse Canyon, mapped four major stillstands of "Pinedale" age on the basis of down-valley extent, and two stades of Bull Lake Glaciation on the basis of moraine morphology and multiple outwash gravel terraces. Neoglacial and Pre-Bull Lake deposits were mapped by Wigley (1976) and Stewart (1977), but no attempt was made to subdivide these deposits.

Elsewhere in south-central Idaho, glacial deposits have been mapped in southern Idaho (Fosberg, 1965), the Lemhi Range (Knoll, 1973; Knoll and Dort, 1973; and Dort, 1960), the Stanley Basin (Williams, 1961), the Snake River Plain (Maulde, 1965). For a complete review of earlier studies, see Dort (1965).

METHODS

This study, a part of the project begun by Lehigh faculty and students, was designed to locate, map, and differentiate glacial deposits in the drainage of the North Fork of the Big Lost River in an attempt to discern the geometry and relative timing of deglaciation of the region. Methods used in this study included those classically used throughout the Rocky Mountains (moraine morphology, cross-cutting relationships, downvalley extent of glaciation), and newer methods (soil clay mineralogy and pebble provenance) designed to promote insight into relative age and source area of glacial deposits, and paleoglacial flow patterns.

Field Work

The surficial deposits of the study area were mapped during the summer of 1977 on aerial photographs (scale 1:20,000) and transferred to a topographic base map (scale 1:24,000). Glacial deposits (moraines and outwash terraces) were differentiated according to age in the field by the following criteria:

A) Down-Valley Extent: glaciers of similar age show similar characteristics in down-valley extent of terminal moraines. Because of the erosive action of an advancing glacier, no extensive deposit in a confined valley can be younger than a deposit located further up-valley.

B) Cross-cutting Relationships: moraines and terraces were relatively dated by correlating paired glaciofluvial terraces that are graded to deposits of the same age, and dissect older deposits. This method proved particularly important in this study area because at several times there existed three separate and mutually independent valley glaciers.

C) Moraine Morphology: morphologic variation in constructional topography, degree of development of drainage, percent undrained hollows, weathering of till clasts, and surface boulder percentage.

Using these techniques, glacial and glacio-fluvial deposits in the drainage of the North Fork of the Big Lost River could be differentiated into two distinct groups (to be discussed) according to age.

A provenance study was undertaken in a complex area at the confluence of Kane, North Fork, and Summit Creeks in Summit Creek Canyon. Twenty-five one cubic foot pits were dug in this three mile square area, and fifty pebbles were taken from each pit for later lithologic identification. This area was selected for provenance studies because during the two periods of morainic deposition, three independent valley glaciers; flowing out of Kane, North Fork, and Summit Creek Canyons, converged in this area. Prior to sampling, a period of time was spent becoming familiar with bedrock lithologies and taking reference samples to enable accurate identification and interpretation of pebble suites in provenance samples.

Six soil pits (see Plate 1 for location), excavated on moraine crests in an attempt to eliminate the effects of colluviation and stream erosion, were dug, described, and sampled. Pits were excavated in the two outermost moraines deposited by ice eminating from each of the three principle valleys. Sample sites in glacial deposits with differing source areas were chosen to determine the effects, if any, of till lithology on pedologic development. For each soil pit, soil profiles were described in terms of color, development, and structure. Soil characteristics such as horizon development, depth of leaching, carbonate build-up, and total thickness were utilized to differentiate deposits of different advances (Jenny, 1941; Birkeland, 1974).

Each soil profile was sampled at ten centimeter intervals (from the base up to avoid contamination). The depth to unaltered parent material, and therefore pit depth, ranged from 150 to 200 cm.

Laboratory Analysis

Sixty-three samples, collected from the six pits dug in moraines, were analyzed to determine clay mineral variations with depth and assumed age (exposure to pedogenesis). Only particles 0.49μm and smaller (greater than 110) were analyzed. This size range was selected because it was suspected that the clay fraction finer than 49μm is predominantly the result of pedogenesis. Studies by Stewart (1977) on similar soils showed that the 80, 90, and 100 clay fractions of soils were predominantly parent minerals inherent in the soil profile, and are not a product of pedogenesis.

Individual field samples were homogenized and mechanically split into 15 gm samples. The finer than 110 fraction was separated by centrifugation (Jackson and Tanner, 1947). Following centrifugation, pretreatment of the fractionated sample for X-ray analysis included; oxidation of organics, removal of free carbonate ions, and removal of amorphous iron.

Organic matter was oxidized with sodium hypochlorite (Anderson, 1961). A 20 ml portion of NaOCl (pH adjusted to 9.5) was added to approximately 10 gm of sample and placed in a hot water bath at 90°C for 45 minutes. Samples were then centrifuged and the supernatant liquid decanted. This treatment was repeated two additional times.

Free carbonate ions were removed from the fractionated soil samples following the method of Jackson (1969). Fifty millileters of 1N sodium acetate (pH adjusted to 5) was added to the sample and allowed to digest for a period of one hour at near boiling temperatures. The suspension was then centrifuged, supernatant liquid discarded, and the filtrate washed twice with 1N NaOAc solution at room temperature. Following the second washing with NaOAc, the sample was finally rinsed with distilled water, centrifuged, and the supernatant liquid was again discarded.

Removal of amorphous iron was accomplished using the sodium citrate, sodium bicarbonate, and sodium dithionite (CBD) method of Mehra and Jackson (1960).

Following the pretreatment of fractionated soil samples, the remaining 110 fraction of clays was suspended in distilled water and drawn through a 0.45μm millipore filter, which retained only the clay fraction. A 10 ml alliquot of 1N $MgCl_2$ was then drawn through the sample to saturate clays in magnesium. This treatment maximizes the 001 intensity of the expansible layer silicates (Jackson, 1969).

Filtrates were then mounted on a 25 mm by 50 mm petrographic slide using the filter peel technique of Drever (1973). Mounted samples were then placed in an ethlene glycol environment at room temperature for 24 hours to expand the montmorillonite lattice to 17Å (Brunton, 1955).

Following glycolation, samples were X-rayed on a standard Norelco wide angle diffractometer using high intensity nickelfiltered copper K α-radiation at 40 KV and 20 MA, the detector was a scintillation counter. All samples were scanned from 2° to 15° 2θ at ½° per minute. Samples BLA (1-10) and PDA (1-6) were also scanned from 24° to 26° at ¼° per minute in an attempt to distinguish relative amounts of chlorite and kaolinite, by the 002 reflection. Each sample was X-rayed at least twice.

Because the presence of montmorillonite can be masked by mixed layer clays, all samples were then heated to 500°C for a 12 hour period to remove all mixed layer clays (Carrol, 1970). Samples were then re-glycolated and X-rayed again.

Relative abundances of montmorillonite, illite, and chlorite and kaolinite (combined) were obtained by measuring and weighing the areas beneath the various diffraction peaks (after Biscaye, 1965). Peak areas were weighed as follows: the area of the 8.9° 2θ peak (illite) was multiplied by 4; the area of the 12.5° 2θ peak (chlorite and kaolinite combined) was multiplied by 2; and the 5.2° 2θ peak area (montmorillonite) was multiplied by 1. These results were then summed and converted to percentage values.

RESULTS AND DISCUSSION

Introduction

The qualitative use of morphologic parameters in conjunction with provenance investigations have been widely used to distinguish age and source of glacial deposits throughout the Rocky Mountains (Richmond, 1960a,b, 1976; Birkeland, et al., 1971; Weber, 1972; Birkeland, 1973, 1978; Mears, 1974; and Madole, 1976), including the Pioneer Mountains of Idaho (Wigley, 1976; Pasquini, 1976; Stewart, 1977; Wigley, et al., 1978; and Evenson, et al., 1979). This study has further applied these methods to the Pioneer Mountains to develop a model of the glacial history of the North Fork of the Big Lost River. In addition, an attempt was made to develop quantifiable pedologic parameters which could be used to differentiate glacial deposits according to age.

This study consisted of two segments; a field segment, and a laboratory segment. For clarity, the results of each of these phases of research will be discussed individually.

Field Work

A) Differentiation by Relative Age Techniques

The location and age of all glacial and periglacial deposits mapped in the drainage of the North Fork of the Big Lost River are presented in Plate 1. The stratigraphic nomenclature used here is unique to this study area; a discussion, description, and designation of the type locality for the terms "North Fork Advance" and "Kane Advance" is presented in Appendix I.

Nomenclature and Correlations

Glacial deposits in the study area have been differentiated into two distinct "Advances"; the "Kane Advance" and the "North Fork Advance", on the basis of morphologic, pedologic characteristics, and down-valley position. For the most part, the morphologic characteristics sited are a function of the length of time deposits have been exposed to weathering and it is inferred that these two advances (Kane and North Fork) represent an older (Kane) and younger (North Fork) episode of glaciation and till deposition.

The mapping of glacial deposits as presented in Plate 1 is complete; the character of all deposits was carefully documented and established through extensive field examination. The glacial advances named in this study are tentatively correlated to the deposits mapped as "Pinedale" and "Bull Lake" by Stewart (1977) and Wigley (1976) elsewhere in the Pioneer Mountains. The terminology in this study is intended to further extend the Rocky Mountain Glacial Model (Mears, 1974) to Idaho, but not intended to imply demonstrated age equivolence of deposits in the study area with deposits of the Pinedale and Bull Lake Glaciations in the Wind River Range, Wyoming where the original model was developed

(Blackwelder, 1915).

Deposits of the Kane Advance are those deposits (moraines) which maintain only a portion of their original constructional topography, and have weathering characteristics similar to those described at the type Bull Lake section in the Wind River Range, Wyoming (Blackwelder, 1915; Richmond, 1962a). The Kane Advance is therefore believed to be the older of the two advances recognized in the study area. Deposits of the Kane Advance are tentatively correlated with deposits of the "Bull Lake" Glaciation of Stewart (1977) and Wigley (1976).

Deposits of the North Fork Advance are those moraines and glaciofluvial gravels deposited by the second, or younger, glacial advance recognized in the study area. Deposits of this advance are located further down valley, and higher along the valley walls than those of the younger Kane Advance. Soil characteristics and moraine morphology indicate North Fork Advance moraines have been exposed to pedologic development for a shorter period of time, and have been less dissected by fluvial activity subsequent to their deposition, than moraines of the Kane Advance. Deposits of the North Fork Advance are tentatively correlated with deposits of the "Pinedale" Glaciation of Stewart (1977) and Wigley (1976).

The lack of absolute dates, and the isolated character of glacial deposits in the study area complicates accurate correlation of these deposits elsewhere in the Rocky Mountains. Previous workers in the Pioneer Mountains (Evenson, et al., 1979; Wigley, et al., 1978; Stewart, 1977; Wigley, 1976; and Pasquini, 1976) have used the classic terms "Pinedale" and "Bull Lake" as stratigraphic designations. Because these terms, since their origin (Blackwelder, 1915), have been used as lithologic-, climatic-, chrono-, and morpho-stratigraphic units, it was concluded that the application of these terms to deposits in the study area would result in confusion rather than clarification.

Pre-Kane Deposits

Both Stewart (1977) and Wigley (1976) recognized deposits older than their "Bull Lake" glaciation in the Pioneer Mountains. These Pre-Bull Lake deposits were poorly defined, well dissected, highly weathered drifts, located at considerably higher elevations than all younger deposits. In the drainage of the North Fork of the Big Lost River, however, deposits with similar characteristics (Pre-Kane deposits) were not encountered. This is probably due to the extreme erosive activity of subsequent glacial and glaciofluvial events in the principal valleys of the study area, which are considerably more constricted than the valleys of the areas of Stewart (1977) and Wigley (1976).

Kane Advance

The geometry of morainic deposits of the Kane Advance, the oldest advance recognized in the study area, indicate that glaciation was more extensive during the time of their deposition than during any subsequent glacial advance. There are no Kane Advance glaciofluvial gravels, although a Kane (?) "age" was assigned to fan gravels dissecting a Kane Advance moraine complex (Plate 1), which overlie a North Fork terrace.

Moraines of the Kane Advance are all; well dissected and washed, within the confines of Summit Creek Canyon, and located down-valley from terminal moraines of the North Fork Advance. The surficial morphology of Kane Advance moraines is extremely subdued. The lack of well defined constructional topography, and the absence of kettles allows differentiation of deposits of this older advance from those of the younger North Fork Advance. Although no morainic complex in this study area exhibits the characteristic Rocky Mountain topography (multiple undrained depressions, poorly integrated drainage, steep sided and sharp crested; Richmond, 1976), the moraines of the Kane Advance have a much smoother appearance than the moraines of the younger North Fork Advance. No where are the moraines of the Kane Advance continuous or complete, and no terminal moraines have been preserved.

Figure 4 and Plate 1 show the deposits of the study area assigned to the Kane Advance. One deposit (Moraine A, Figure 4), consisting of six mappable remnants, is located northeast of the mouth of Kane Creek Canyon. A second moraine (Moraine B, Figure 4), consisting of two remnants, is located in the center of Summit

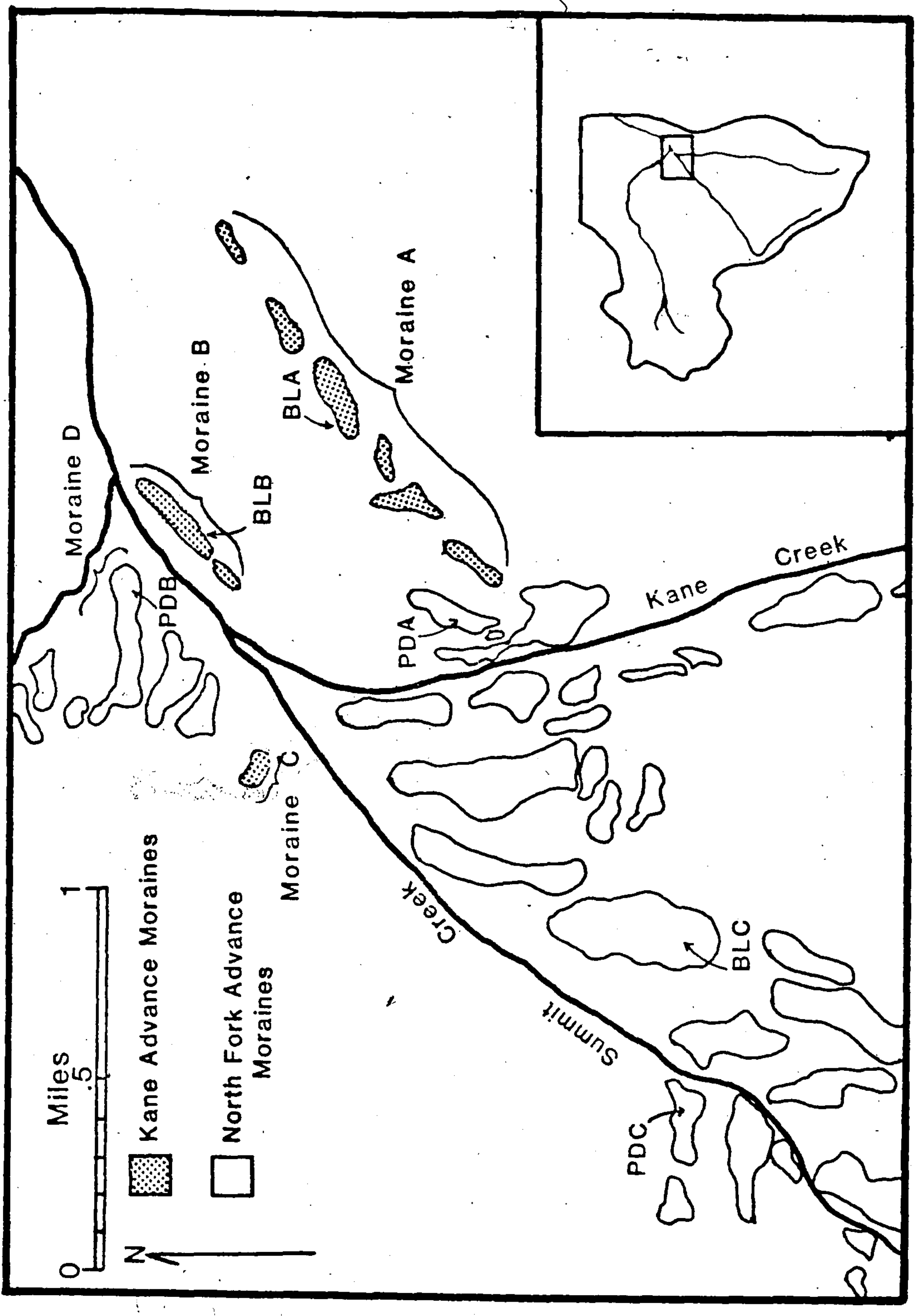


Figure 4. Morainic deposits of the Kane Advance, and selected moraine complexes of the North Fork Advance. Moraine complexes A, B, C, and D are discussed in the text. Small arrows indicate soil profile locations.

Creek Canyon, east of the confluence of Summit and Kane Creeks. Also assigned to the Kane Advance is a small isolated moraine remnant on the west side of Summit Creek Canyon, south of the mouth of the canyon of the North Fork of the Big Lost River (Moraine C, Figure 4).

Moraine A (Figure 4) extends from the mouth of Kane Creek Canyon northeastward approximately 2.5 km. The till pebble lithology of this moraine complex (see discussion, p. 55) is migmatite rich, indicating that the ice which deposited this moraine eminated from Kane Creek Canyon.

Field studies of soil profiles in tills rich in migmatite lithologies (BLA and PDA, Figure 4, Appendix III) indicate the amphibolite member of the Migmatite Complex is one of the least resistant lithologies to chemical weathering in the area. The soil profile developed in the Moraine A complex (BLA, Figure 4, Appendix III) of the Kane Advance has relatively few amphibolite boulders remaining in the A- and B-horizons. Those amphibolite clasts that were found in the profile were completely grussified "ghosts". In moraines of the younger North Fork Advance with the same provenance (see discussion, p. 55), many amphibolite boulders were present in the soil profile (PDA, Figure 4 and Appendix III) and for the most part, they were ungrussified. The contrast in the degree of weathering of migmatite clasts in these two profiles (PDA and BLA) indicates that Moraine A (profile BLA) has been exposed to weathering for a greater period of time.

The exact origin and mode of deposition of Moraine B of the Kane Advance (Figure 4) is problematic. Although at least two of the three major ice streams in the area were contributing to its deposition (see discussion, p. 57), the provenance of Moraine B is dominated by a lithologic suite (see p. 57 and Appendix II) deposited by ice flowing out of North Fork Canyon.

Moraine B has been assigned to the Kane Advance for a number of reasons. The surficial morphology of Moraine B is extremely subdued, indicating a greater period of exposure to weathering processes. Moraine B is located down-valley from all other moraines deposited by ice flowing from North Fork Canyon, indicating a period of more extensive glaciation. Other moraine remnants of the Kane Advance indicate a greater extent of glaciation than moraines of the North Fork Advance. In addition, the highest (oldest) glaciofluvial terrace, North Fork II terrace, is graded to a moraine up-valley from Moraine B (see discussion, p. 40) indicating that it is at least as old as North Fork I Advance, and possibly of the Kane Advance.

Further evidence for the inclusion of Moraine B in the Kane Advance was supplied by soil profiles. The two soil profiles excavated in moraines deposited by ice flowing out of North Fork Canyon (Moraines B and D, Figure 4, sample sites 5 and 6) were calcorthids; that is there is a buildup of calcium carbonate in the C (Cca) horizon. The Cca horizon in Moraine B (Kane Advance) is extremely well-developed, almost to the point of becoming "hard-pan". The Cca horizon in Moraine D (North Fork Advance) is poorly developed, less well-defined, and thinner (Appendix II). This indicates that Moraine B has been exposed to the processes of pedogenesis for a longer period of time (Birkeland, 1974).

The calcium carbonate in these moraines is probably derived from the weathering of calcareous lithologies of the Challis Volcanics found throughout the study area (Figure 3). The calcium carbonate buildup was probably greatly enhanced by the overlying sagebrush vegetation (Jenny, 1958). A Cca horizon forms when calcium carbonate in the parent material goes into solution in the A- and B-horizon, and is translocated downward by water in the vadose zone. Although many things can influence the formation of a Cca horizon, these soils (calcorthids) are more common in a desert environment because of the grassland vegetation (increasing soil acidity and high CO_2 demand causing ions to go into solution) and low precipitation (evaporation of water in the vadose zone causes $CaCO_3$ to precipitate). A well-developed Cca horizon indicates an older soil.

None of the other four soil profiles (Figure 4 and Appendix II) studied in this area revealed calcorthid type soils, or the build-up of calcium carbonate in the C-horizon.

Moraine C (Figure 4) was assigned to the Kane Advance strictly on the basis of moraine morphology, down-valley location, and its relation to younger terrace levels. No soil investigation was conducted on this moraine.

Although both Stewart (1977) and Wigley (1976) recognized two depositional events within their "Bull Lake" glaciation in immediately adjacent areas, no clear relationships exist in the study area to allow subdivision of the Kane Advance (Plate 1, Figure 4) to multiple depositional events. Therefore, all three moraines are assigned to a single depositional event; the Kane Advance.

The North Fork Advance

As previously discussed, two distinct, differentiable glacial advances (Kane Advance and North Fork Advance) were identified in the study area on the basis of morphologic, pedologic, and sequence characteristics; all of which are considered indicators of relative age. The younger advance is here named the "North Fork Advance" (see Appendix I). Although absolute ages cannot be assigned to the two advances, it is assumed, because they are so distinct, that the deposits of these two advances represent two temporally distinct, climatically controlled, glacial events. Theoretically, these two glaciations were separated by a period of ice retreat and soil development.

Aside from the moraines of the Kane Advance, all glacial deposits in the area are included in the North Fork Advance.

Glaciofluvial deposits (including several paired terraces of differing elevation) graded to the moraines of the North Fork Advance are designated "North Fork" gravels.

Moraines of the North Fork Advance are located up-valley from Kane Advance moraines (Plate 1). It is unknown whether the North Fork moraines (North Fork I through North Fork IV; Plate 1) represent a single continuous deglaciation, or a series of advance and retreat events to and from successive up-valley ice margin positions.

Individual moraines of the North Fork Advance cannot be differentiated on the basis of surface morphology, therefore the depositional episodes of the North Fork Advance (North Fork I through North Fork IV) have been distinguished on the basis of down valley extent and their relationship to terraces.

Moss (1974) has discussed the relation of glaciofluvial terraces and glacial advances in Wyoming. Moss (1974) has found that there is a genetic relationship between moraine positions and terrace levels graded to them, and has implied synchroneity of glaciofluvial terraces and the associated moraines deposition. It is assumed, in this study, that elevated terrace gravels are glaciofluvial in origin and that they were formed during periods of glacial advance or standstill. Conversely, downcutting and the attainment of lower terrace levels is associated with deglaciation and interglacial conditions (Moss, 1974).

The geometry of North Fork I moraines (or North Fork maximum; Figures 5 and 6) indicate that during their deposition, the ice streams flowing out of Kane Creek, North Fork, and Summit Creek Canyons coalesced and interacted, but not to the extent that they did during the previous advance (see discussion, p. 60). During the North Fork I Advance (Figure 6), northward flowing ice from Kane Creek Canyon diverted the terminus of the northeastward flowing ice in Summit Creek Canyon slightly to the west (Figures 5 and 6) as indicated by the orientation of Moraine E, Figure 5. While these two lobes were in contact, ice flowing out of North Fork Canyon remained near the mouth of the canyon (Figures 5 and 6) allowing meltwater from Summit and Kane Creek Canyons to flow down valley.

No terrace levels were found in association with North Fork I moraines. The highest (oldest) terrace (18 m above present stream level) is graded to those moraines mapped as North Fork II moraines (Plate 1) and thus is named the "North Fork II Terrace". The well-defined level of the North Fork II Terrace enables an accurate correlation of the North Fork II moraines for each of the three ice streams in the area.

North Fork II moraines have morphologic and pedologic (Appendix II) characteristics similar to those of the North Fork I moraines. North Fork II moraines are located at the mouths of Kane Creek and North Fork Canyons, and up-valley from the North

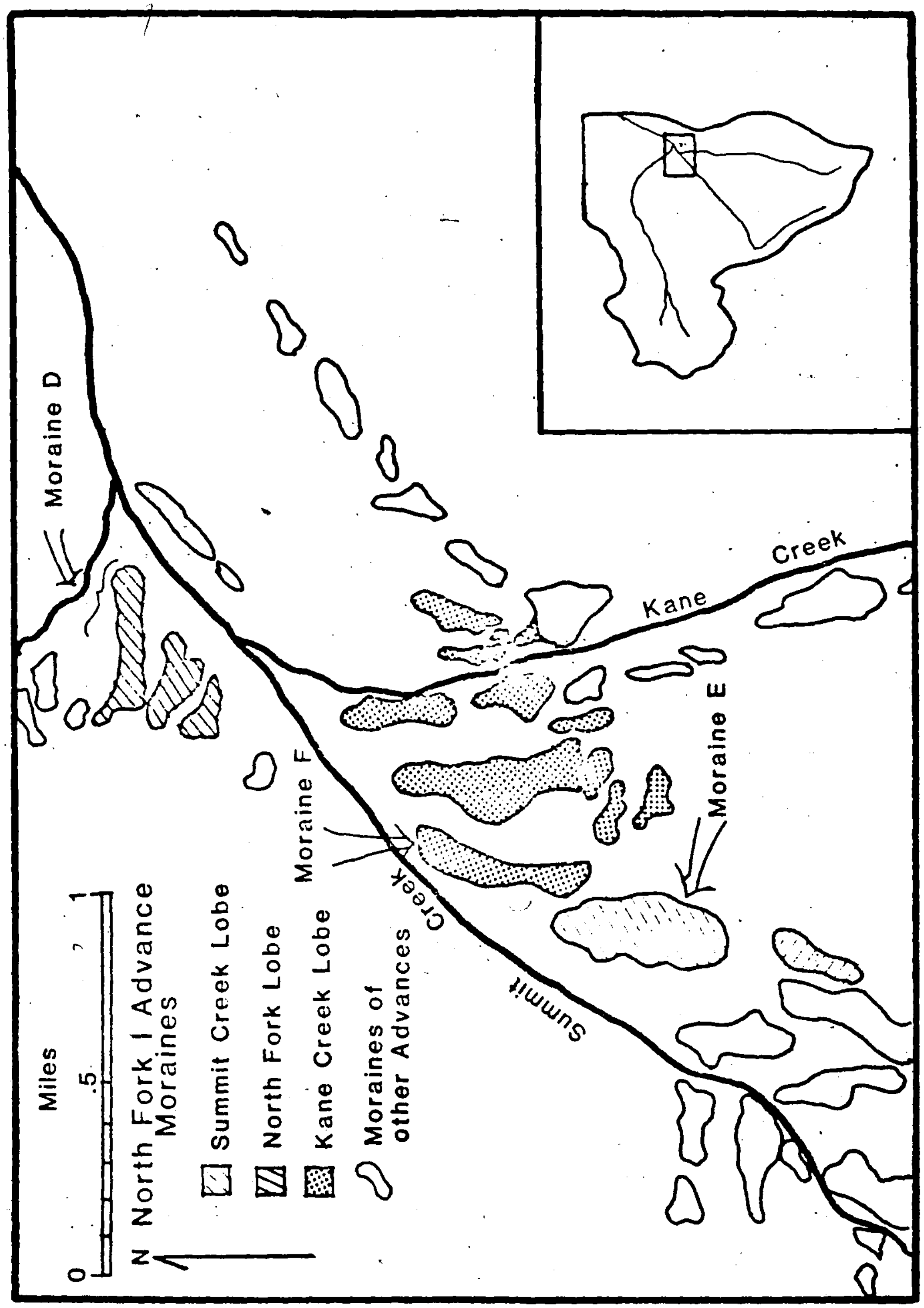


Figure 5. Terminal Moraine complexes of the North Fork Advance (North Fork I). Moraine complexes D, E, and F are discussed in the text.

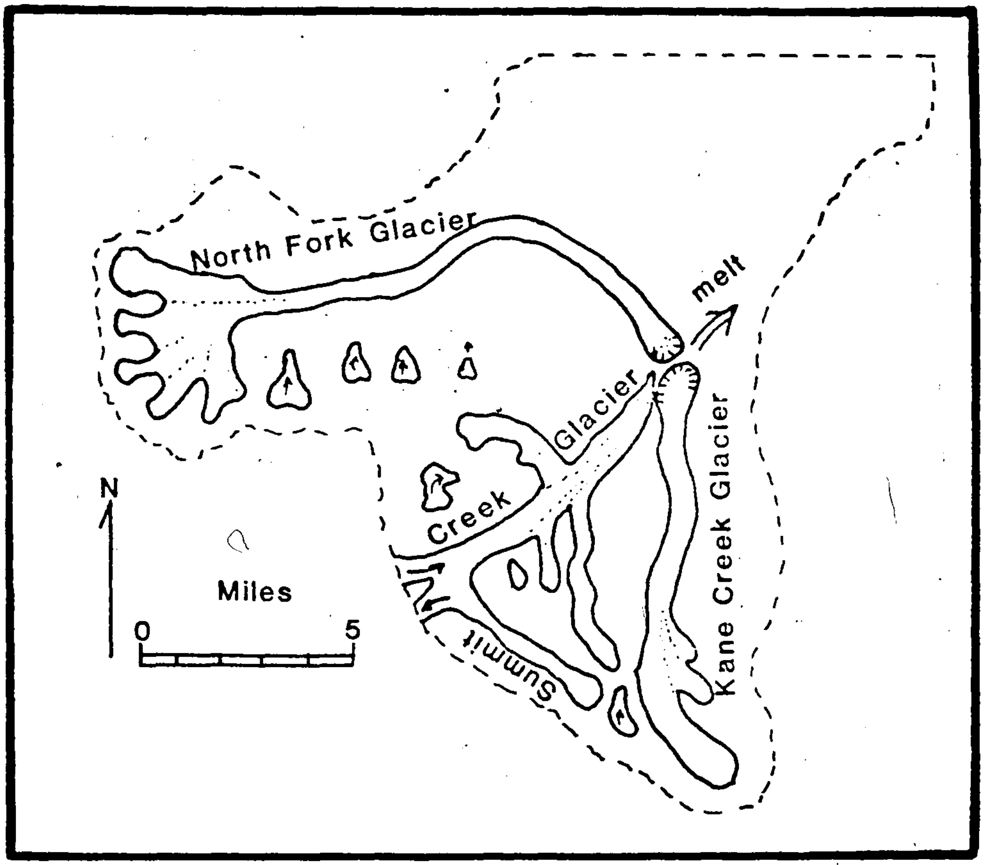


Figure 6. Reconstruction of North Fork I ice lobe geometry. Arrow indicates direction of melt-water flow.

Fork I moraine in Summit Creek Canyon (Figure 7). Moraine geometry thus indicates that unlike earlier stages of glaciation, ice streams during the deposition of the North Fork II moraines were restricted to the principle canyons, and did not have the "expanded feet" characteristic of the previous more extensive episodes of deposition. A reconstruction of the geometry of ice margins during the deposition of North Fork II moraines (Figure 8) indicates that at no time were any of the three ice streams in contact.

North Fork III moraines are located up-valley from North Fork II moraines. A paired terrace (North Fork III Terrace; Plate 1) is graded to North Fork III moraines. The North Fork III Terrace is lower (5 m above present stream level) and less extensive than the older North Fork II Terrace; but as does the older terrace, the North Fork III Terrace represents a distinct ice margin position, simultaneous in all three principal valleys (Figure 9), and allows accurate correlation of the ice front positions at this stage of deglaciation.

In the study area, North Fork IV moraines are small, dissected and remote from other deposits. Moraine geometry indicates a major change in the pattern of glaciation occurred following the deposition of the North Fork III moraines. North Fork IV moraines deposited in all three major valleys represent ice margins well up-valley from those during the deposition of older moraines, and

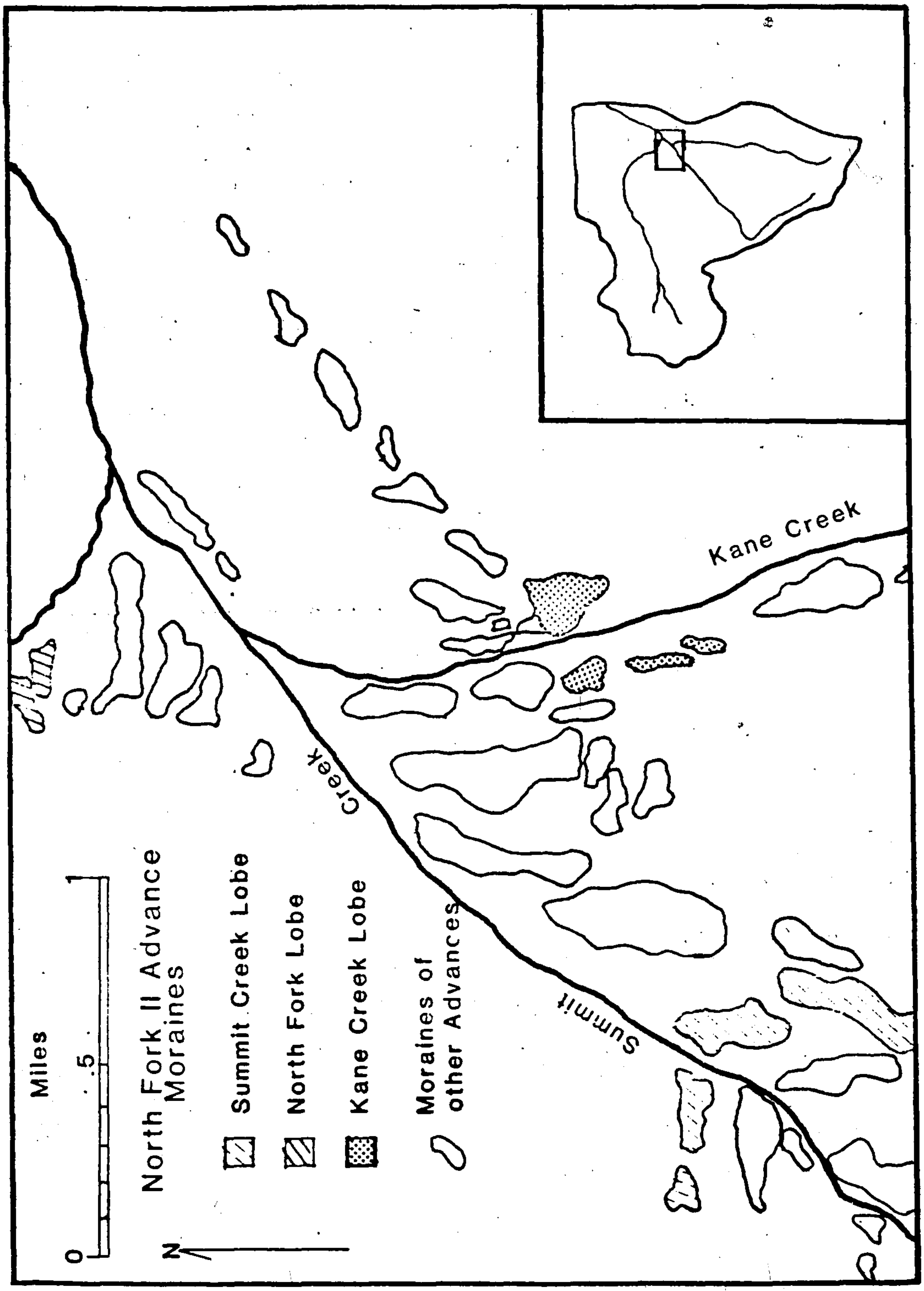


Figure 7. Moraine complexes of the North Fork II Advance.

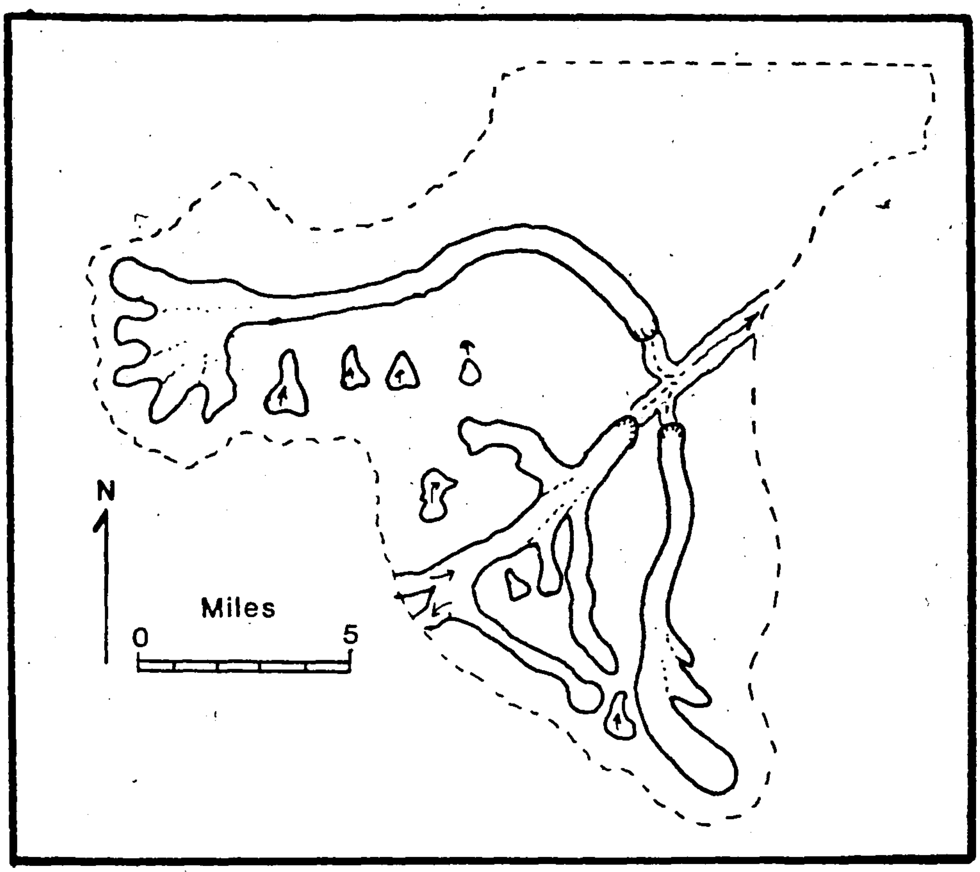


Figure 8. Reconstruction of North Fork II ice lobe geometry and outwash terrace.

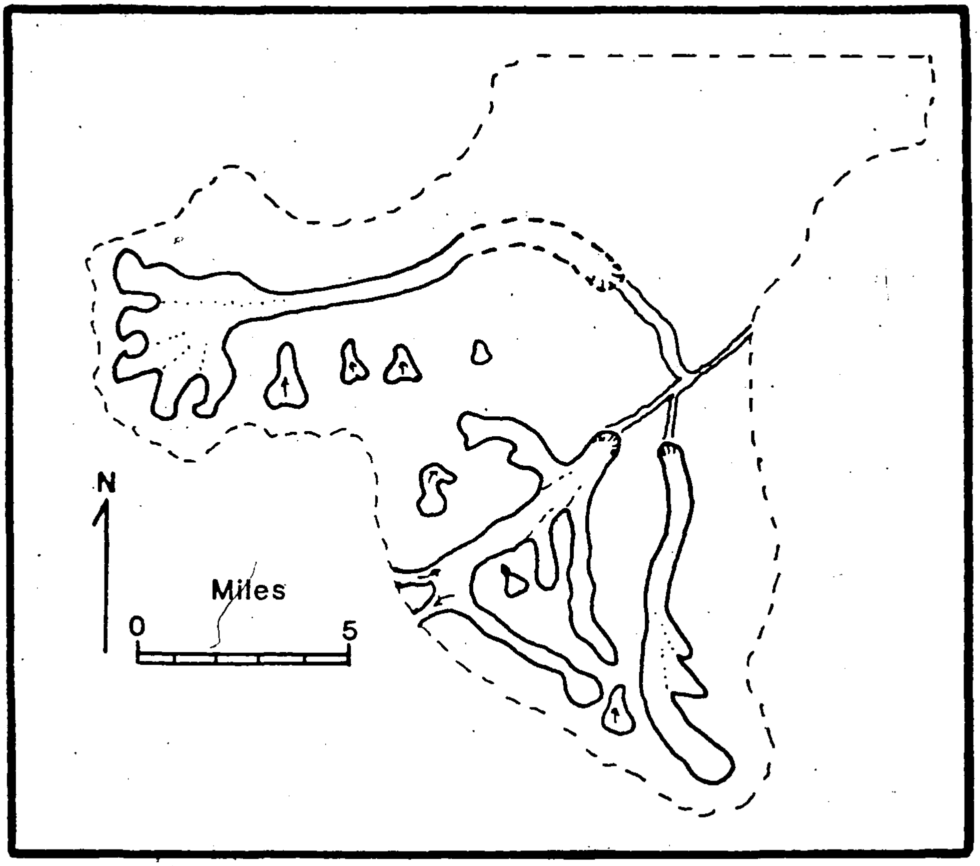


Figure 9. Reconstruction of North Fork III ice lobe geometry and outwash terrace.

moraines in canyons tributary to Summit Creek Canyon indicate the complex valley glacier that occupied Summit Creek Canyon had lost most of its tributary inflow.

A low (2 to 3 m above present stream level), unpaired terrace is graded to North Fork IV moraines. For this reason, and because North Fork IV moraines are located at varying higher elevations (Plate 1), it is believed that the duration and timing of the deposition of these moraines probably varied from valley to valley. Therefore, the correlation of the deposits mapped as North Fork IV moraines must be considered tenuous. Figure 10 is an attempt to reconstruct the geometry of ice margins during the deposition of North Fork IV moraines.

Neoglacial Deposits

Deposits assigned a Neoglacial age (Plate 1) in this study consist entirely of alluvium, rock glacier, and rock slide deposits. No morainic or glaciofluvial deposits of Neoglacial (post-altithermal) age were encountered.

It is readily apparent that the glacial deposits of various depositional events can be differentiated and tentatively correlated by; their surficial morphology, their down valley position, and certain pedologic characteristics. Ideally, these distinctions should also be recognizable in the quantifiable aspects of pedologic development. Following a discussion of

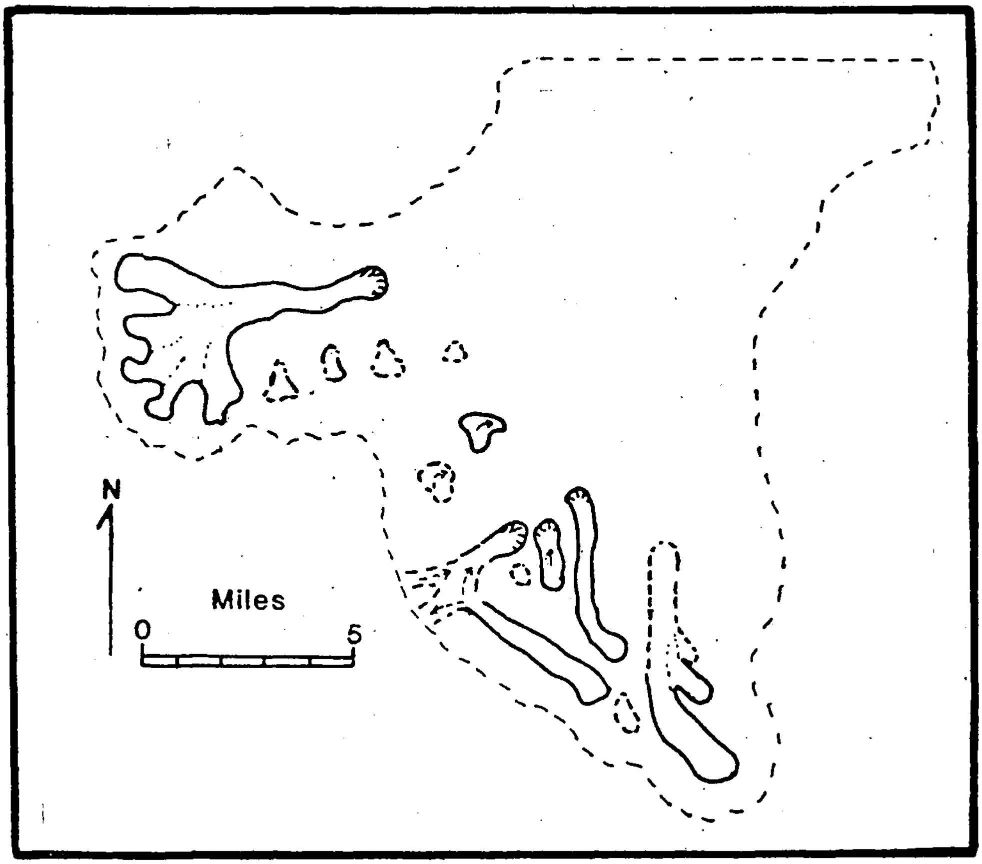


Figure 10. Reconstruction of North Fork IV ice lobe geometry.

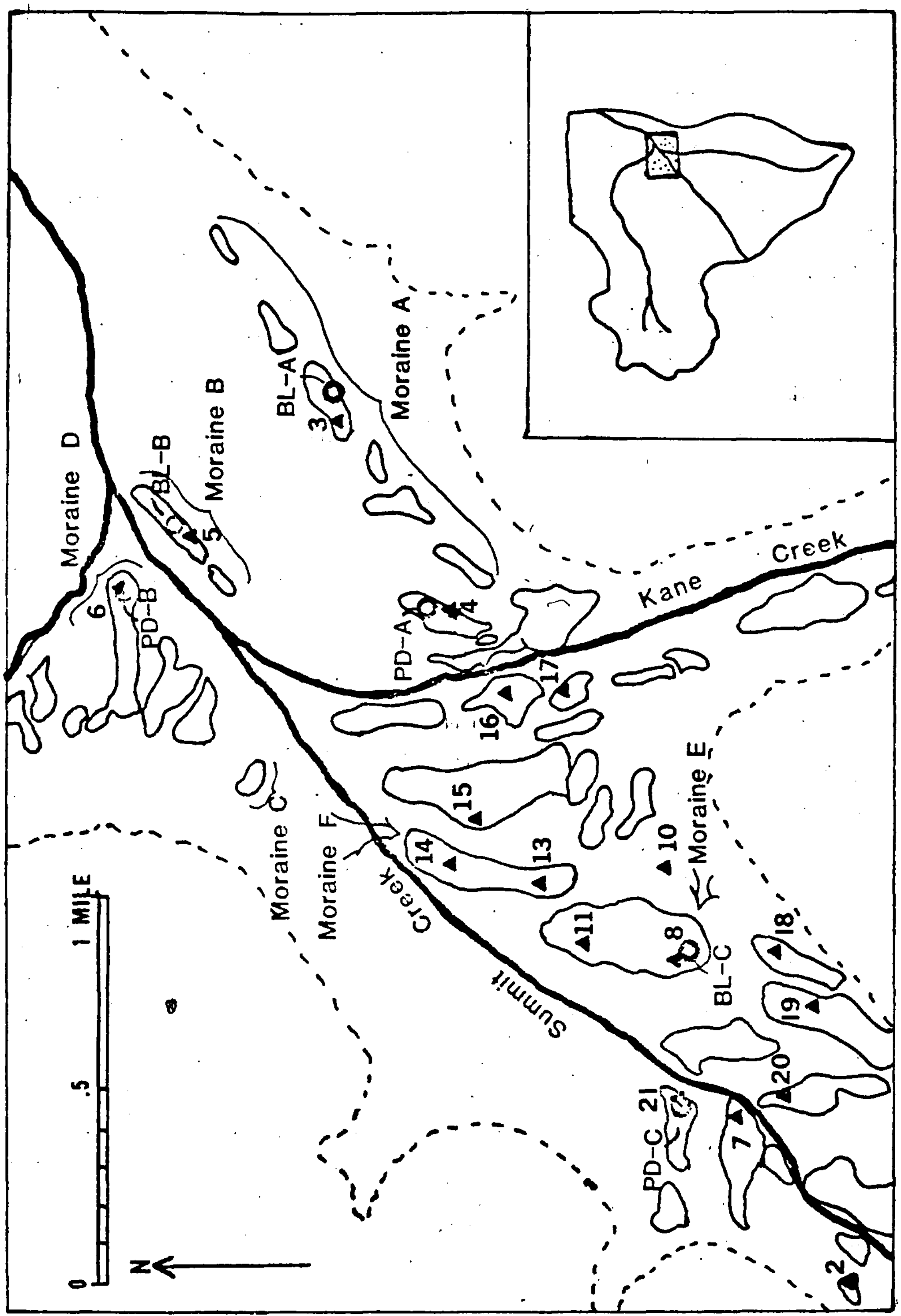
provenance studies, the attempt made during the laboratory portion of this study to find these quantifiable pedologic parameters will be discussed.

B) Provenance Analysis

A pebble provenance investigation was conducted in a small, complexly glaciated area near the junction of Kane and Summit Creeks, and the North Fork of the Big Lost River. Figure 11 shows the provenance investigation area, sample sites and moraines discussed in the text. The goal of this study was to provide additional data for the reconstruction of paleo-ice margins, and to discern the source and direction of transport of moraine remnants whose origin could not be determined by moraine geometry along (e.g. moraines A, B, E, and F, Figure 11). Fortunately, the source of most of the moraines in the study area was easily determined from location and geometry. Provenance characteristics of these moraines were then matched with characteristics of problematic origin resulting in the assignment of all moraines to three distinct provenance groups (Figure 12).

Early workers in the North Fork area recognized that although glaciation was extensive, it was never so extensive that principal valley glaciers in the area "out grew" the influence of their confining valleys (Umpleby, et al., 1930; their Figure 4). The results of this study support this early work and indicate that ice deployment, as evidenced by characteristics of both provenance

Figure 11. Location map of provenance study area and sample sites. Dashed line is 7600 ft. contour. Triangles indicate provenance sample locations, circles indicate soil profile locations. Moraines A, B, C, D, E, and F are discussed in the text. Also see Appendix III and Plate 1.


Moraine A
Moraine B
Moraine C
Moraine D
Moraine E
Moraine F
BL-A
BL-B
BL-C
PD-A
PD-B
PD-C
Kane Creek
Summit Creek
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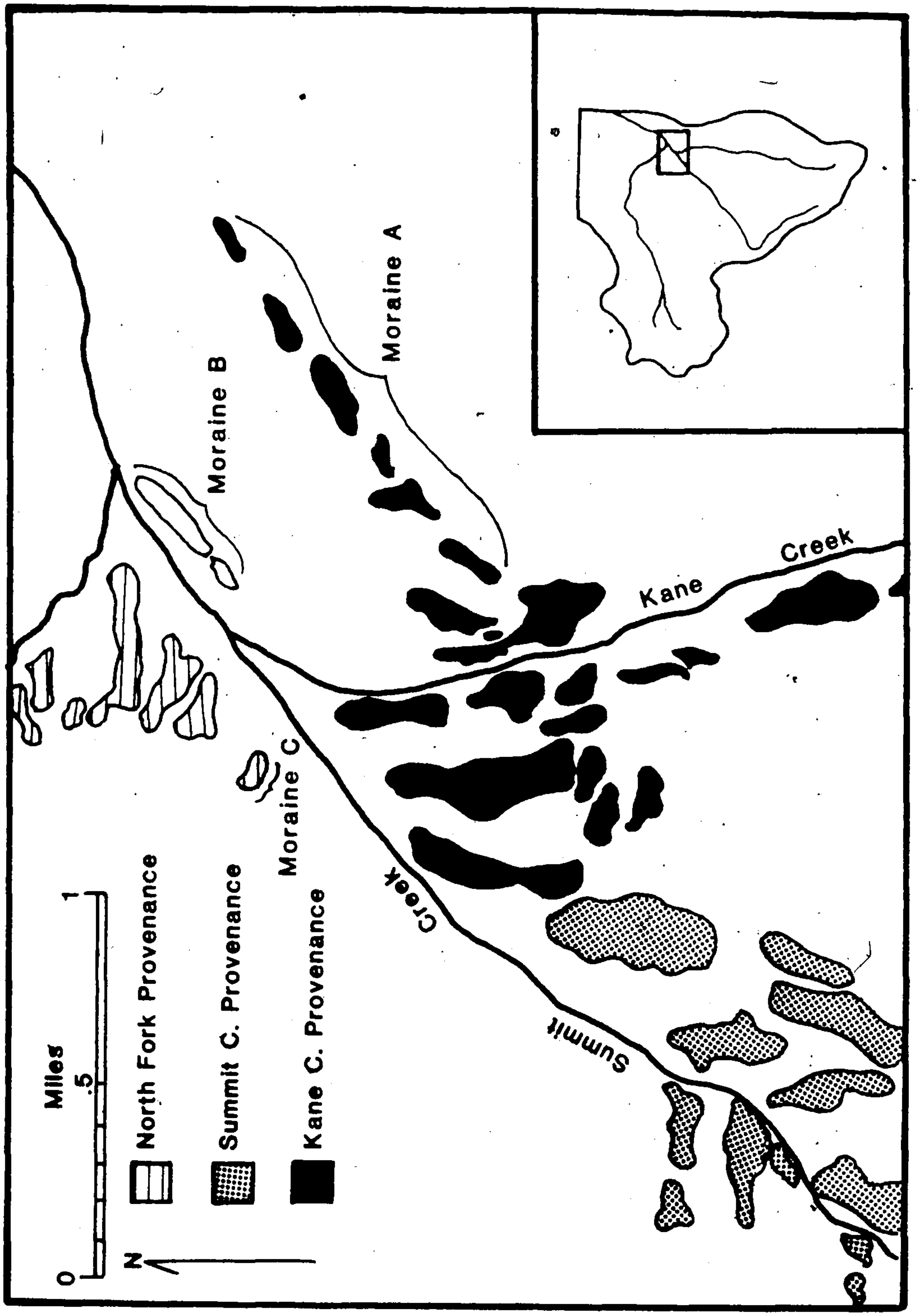


Figure 12. Provenance of moraine complexes, see Figure 11 for location. Unpatterned moraine (Moraine "B", Figure 4) is of undetermined provenance.

and moraine geometry, consisted of three mutually independent trunk glaciers; the Kane Creek Canyon glacier, the Summit Creek Canyon glacier, and the North Fork glacier (e.g. Figures 6, 8, 9, and 10). Although varying in length, number of tributaries, thickness, and extent of southern exposure of source area, these three ice streams probably reacted synchronously, and to a similar extent, to changes of climatic conditions.

No individual bedrock lithology is unique to the drainage of any single valley in the study area. For this reason, the deposits of the three principal trunk glaciers had to be differentiated by characteristic till pebble lithology suites. An attempt was made to quantify the results of this portion of this study (Parks, 1966, 1970), however there was insufficient data (R-mode factor analysis required 6 factors to account for 80% of the variance, which is too many factors for the number of data variables). Thus, the following discussion serves only as a qualitative review of the results provenance investigations, and the three major pebble suites (Kane Creek Canyon, North Fork Canyon, and Summit Creek Canyon).

The predominant lithology group in tills deposited by the Kane Creek Canyon glacier (Figure 12; sample sites 3, 4, 10, 13, 14, 15, 16, 17; Figure 11) is the carbonate-clastic lithologies of the Copper Basin Group (54-29%; Appendix III), found throughout the study area (Figure 3). The headwaters of Kane Creek, however, are in part underlain by the Wildhorse Migmatite Complex (Lithology M; Figure 3) and as a result, tills deposited by ice with this source area contain clasts of amphibolite (0 to 2%), quartzite (0 to 10%), and other crystalline lithologies (0 to 27%; Appendix III). Although the Kane Creek Canyon is not the only canyon in the study area incised into the migmatite complex, it is, however, more extensively incised in the migmatite than any other canyon. Therefore, any till found within the provenance study area with a substantial portion of migmatite clasts is considered to have been deposited by ice flowing out of Kane Creek Canyon.

Most of the drainage basin of Summit Creek is underlain by the carbonate clastics of the Copper Basin Group (Lithology C; Figure 3). As expected, these lithologies predominate (36 to 82%; Appendix III) in tills deposited by the Summit Creek Canyon glacier (sample sites 1, 2, 7, 8, 11, 18, 19, 20, 21, and 22; Figure 11). Of secondary importance in these tills are clasts of the Cretaceous intrusives (14 to 46%), found in both Phi Kappa and Summit Creek Canyons (Lithology I; Figure 3). The Summit Creek intrusives range in composition from granite to quartz monzonite and are easily recognized in provenance samples. Though these are not the only intrusives in the area, these particular lithologies are quite distinctive and restricted in areal extent (Figure 3). Moraines deposited by Summit Creek Canyon ice which flowed over these intrusives are readily differentiated from other moraines in the area on the basis of provenance.

Moraines deposited by the North Fork Canyon glacier (Figure 12) had no distinctive lithologies unique to this drainage (sample sites 5 and 6; Figure 11). Rather, negative evidence (the absence of intrusive or migmatitic clasts), along with high percentages (29 to 34%; Appendix III) of Challis Volcanics and carbonate-clastics of the Copper Basin Group (55 to 64%), was used to distinguish deposits of this provenance. Since deposits of this provenance were, for the most part (Figure 12), restricted to North Fork Canyon and its mouth, these criteria were not heavily relied upon. In the case of moraines of complex origin (deposited by more than one ice stream; see discussion, p. 57), at least partial deposition by ice flowing from North Fork Canyon was evidenced by a distinctive calcium carbonate horizon (Cca horizon). This Cca horizon was only recognized in moraines of this provenance (Figure 11; sites 5 and 6; Soil Profiles Pd-B and Bl-B).

As discussed, there was insufficient data to allow complete confidence in the results of this provenance study. When used in conjunction with geometry of moraines and flow direction indicators, however, provenance was useful in the reconstruction of patterns of glaciation and deglaciation.

Provenance and geometry of Kane Advance moraines (Figure 12) indicate that during their deposition, the three principal trunk glaciers in the study area were in contact, and may have merged to form a complex valley glacier during the Kane Advance Maximum. Ice flowing westward out of Kane Creek Canyon advanced well into Summit Creek Canyon and either "expanded", or was "turned" northeastward by the Summit Creek Canyon glacier (indicated by Moraine A, Figure 11). This northeastward shift in flow was caused by the interaction of the Kane Creek Canyon glacier with at least one other of the principal glaciers in the area. The nature and extent of this interaction, however, is difficult to discern.

As previously discussed, Moraine B of Figure 11 has a pebble lithology provenance characteristic of ice eminating from North Fork Canyon (29% volcanics, 55% carbonate-clastics, sample 5, Figure 11; Appendix III), but also has clasts indicative of at least one other source area (9% intrusives, Summit Creek source area; 7% migmatite, Kane Canyon source area; Appendix III). It is therefore believed that Moraine B of Figure 11 represents either: a) an interlobate end moraine deposited between the Kane Creek Canyon glacier and the North Fork Canyon glacier (Figure 13) if the secondary source of clasts is Kane Canyon ice; or b) a medial moraine deposited between ice streams flowing out of North Fork and Summit Creek Canyons (Figure 14) if the secondary source is Summit Creek Canyon. Provenance data is inconclusive, therefore the origin of Moraine B remains problematic.

Provenance studies of moraines of the North Fork Advance aided in the "assignment" of individual moraines to·their source

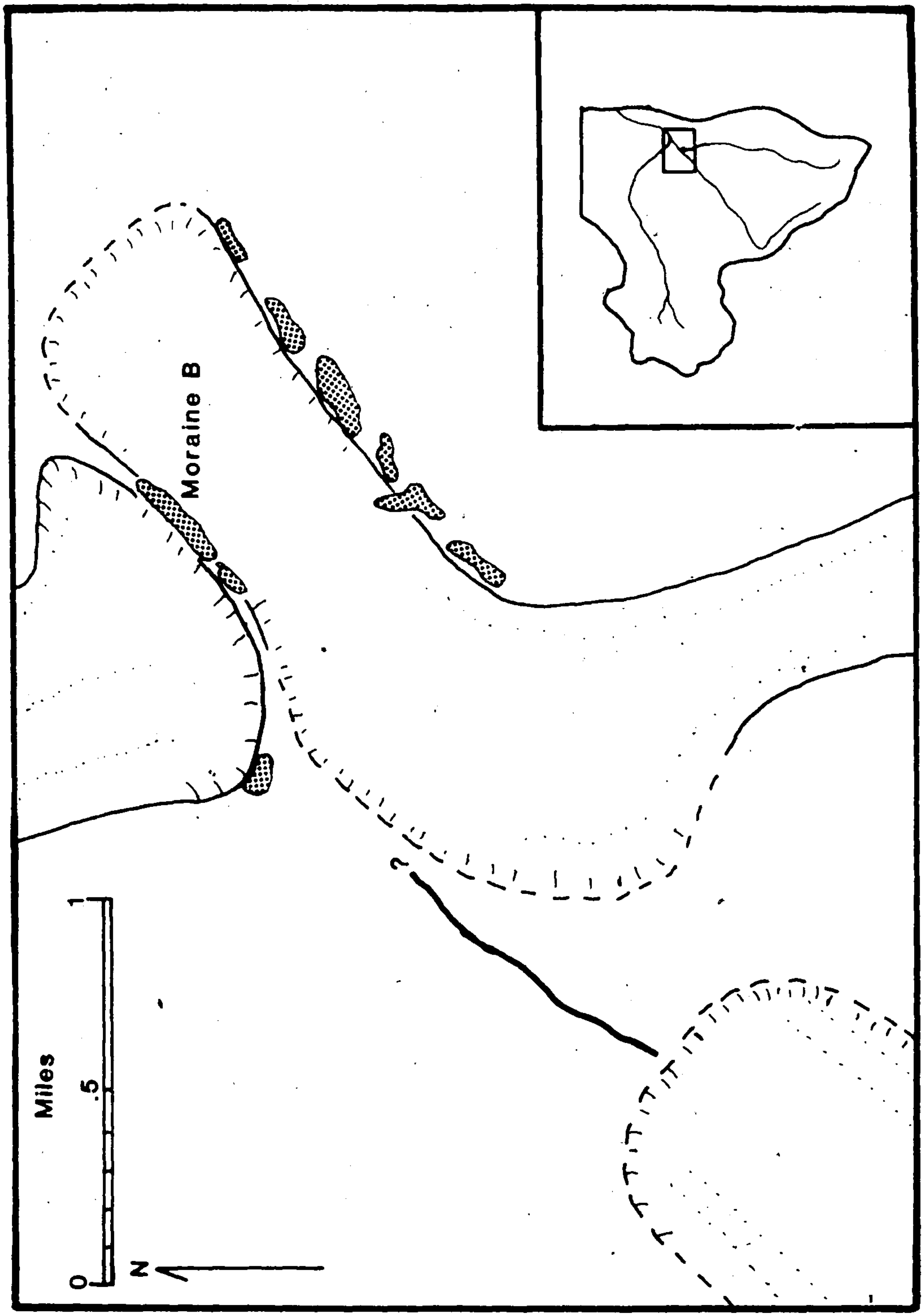


Figure 13. Possible origin of a Kane Advance Moraine (Moraine "B", Figure 11); A) interlobate end moraine. Stippled moraines are Kane Advance Moraines, see Figure 11 for location.

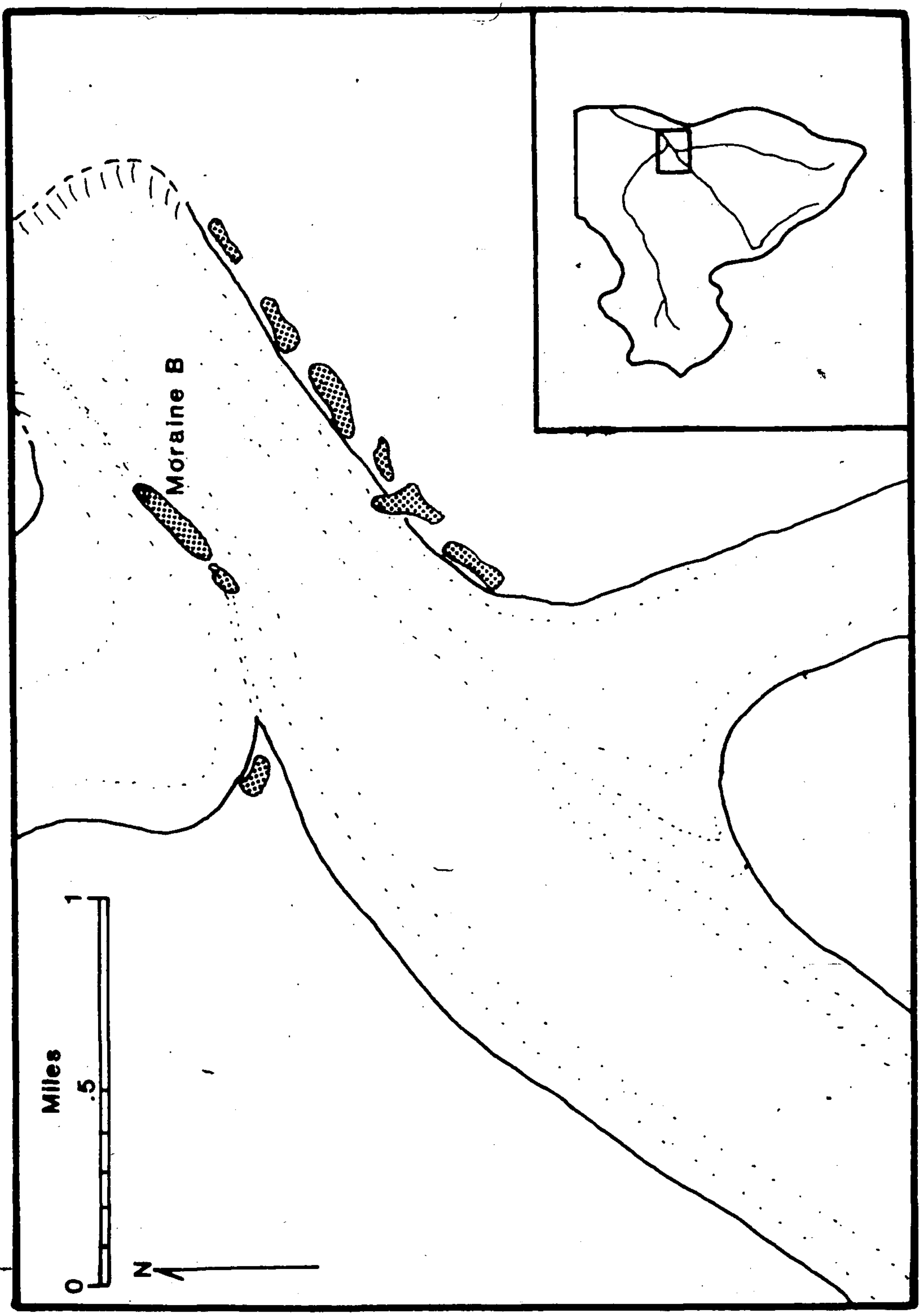


Figure 14. Possible origin of a Kane Advance Moraine (Moraine "B", Figure 11); B) medial moraine. Stippled moraines are Kane Advance Moraines, see Figure 11 for location.

area (Figure 12). As indicated by moraine geometry, glaciation was less extensive during the deposition of the moraines of the North Fork Advance and there was less interaction between the termini of the three principal glaciers. As previously discussed, only Kane Canyon (Moraine F, Figure 11; Samples 13 and 14, Appendix III) and Summit Creek Canyon (Moraine E, Figure 11; Samples 8 and 11, Appendix III) valley glaciers converged, resulting in a westward shift of flow of the Summit Creek Canyon ice. This occurred only during the maximum extent of the North Fork Advance (NF I; Figure 5 and Plate 1). Moraine geometry and provenance analysis indicates that during subsequent periods of deposition (NF II through NF IV) the termini of the three principal glaciers were not in contact.

Laboratory Analysis: Determination of Relative Age

This study was designed to determine if pedogenic characteristics (clay mineral variation) could be used to quantitatively differentiate glacial deposits of varying age in the investigation area. Clay mineral variation was selected because it appeared, in previous studies (Wigley, et al., 1978; Stewart, 1977; Wigley, 1976), to best reflect soil development as a function of age.

Soil Development

Soil profiles form during episodes of landscape stability, when erosion and deposition are negligible (Morrison, 1978).

Soil stratigraphic studies have aided in the subdivision of local deposits, provided data on interval lengths between periods of deposition, and facilitated short- to long-range correlations in the Rocky Mountains (Birkeland, 1974). Any given soil stratigraphic unit is subject to lateral variation in its physical and chemical characteristics caused by changes in parent material, slope, climate, vegetation, and subsequent erosional modifications (Morrison, 1978). This study examined variations in clay mineralogy within soil profiles of tills that have been differentiated as Kane and North Fork Advances in the field using relative age dating techniques, in an effort to determine if this particular pedologic characteristic would enable quantifiable differentiation. The isolated nature of deposits in the study area prevents correlation with deposits in adjacent drainage basins, therefore, a means by which glacial deposits could be quantitatively differentiated in each basin (using clay mineral percentages) might enable accurate short-distance correlations.

Six soil pits (Plate 1 and Figure 11) were excavated on moraine crests (between 2300 and 2500 m above sea level) within a small enough area to consider climate and vegetation constant. The climate is typical of an alpine semi-arid basin, with rainfall averaging 40 to 50 cm per year (Knoll and Dort, 1973). Maximum precipitation occurs in the winter months, averaging 5.3 to 5.6 cm per month, dropping to 0.5 cm per month during the summer. The mean annual air temperature is 6.4°C, with an average of 20°C in July; and a January average of -7.4°C.

Vegetation is characteristic of a sagebrush steppe community, composed primarily of *Artemesia tridentata* (big sage), *Festuca idahoensis* (Idaho fescue), *Agropyron spicatum* (bluebunch wheatgrass), and scattered communities of *Poa* spp. (sandburg bluegrass) and *Phlox* spp. (long leaf and Hood's phlox) (Knoll and Dort, 1973).

Since climatic and vegetative factors are essentially constant for all the soil profiles excavated, the variables that would have affected pedogenesis in the study area are assumed to be parent material, slope, time, and paleo-climatic fluctuations.

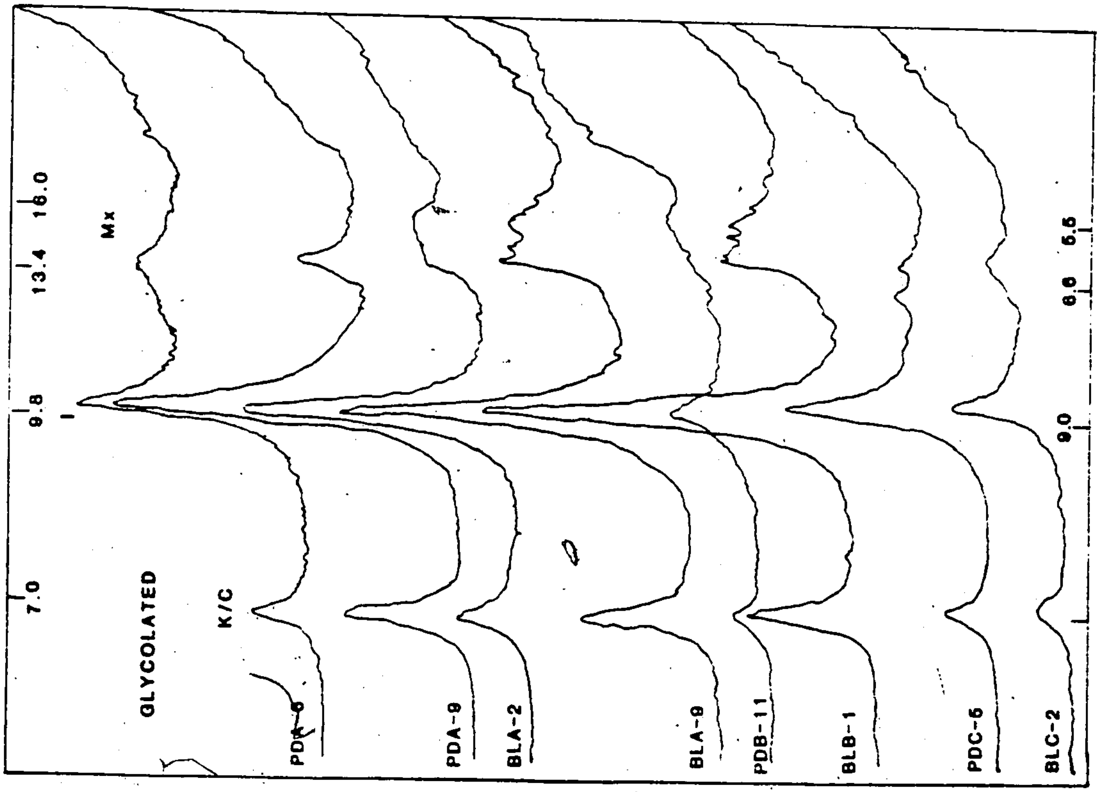
All soils sampled are calcorthids (PDB and BLB; Appendix II) or camborthids (PDA, PDC, BLA, and BLC; Appendix II), depending upon the extent of development of the calcic horizon at the base of the solum (a Cca horizon is present in calcorthids). Soil profiles are weakly to moderately developed and are characterized by cambic B horizons and at least stage I calcium carbonate accumulations at the base of the solum. The soils reflect a poorly leached, closed chemical system, which are typified by high base levels in the cambic horizons (Buol, et al., 1973).

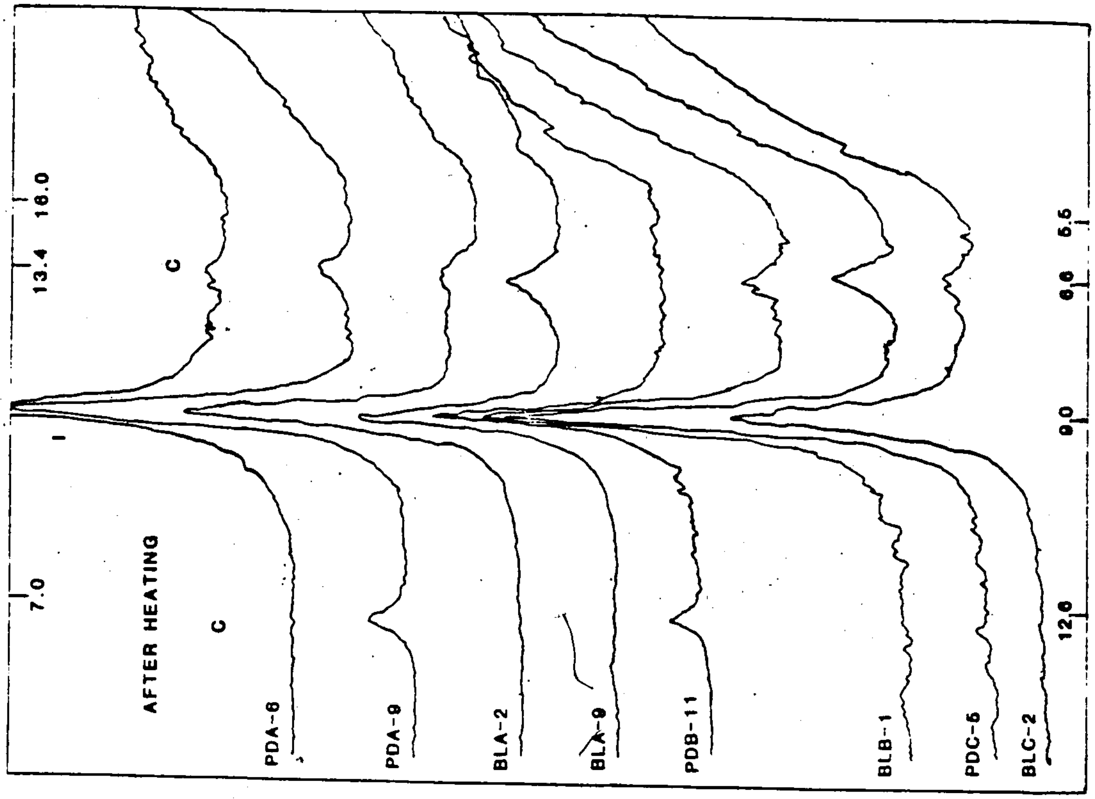
Soil Clays

Previous workers in the Pioneer Mountains (Evenson, et al., 1979; Wigley, et al., 1978; Stewart, 1977; Wigley, 1976) have investigated clay mineral variation in soils developed on tills. Using semi-quantitative clay mineral determinations (Biscaye, 1965) and multivariate analysis, these workers noted trends in the vertical abundances of four clay mineral variables (montmorillonite, illite, chlorite and kaolinite, and relative percent of chlorite vs. kaolinite) with age. These studies concluded that soils in the Pioneer Mountains are characterized by the build up of alteration products of pedogenesis in the B horizon with time. The alteration products include; illite, from chlorite in the parent material (till), and montmorillonite, from illite which is both an alteration product and a parent mineral. This study attempted to further document this characteristic in soils developed on tills in a different area in the Pioneer Mountains.

In soils developed on tills in the Wildhorse Canyon area (immediately adjacent to the study area), montmorillonite in the finest clay fractions (smaller than 49μm) was assumed to represent the ultimate weathering clay alteration product (Stewart, 1977). The sharp 16Å montmorillonite peak reported by Stewart (1977) and Wigley (1976), however, was not found in soil samples from the North Fork area, instead, a broad, poorly defined variable peak was encountered in most samples between 15.6Å and 16.4Å (Figure 15). This type of peak (broad and poorly defined) is believed to represent a considerable amount of masking of montmorillonite by interlayer clays (Carrol, 1970). Following heating at 500°C for

Figure 15. Ten randomly selected X-ray diffraction patterns of soil clays in the study area, before and after heating at 500 C for 12 hours. Principle Peaks: Mx - Mixed layer clays; I - Illite; C - Chlorite; K/C - Kaolinite and Chlorite combined.


GLYCOLATED
K/C
Mx
7.0
9.8
13.4
16.0
9.0
6.6
5.5
PDA-6
PDA-9
BLA-2
BLA-9
PDB-11
BLB-1
PDC-5
BLC-2


AFTER HEATING
C
C
I
7.0
13.4
16.0
12.8
9.0
6.6
5.5
PDA-6
PDA-9
BLA-2
BLA-9
PDB-11
BLB-1
PDC-5
BLC-2

12 hours, this peak was substantially reduced or absent (Figure 15) indicating that the original peak (that measured prior to heating) was made up predominantly by mixed layer clays and that the North Fork soils studied here contain minimal amounts of montmorillonite.

In previous studies (Wigley, et al., 1978; Stewart, 1977; Wigley, 1976) montmorillonite was encountered in soils of all ages, thus eliminating the possibility that soils in the North Fork area had simply not had enough time to pedogenically generate montmorillonite. Other factors which may have resulted in the dichotomy of these results and the results of previous workers include technique and parent material, however, the extent of influence of either of these two factors cannot be determined.

The absence of montmorillonite as indicated by X-rays of heated samples (Appendix IV), from soils in the study area eliminates one of the four variables (e.g. montmorillonite, illite, chlorite and kaolinite, and percent chlorite vs. kaolinite) with which soils of different ages can be distinguished.

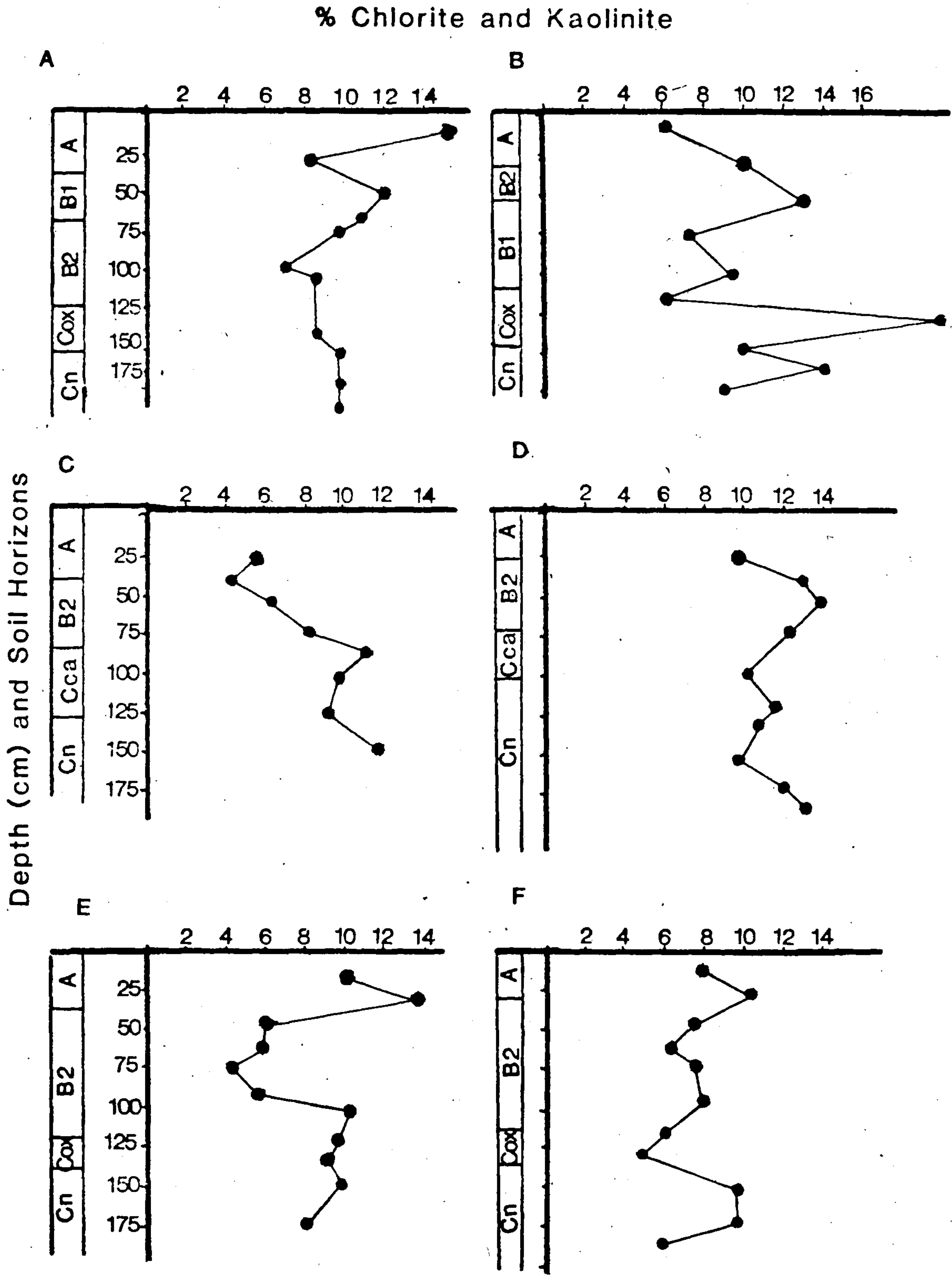
An attempt to differentiate relative percents of chlorite vs. kaolinite was made on samples of two soil profiles (BLA 1-10, PDA 1-6; Appendix IV) in tills of the same provenance. In none of the samples could the difference between relative heights of the secondary peak of chlorite (3.5Å) and kaolinite (5.0Å) be determined. Because variations between the amounts of chlorite and kaolinite could not be determined, both minerals probably occur in equal amounts in soils in the study area.

Since relative amounts of chlorite and kaolinite were indistinguishable, and montmorillonite is absent from the soil clays studied (Appendix IV), the four variables (montmorillonite, illite, chlorite and kaolinite, percent chlorite vs. kaolinite) that previous workers in the Pioneer Mountains (Wigley, et al., 1978; Stewart, 1977; Wigley, 1977) utilized to distinguish tills of differing ages were reduced to two (illite, and chlorite and kaolinite) in the soils of the North Fork area.

Relative changes in percent chlorite and kaolinite in soil clays are presented here (Figure 16). Figure 16 includes the results of soil profiles excavated in moraines of both the Kane and North Fork Advances that were deposited by ice flowing out of Kane Creek Canyon (Figure 16, Profiles A and B), North Fork Canyon (Profiles C and D), and Summit Creek Canyon (Profiles E and F).

The percent chlorite and kaolinite curve of soil profile BLA (Plate 1; Figure 11), has a distinct peak (12 to 20 cm, Profile A; Figure 16) which coincides with the B1 and upper B2 horizons on this older soil (Kane Advance). This B1 horizon peak of percent chlorite and kaolinite is also recognized in the younger soil (North Fork Advance) in till of this provenance (Kane Creek Canyon Provenance), however, the North Fork Advance soil (Profile B; Figure 16) there is an additional, more prominant peak coinciding with the Cox horizon (50 cm) which is not recognized in the soil of the older advance (Profile A). Although the B horizon

Figure 16. Percent chlorite and kaolinite (combined) with depth in soil profiles. Soil horizons are given at right. Profile A = BLA, B = PDA, C = BLB, D = PDB, E = BLC, F = PDC (see Figure 11 for location). Also, see Appendix IV and Plate 1 (map).


% Chlorite and Kaolinite
Depth (cm) and Soil Horizons
A
2 4 6 8 10 12 14
A
B1
B2
Cox
Cn
25
50
75
100
125
150
175
B
2 4 6 8 10 12 14 16
A
B2
B1
Cox
Cn
C
2 4 6 8 10 12 14
A
B2
Cca
Cn
25
50
75
100
125
150
175
D
2 4 6 8 10 12 14
A
B2
Cca
Cn
E
2 4 6 8 10 12 14
A
B2
Cox
Cn
25
50
75
100
125
150
175
F
2 4 6 8 10 12 14
A
B2
Cox
Cn

peaks in both these profiles (Profiles A and B) are distinctive, they represent only a 4 to 6% increase in chlorite and kaolinite combined and are therefore believed to have minimal significance.

In soils in drift deposited by ice flowing out of North Fork Canyon (Figure 16; Profiles C and D), again chlorite and kaolinite percentages change very little (4 to 7%) throughout the length of the soil profile. As with the previously discussed profiles (Profiles A and B), peaks in Profiles C and D are distinct, but no clear pattern can be recognized which would enable the differentiation of these two soils, or enable the correlation of these two soils with the soils of Profiles A and B (Figure 16).

Profiles E and F present the percent chlorite and kaolinite curves of soil profiles in two moraines of the North Fork Advance (North Fork I and North Fork II, Plate I and Figure 11) which were deposited by ice flowing out of Summit Creek Canyon (no Kane Advance moraines deposited solely by ice flowing out of Summit Creek Canyon were recognized in the area). As with the profiles previously described, neither does the extent nor pattern of the variation of percent chlorite and kaolinite enable correlation with other North Fork Advance soils or the differentiation of these two soils.

The lack of any clear patterns in the variation of clay minerals in the study area (due in part to the reduced number of clay mineral variables; two variables from four), prohibits the differentiation, quantitatively, of moraines of drifts of differing ages. Although soil studies have been used elsewhere to differentiate Quaternary deposits (Birkeland, 1974), no suitable quantifiable soil characteristic has been determined for this purpose in the Pioneer Mountains.

It is possible that during the interval between the older and younger advances in this area, that climatic conditions inhibited pedogenesis, or erased all previous pedogenesis during a later advance through extensive cryoturbation. If this were the case, all soils in the study area would be of the same "age", although they were formed on features of varying ages. At present, however, no information exists for glacial or interglacial paleoclimatic conditions in the Pioneer Mountains.

CONCLUSIONS

The drainage area of the North Fork of the Big Lost River has been modified by at least two major episodes of glaciation, both of which resulted in the deposition of a number of moraine complexes. These moraines have been differentiated by a number of relative age dating techniques (moraine morphology, pedogenic characteristics, extent of glaciation, terrace associations), and grouped into informal units here named; the "Kane Advance" (oldest) and the "North Fork Advance" (Appendix I). Evidence of minor Neoglacial activity has also been documented in the form of rock-glaciers in present day cirques.

The relative age stratigraphy nomenclature (Birkeland, et al., 1979) developed for this study area further extends the Rocky Mountain Glacial Model (Mears, 1976) to south-central Idaho. It is not possible at this time to correlate deposits in this study area with the time-stratigraphic units of the Rocky Mountain Model (Table 1) at their type-localities in the Wind River Range, Wyoming. However, deposits of the three advances mapped (Kane Advance, North Fork Advance, and Neoglacial) are tentatively correlated with deposits mapped elsewhere in the Pioneer Mountains using relative age dating techniques (Wigley, et al., 1978; Stewart, 1977; Wigley, 1976).

The Kane Advance (oldest) is represented by three groups of morainic deposits. Through reconstruction of ice lobe geometry and provenance analysis, it has been tentatively assumed that these moraines were deposited synchronously. Although Kane Advance moraines are readily distinguishable from North Fork Advance moraines, no terrace levels or glaciofluvial gravels were found in association with Kane Advance moraines, inhibiting further stratigraphic correlations and reconstructions.

Multiple, well preserved, recessional moraines of the North Fork Advance indicate that there were at least four "stadials" during this episode of glaciation. Deposits of the three oldest stadials have been correlated principally on the basis of down-valley extent and stratigraphic association to glaciofluvial terraces. Deposits of the final stadial (North Fork IV) were deposited well up-valley from all older moraines in both tributary and trunk stream valleys. Because of their isolated nature, it is unknown whether deposits of this stadial were formed synchronously or represent local (individual valleys) interruptions of deglaciation of varying extent and duration.

Provenance studies were undertaken in order to determine the source area for moraines in Summit Creek Canyon, which were deposited by mutually independent ice streams. The determination of source area enabled the reconstruction of ice lobe geometry during varying extents of glaciation (Figures 6 through 9).

Provenance data indicate moraine complexes were deposited by three compound valley glaciers flowing out of North Fork (Volcanic-rich deposits), Kane Creek (Migmatite-rich deposits), and Summit Creek (Intrusive-rich deposits) Canyons (Figures 3, 11, and 12). During the maximum extent of glaciation (Kane Advance), two or three of these major valley glaciers combined, but did not mix, to form a compound foot (Figure 13), or complex valley (Figure 14) glacier. During the North Fork Advance maximum (N.F. I), the expanding "foot" of ice flowing out of Kane Creek Canyon diverted flow of ice in Summit Creek Canyon to the west (Figure 6). This was the only time during the North Fork Advance that any of the termini of the three principal ice streams were in contact.

Field relationships and analysis (pedologic and morphologic) of Kane and North Fork Advance deposits and soils developed on the moraines of these advances demonstrate:

A) Differentiation of the deposits of the two episodes of glaciation (Kane and North Fork Advances) can readily be accomplished in the field by morphologic (see p. 31) and pedologic parameters (see p. 36).

B) The differentiation and correlation of the moraines of a single advance with multiple stades (e.g.; North Fork I, II, III, and IV) can most accurately be made using genetic to glaciofluvial terraces and down-valley extent of glaciation (see p. 40).

C) The alteration of clay minerals (finer than 49μm) show no consistant variation with either depth or age (see p. 67). The absence of any clearly distinctive characteristic in soils of the two advances may be due to: 1) the attainment of a terminal grade of soils early in their development; 2) interglacial climatic conditions that inhibited pedogenesis; or 3) post-glacial climatic conditions (periglacial) which erased the effects of previous pedogenesis. The inability to distinguish relative percentages of chlorite and kaolinite and the absence of montmorillonite from soils in the study area may have reduced the effectiveness of this study.

The results of laboratory studies indicate that the clay mineral variation expected as a function of age may not be a viable parameter for the quantitative differentiation of glacial deposits in the study area. The results of this, and previous studies, may indicate that a method of correlating and distinguishing glacial deposits for the entire region using one quantitative pedologic characteristic may not exist.

FURTHER RESEARCH

The resolution of this study will be greatly enhanced by the results of further provenance studies now being completed (Repsher, 1981; Repsher, et al., 1980). Future work concerning pedologic characteristics might focus on the variation of calcium carbonate and carbonate content with depth and age. This type of study would be especially valuable in tills of suitable parent material underlying sagebrush communities.

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Appendix I

Stratigraphic Nomenclature

The problems of the stratigraphic nomenclature of the glacial deposits of the Rocky Mountains have existed since Blackwelder (1914) used the same terms in a morpho- (e.g.; Pinedale Moraine) and a climato- (Pinedale Glaciation) stratigraphic sense. Since then, workers in the Rocky Mountains have generally taken two approaches for naming glacial deposits; either using the same stratigraphic names over large areas, or proposing new formal names for deposits in each drainage basin (Birkeland, et al., 1979). The problems with the former approach is that using the same stratigraphic name implies long-distance correlations which have often not been sufficiently documented. The problem with the latter approach is that there is an exorbitant number of terms in use, resulting in confusion among workers outside the area. To avoid these problems, this study proposes a new, <u>informal</u> stratigraphic nomenclature for use only until deposits in the area can be correlated with, and included in, a more far-reaching stratigraphic system in the drainage of the North Fork of the Big Lost River.

The nomenclature developed for this study was designed to avoid both the implications of long-distance correlation, and the ambiguities of the terms,"Bull Lake" and "Pinedale" (previously used in the Pioneer Mountains), which have been used at various times for morpho-, climato-, soil-, rock-, and chrono-stratigraphic designations throughout the Rocky Mountains. In addition, the term, "Advance" was used in this study rather than the morphostratigraphic term, "drift" recognized by the Illinois Geologic Survey (Willman and Frye, 1970), because multiple relative dating techniques were used, including soil, morphologic, and weathering characteristics. This study then utilizes the Relative-Dating Stratigraphy of Birkeland, et al. (1979) with units defined by "physical features resulting from post-depositional modification, the extent of which depends on age" (Birkeland, et al., 1979).

The following is a description of the terms (Kane Advance, North Fork Advance) used in this study. Informal names, rather than letters (e.g.; Crandell, 1967), were used for ease of correlation to adjacent basins in which similar studies were undertaken.

Deposits assigned to the Kane Advance include moraines which have characteristics similar to those of the Bull Lake deposits of the Wind River Range, Wyoming (Richmond, 1962b, 1965, 1976). Moraines of the Kane Advance are well dissected, morphologically subdued, and contain no undrained hollows. In the study area, moraines of the Kane Advance are found down-valley of moraines of the younger advance. A type location is here designated for the Kane Advance, it is the moraine located northeast of the mouth of Kane Creek Canyon, in Summit Creek Canyon (Moraine A, Figure 4).

The North Fork Advance (younger) includes all other moraines (than the Kane Advance Moraines) in the study area. Moraines of this advance are well preserved, poorly dissected, and reflect several stadials of deposition. All moraines of the North Fork Advance are located up-valley from moraines of the Kane Advance. A type locality for the North Fork Advance is here designated as the moraine in the mouth of North Fork Canyon, due east of the confluence of Kane and Summit Creeks (Moraine D, Figure 5).

Two distinct levels of glaciofluvial gravels (18m and 5m above present stream level) were mapped in the study area, both are genetically associated to moraines of the North Fork Advance. These gravels are included in the North Fork Advance on Plate 1 and in discussions in the text of this study.

Appendix II

Soil Profiles

This appendix contains detailed description of all soil profiles sampled. Soil sample sites are located on Plate 1 and Figure 11. Observations are an integration of field logging and laboratory analysis. The soils are classified and described according to the guidelines of the Soil Survey Staff, U.S.D.A. (1951), 7th Approximation.

Profile: BLA

Age: Kane Advance

Location: Kane moraine complex north of Kane Creek in Summit Creek Canyon (Moraine A, Figure 11); 7280 ft. (2219 m).

Parent Material: Till, predominantly Copper Basin Group clastics (60%) and Migmatite lithologies (32%).

Classification: Camborthid

Soil Horizons	Depth (cm)	Description
A	0-36	Dark yellowish-brown (10YR 4/6) fine silt loam with well-developed blocky peds. Till clasts are cracked and weathered. Unreactive to HCl.
B	36-67	Olive brown (2.5YR 4/4) very fine silt loam with well-developed blocky peds. Pebbles are completely coated and crystalline clasts are grussified. Soil is slightly reactive with HCl.
B2	67-122	Yellowish-brown (10YR 5/4) texturally same as B1 horizon. Migmatite clasts are highly grussified, "ghost" pebbles are present. Soil is reactive to HCl.
Cox	122-154	Olive yellow (2.5Y 6/6) fine silt loam, with some ped development. Pebbles are highly weathered and coated.
Cn	154-193	Olive (5Y 4/4) coarse grained pebble matrix of unweathered argillite clasts. Unreactive to HCl with depth.

Sampling: [No. - depth (cm)]

#1 - 190
#2 - 176
#3 - 158
#4 - 142

Sampling (cont.):

#5 - 114
#6 - 95
#7 - 77
#8 - 67
#9 - 52
#10 - 34
#11 - 15

Profile: PDA

Age: North Fork Advance

Location: Terminal North Fork Moraine (N.F.I) at mouth of Kane Creek (Figure 11); 7280 ft. (2219 m).

Parent Material: Till, predominantly clastics of the Copper Basin Group (70%) with Migmatite (20%) lithologies.

Classification: Camborthid

Soil Horizons	Depth below surface (cm)	Description
$A_{\text{(ochric)}}$	0-32	Dark yellowish brown (10YR 4/6) fine to very fine grained silt loam. Well-developed soil peds, sticky, not plastic. Gradation (5 cm) contact with cambic horizon.
B_{1} (cambic)	32-60	Light grey (10YR 7/2) fine to medium grained silt loam. Some soil ped development. Highly weathered argillite clasts and grussified migmatite clasts. Reacts to HCl.
B_2	60-113	Brown-dark brown (7.5YR 4/4) texturally same as B_1 horizon. Similar reaction to HCl.
Cox	113-145	Color varies (approximately olive yellow; 5YR 6/6). Lenses of leaching result in variable color appearange of unweathered clasts.
Cn	145-191	Dark brown (7.5YR 4/4) medium grained silt loam. Few soil peds, not sticky, unweathered argillite clasts are common.

Sampling: [No. - depth (cm)]

#1 - 178
#2 - 163
#3 - 147

Sampling (cont.):

#4 - 132
#5 - 117
#6 - 102
#7 - 76
#8 - 53
#9 - 30
#10 - 10

Profile: BLB

Age: Kane Advance

Location: Interlobate (?) Moraine at mouth of North Fork Canyon (Moraine B, Figure 11); 7160 ft. (2182 m).

Parent Material: Till, predominantly Copper Basin Group (55%) and Challis (24%) clasts, with some Intrusive and Migmatite lithologies.

Classification: Calcorthid

Soil Horizons	Depth below surface (cm)	Description
$\mathrm{A}_{\text{(ochric)}}$	0-41	Strong brown (7.5YR 5/6) plastic soil with well-formed peds. Pebbles are predominantly grussified.
B_2(cambic)	41-77	Reddish brown (5YR 4/3) fine silty loam, with well-formed peds. Thick weathering rinds in argillite clasts, crystalline clasts are well grussified. Gradational contact with Cca horizon.
Cca	77-127	Varying color. Distinctive change in competancy to "hard pan". All pebbles are completely coated with $CaCO_3$. Horizon very reactive to HCl.
Cn	127-152+	Dark brown (10YR 4/3) slightly reactive to HCl (reactivity decreases with depth). Unweathered pebbles are encountered increasingly with depth.

Sampling: [No. - depth (cm)]

#1 - 150
#2 - 124
#3 - 107
#4 - 90
#5 - 75

Sampling (cont.):

#6 - 57
#7 - 41
#8 - 32
#9 - 13

Profile: PDB

Age: North Fork Advance

Location: North Fork Terminal (N.F.I.) moraine in mouth of North Fork Canyon (Moraine D, Figure 11); 7120 ft. (2170 m).

Parent Material: Till, consisting of Copper Basin Group (64%) and Challis (34%) lithologies.

Classification: Calcorthid

Soil Horizons	Depth below surface (cm)	Description
A	0-23	Reddish brown (5YR 4/4) blocky, well-developed peds, well cemented and sticky. Reactive to HCl and some coating of pebbles.
B_2	23-58	Dark brown (7.5YR 3/2) well cemented, very blocky, sandy loam. Pebbles are well weathered and $CaCO_3$ coated.
Cca (?)	58-104	Varying color, poorly developed horizon. Well cemented and very reactive to HCl.
Cn	89-185+	Light olive brown (2.5YR 5/4) silty loam with large unweathered pebbles. Decreasing reactivity to HCl with depth.

Sampling: [No. - depth (cm)]

#1 - 185
#2 - 173
#3 - 157
#4 - 134
#5 - 119
#6 - 104
#7 - 86
#8 - 71
#9 - 53
#10 - 38
#11 - 23

Profile: BLC

Age: North Fork Advance

Location: North Fork Terminal (N.F.I) moraine in Summit Creek Canyon between Kane and Phi Kappa Creeks (Moraine E, Figure 11); 7400 ft. (2256 m).

Parent Material: Till, predominantly Summit Creek intrusives (38%) and Copper Basin Group (58%) clasts.

Classification: Camborthid

Soil Horizons	Depth below surface (cm)	Description
A	0-36	Brown (7.5YR 5/4) fine sand loam. Plastic not sticky, blocky ped development
B_2	36-124	Very dark grayish brown (10YR 3/2) fine sandy loam. Soil is neither sticky or plastic. Horizon does not react with HCl.
Cox	124-147	Black (5YR 2.5/1) fine sand matrix with few peds. Argillite clasts common, horizon reacts to HCl.
Cn	147-170+	Very dark grey (5YR 3/1) fine sand loam. Increased number of argillite clasts, decreased reaction to HCl.

Sampling: [No. - depth (cm)]

#1 - 168
#2 - 152
#3 - 137
#4 - 122
#5 - 107
#6 - 91
#7 - 76
#8 - 61
#9 - 46
#10 - 30
#11 - 15

Profile: PDC

Age: North Fork Advance

Location: North Fork Recessional (N.F.III) moraine in Summit Creek between Kane and Phi Kappa Creeks; 7400 ft. (2256 m).

Parent Material: Till, predominantly Summit Creek Intrusive (46%) and Copper Basin Group (61%) clasts.

Classification: Camborthid

Soil Horizons	Depth below surface (cm)	Description
A	0-34	Dark yellowish brown (10YR 4/4) moderately developed blocky peds, soil neither sticky nor plastic. Fine sand loam. Not reactive to HCl.
B_2	34-122	Olive brown (2.5YR 4/4) fine sand loam. Moderate ped development. Friable and poorly compacted. Not reactive to HCl.
Cn	122-193+	Variable color fine sand loam. Soil is friable with no ped development both argillite and crystalline clasts are unweathered uppermost 15 cm are slightly reactive to HCl.

Sampling: [No. - depth (cm)]

#1 - 188
#2 - 173
#3 - 157
#4 - 137
#5 - 117
#6 - 97
#7 - 76
#8 - 64
#9 - 48
#10 - 30
#11 - 11

Appendix III

Provenance Analysis

This appendix contains the results of provenance analysis of pebbles. Percentages of lithologies listed are based on counts of approximately 50 or more. Sample locations are located on Figure 11. Individual lithologies have been grouped in bedrock lithologies described and located in Figure 3.

	Copper Basin Group				Wildhorse Migmatite Complex			Summit Creek Intrusives			Challis	
Sample Number	Argillite	Greywacke	Dark Quartzite	Light Quartzite	Migmatic	Amphibolite	White Quartzite	Granite	Qtz. Monzonite	Porphery Granite	Volcanics	Total
1	20	14	33	2	0	0	4	10	8	6	0	49
2	32	32	13	2	0	0	0	13	2	2	4	47
3	12	14	29	5	27	0	5	3	2	0	3	59
4	17	36	15	2	8	2	10	3	2	0	5	59
5	7	14	24	10	7	0	0	7	0	2	24	58
6	32	14	14	4	0	0	0	2	0	0	34	50
7	13	0	6	17	13	0	2	25	19	2	4	48
8	19	9	40	1	1	0	0	11	13	4	1	47
9	22	4	24	8	0	0	2	12	24	2	0	49
10	35	15	38	5	0	0	3	0	0	5	0	40
11	7	17	28	30	4	0	0	7	7	0	0	46
13	7	23	19	5	26	0	7	5	7	2	0	43
14	10	4	20	32	8	2	8	6	2	0	8	50
15	2	6	12	40	10	0	16	6	4	0	6	51
16	20	16	33	0	14	0	6	6	0	0	4	49
17	22	20	37	8	0	0	0	2	8	2	2	51
18	23	0	40	9	2	0	0	13	8	4	2	53
19	8	12	40	4	4	0	8	17	4	9	6	53
20	19	23	9	0	2	0	2	28	16	2	0	57
21	12	21	19	10	0	0	0	19	10	10	0	52
22	2	17	36	2	6	0	6	8	21	4	0	53

Appendix IV

Clay Mineral Analysis

Contained in this appendix are the results of laboratory and X-ray analysis of glycolated clay minerals from samples collected in the field (Figure 16). The results are tabulated as samples within the profile and clay mineralogy of the sample. Abbreviations used in column heads denote the following:

I (9.8Å) - Percentage of Illite with diagnostic glycolated diffraction (001) spacing.

K/C (7.0Å) - Percentage of Kaolinite and Chlorite with diagnostic glycolated (001) spacing.

Depth - Depth in centimeters from soil surface.

Percent montmorillonite (16.6Å) was not calculated due to masking by mixed layer clays. Individual percentages of chlorite and kaolinite were indistinguishable (see text).

Sample Number	% Illite	% Chlorite & Kaolinite
BLA-1	90	10
-2	91	9
-3	90	10
-4	89	11
-5	91	9
-6	93	7
-7	90	9
-8	88	11
-9	88	11
-10	91	9
-11	85	15
PDA-1	91	9
-2	85	15
-3	90	10
-4	78	22
-5	94	6
-6	90	10
-7	92	8
-8	87	13
-9	90	10
-10	94	6
BLB-1	93	7
-2	91	9
-3	91	9
-4	90	10
-5	90	10
-6	94	6
-7	96	4
-8	94	6
-9	--	--
PDB-1	86	14
-2	88	12
-3	90	10
-4	89	11
-5	88	12
-6	90	10
-7	--	--
-8	88	12
-9	87	13
-10	86	14
-11	90	10

Sample Number	% Illite	% Chlorite & Kaolinite
BLC-1	92	8
-2	90	10
-3	91	9
-4	90	10
-5	89	11
-6	95	5
-7	95	5
-8	94	6
-9	86	14
-10	90	10
-11	90	10
PdC-1	94	6
-2	90	10
-3	91	9
-4	95	5
-5	94	6
-6	91	9
-7	92	8
-8	95	5
-9	92	8
-10	90	10
-11	92	8

VITA

James F. P. Cotter was born August 4, 1954 in Rockeville Center, Long Island, New York; the third of four children born to Theresa M. and Dr. C. Francis Cotter.

Mr. Cotter attended elementary school in the neighboring towns of Plainview and Old Bethpage, and graduated from John F. Kennedy High School in June, 1972. He entered Franklin and Marshall College, Lancaster, Pennsylvania in September, 1972 receiving a B.A. in Geology in June, 1976.

Mr. Cotter entered the graduate school of Lehigh University in September, 1976. On June 3, 1978, he was married to Adele Politi and they now reside in Bethlehem, Pennsylvania.

Mr. Cotter is a member of the Lehigh Chapter of Sigma Xi, the New York Academy of Sciences, and The Friends of the Pleistocene. He is presently completing a Ph.D. dissertation entitled, "The Deglaciation Chronology of Northeastern Pennsylvania".