LATE QUATERNARY GLACIAL AND VOLCANIC STRATIGRAPHY NEAR WINDY CREEK, KATMAI NATIONAL PARK, ALASKA

By

DeAnne Sue Pinney

RECOMMENDED: ______________________________

____

____

____
Advisory Committee Chair

____
Department Head

APPROVED: ______________________________
Dean, College of Natural Sciences

____
Dean of the Graduate School

____
Date

LATE QUATERNARY GLACIAL AND VOLCANIC STRATIGRAPHY NEAR WINDY CREEK, KATMAI NATIONAL PARK, ALASKA

A

THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

By

DeAnne Sue Pinney, B.A.

Fairbanks, Alaska

May 1993

ABSTRACT

This study was undertaken to develop a Quaternary history of the Katmai area using deposits preserved near Windy Creek. Detailed mapping and tephrochronology were used to accomplish this goal. Ukak drift (*ca.* 11,000 yr B.P.) forms moraines in the lower Valley of Ten Thousand Smokes. Katolinat drift (*ca.* 9,000 yr B.P.) records a less extensive glaciation. Lethe volcaniclastic deposits (12,500-16,000 yr B.P.) were generated by large pyroclastic eruptions in the upper Valley of Ten Thousand Smokes, and the ash forms an important marker horizon on the Kenai Peninsula. Electron microprobe analysis of volcanic glass allowed four tephras to be traced through multiple Windy Creek localities. Comparisons with tephra chemistries from sites throughout Alaska showed that ash of the Windy Creek ashflow deposit may be traceable to west-central Alaska, one tephra was derived from the mid-Holocene Aniakchak eruption, and another may have originated at Augustine.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

My deepest regard and appreciation go to all those who have had a part in seeing this project to its end, and I apologize in advance for any names I might be overlooking. For his patience, advice, and unstinting enthusiasm, Jim Begét, who introduced me to the Valley of Ten Thousand Smokes and the wonders it holds. To Sam Swanson and Dave Hopkins for hanging on through the years it has taken to complete the project, and for their invaluable critiques of this thesis. For their generosity in sharing unpublished data: Vic Avery, Tom Bundtzen, Jim Begét, Sam Swanson, Kathy Campbell and Dick Reger. To Scott Cornelius and Diane Johnson at the WSU microprobe laboratory, for being great people as well as great lab technicians. Extreme gratitude for financial support goes to the Alaska Center for Tephrochronology (ACT), the Alaska Quaternary Center (AQC), Juergen Kienle at the Alaska Volcano Observatory (AVO), the University of Alaska Department of Geology and Geophysics, the UA Foundation through the Peter McKeith Memorial Scholarship, Dave Stone and Doug Christenson of the Geophysical Institute of the University of Alaska, and the Alaska Division of Geological and Geophysical Surveys (DGGS). On a more personal level, my thanks for moral support go to my longtime partner-in-crime Kathie Queen, my long-suffering roommate and compatriot Kathy Campbell, fellow geo-chick and Katmai-junkie Vic Avery, my boss and friend Dick Reger, my GIS-consultant Richard Clement, and all those in the UAF geology department who knew better than to ask me how my thesis was going. Lastly, my heartfelt appreciation goes out to my parents, who have stood by me in patient (or not-so-patient!) vigil throughout my long tenure as a student.

CHAPTER 1: INTRODUCTION

1.1 OBJECTIVES

This study began as an attempt to map and describe the Quaternary glacial and volcanic deposits of the Windy Creek area near the Valley of Ten Thousand Smokes, and to use tephrochronology and radiocarbon dating to derive a history of Holocene glacial fluctuations for the region. Following the first field season the project scope was expanded to include latest Wisconsin glacial activity and two major Quaternary volcanic deposits. In its final form, the objectives of the Windy Creek study are four-fold: 1) map and describe the Quaternary deposits of the approximately 40 km^2 Windy Creek study area; 2) relate Quaternary stratigraphy in Windy Creek to the late Quaternary glacial chronology of the northern Alaska Peninsula; 3) carry out a tephrochronologic study of preserved ash layers, including field descriptions, petrography, and geochemistry; and 4) develop a synthesized Quaternary geologic history of the Windy Creek study area.

1.2 SETTING

1.2.1 Geographic Setting

The Windy Creek study area is located immediately west of the Valley of Ten Thousand Smokes on the northern Alaska Peninsula (Fig. 1.1). The spine of the Alaska Peninsula is a chain of volcanoes that generally follow the southern coastline. These volcanoes, many of which exceed elevations of 2,200 m, are for the most part heavily glaciated. Recently active peaks include Mageik, Trident, Martin, and Katmai. The peninsula is bordered on the north by

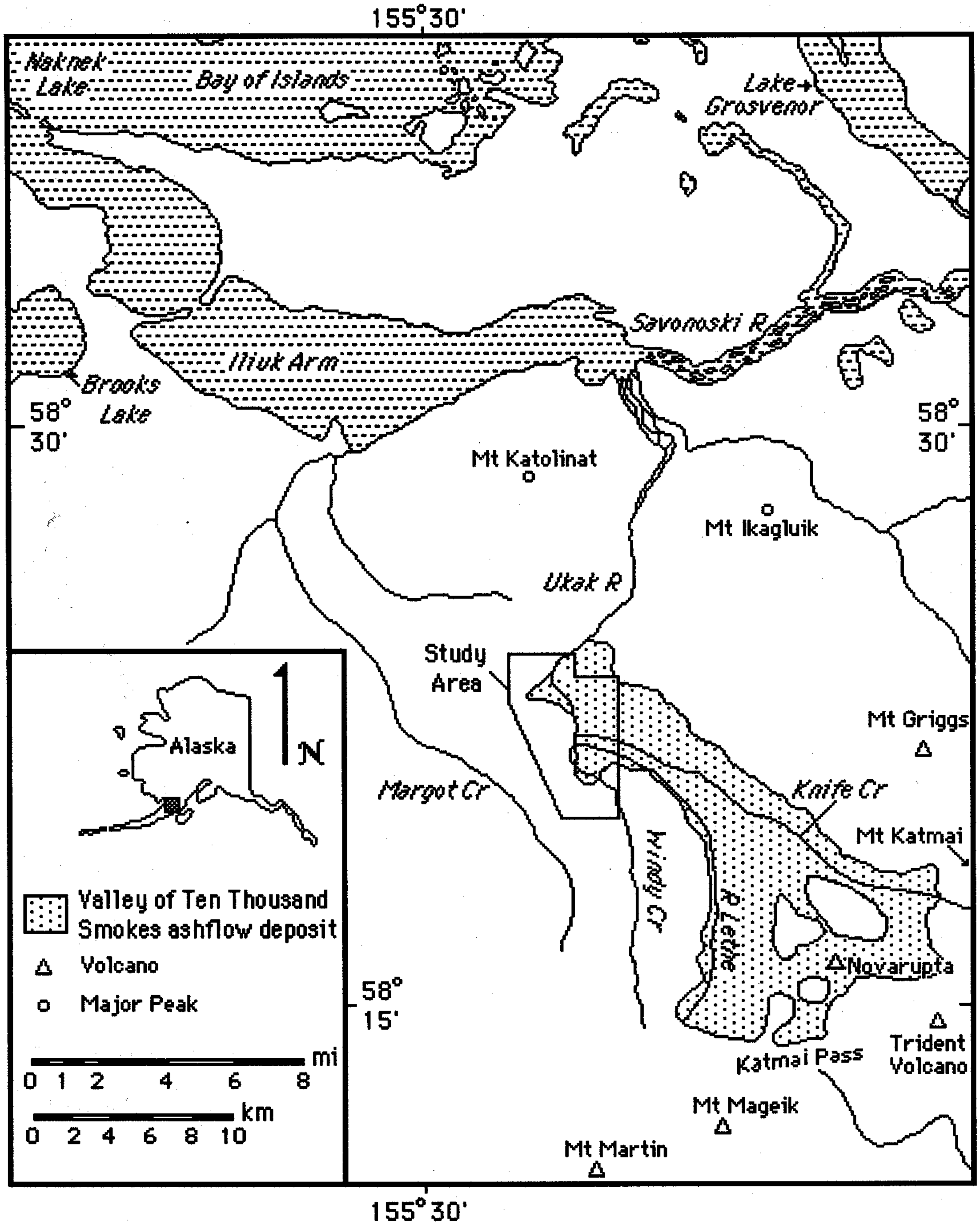


Figure 1.1 Location map for the Windy Creek study area.

Bristol Bay and on the south by the Pacific Ocean. Also to the south is Kodiak Island, separated from the peninsula by the approximately 50-to-75 km-wide Shelikof Strait. The broad lowland bordering Bristol Bay on the northern half of the Alaska Peninsula is dominated by a series of large lakes. Drainages in the Windy Creek area empty into the Iliuk Arm of Naknek Lake, via Margot Creek and the Ukak River.

The boundaries of the study area are roughly defined by Mt. Katolinat to the north, the Valley of Ten Thousand Smokes and the Buttress Range to the east, and the Margot Creek drainage to the west. The southern boundary is approximately halfway up Windy Creek Valley. The main geographic features in and near the study area are shown in figure 1.2.

1.2.2 Geologic Setting

More than 50 percent of the Alaska Peninsula is composed of Quaternary deposits of primarily glacial or volcanic origin. Pleistocene ice caps and glaciers blanketed much of the Peninsula in drift, with most preserved deposits being of Wisconsin age or younger (Detterman, 1986). Volcanoes have played a major role in building the Peninsula and active cones continue to dominate the landscape. One of the most notable chapters in the recent volcanism of the Alaska Peninsula occurred in 1912, when a major ignimbrite-producing eruption occurred at Novarupta, accompanied by collapse of the summit of Mt. Katmai. The largest of its kind in this century, the eruption transformed the valley north of Katmai Pass into the steaming, pumice-covered wasteland that became known as the Valley of Ten Thousand Smokes.

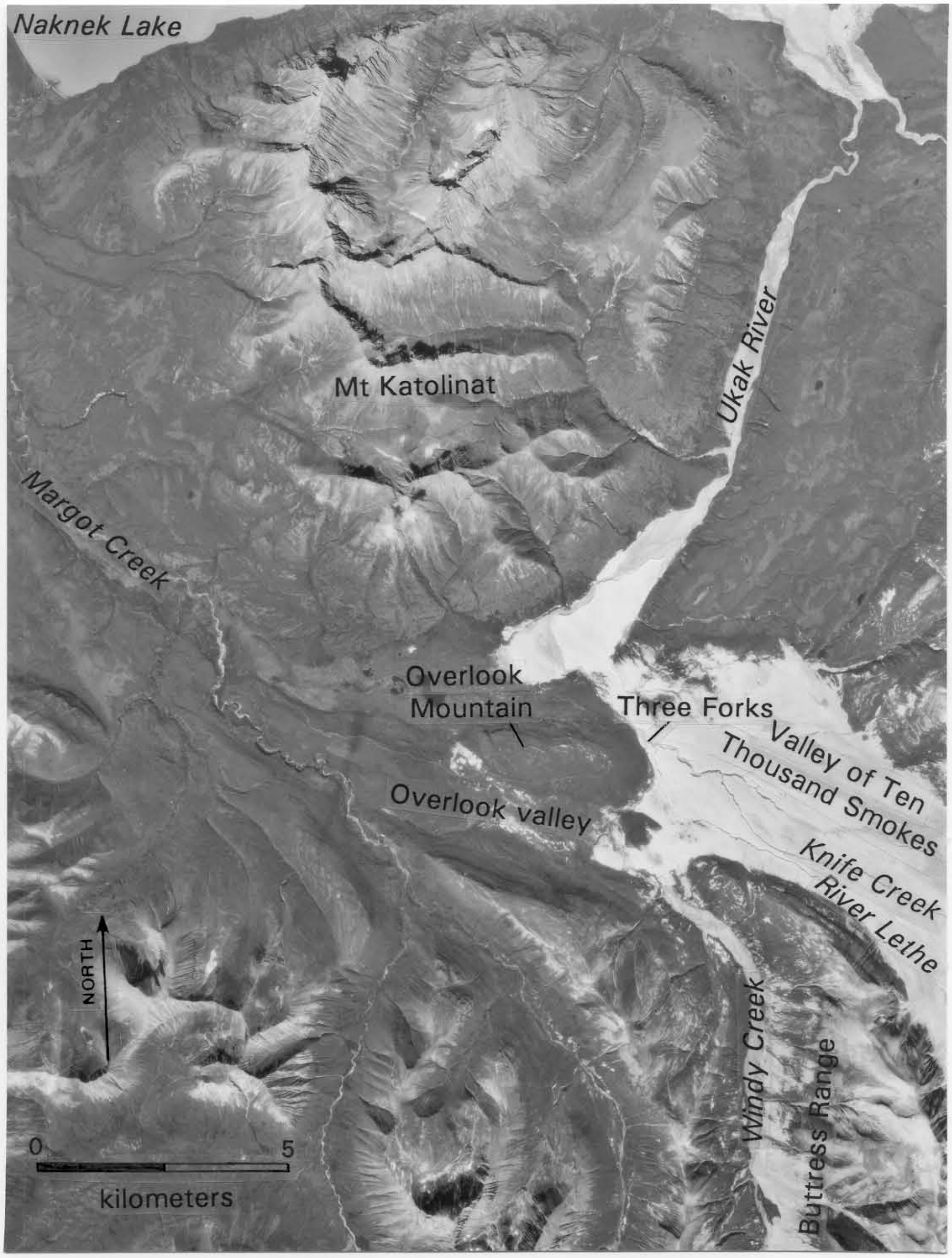


Figure 1.2 Aerial photograph of the Windy Creek study area showing major geographic features.

1.2.3 Climate, Flora and Fauna

Climate at Katmai is controlled by Bristol Bay and the Pacific Ocean, and their respective weather systems. This leads to weather that is characteristically unstable and subject to frequent, sudden storms. Winds forced over the mountains may blow in excess of 160 km/hr at Katmai Pass. Annual precipitation at Brooks Camp ranges from 50 to 100 cm, but may exceed 500 cm on the highest eastern slopes. Proximity to the ocean also results in a moderation of temperature, with summer mean temperatures of 10 to 15°C and winter mean temperatures of -6 to -12°C at Brooks Camp (National Park Service, 1985).

Vegetation in the Katmai area is principally dependent on elevation, with tundra occurring at the highest elevations and boreal forest on the lower slopes and valleys. The tundra ecosystem of Katmai is composed of low-growing species hardy enough to survive the harsh, wind-swept conditions, and includes mosses, lichens, and some shrubs. The boreal forest ecosystem consists of white spruce, birch, poplar and balsam forests, alder and willow thickets, or grasslands, depending on local conditions.

The more than 16,000 km^2 expanse of Katmai National Park and Preserve is home to a prodigious array of wildlife. Park surveys have documented some 29 species of land mammals, 6 species of marine mammals, 150 species of birds, and numerous fish and insects. Of particular note is the magnificent coastal brown bear, the preservation of which prompted the expansion of the original National Monument's boundaries and its declaration as a Park and Preserve in 1980. The park is one of the few places in the world where these awesome animals can be viewed in their natural setting, and they are the main attraction for most visitors.

1.3 PREVIOUS WORK

The Katmai area has been the subject of scientific scrutiny since before the turn of the century. The earliest documented geological study was an 1898 U.S.G.S. reconnaissance expedition to southwestern Alaska (Spurr, 1900). Led by Josiah Spurr, the party made a hasty voyage up Iliuk Arm and traversed Katmai Pass in the waning days of summer before the much-feared arrival of the autumn storms to barely catch the last boat of the year from Kodiak to Seattle. National interest in the region was sparked following the 1912 eruption at Katmai, and the National Geographic Society ultimately sent six expeditions into the area between 1912 and 1921. Fascinating descriptive accounts by these early explorers can be found in Martin (1913), and Griggs (1922). The extraordinary nature of the Valley of Ten Thousand Smokes as revealed by these men led to the area being declared a National Monument in 1918.

The 1912 eruption and its products constitute the subjects of the largest body of Katmai research. Fenner laid the groundwork for petrology in the Valley of Ten Thousand Smokes, as well as studying Katmai's earth movements and taking part in the 1919 National Geographic Society expedition (Fenner, 1920; 1921; 1925; 1926; 1950). The stratigraphy and petrology of the ashflow deposit were also the subjects of Curtis (1968), Hildreth (1983; 1987; 1991), and Hildreth and others (1984). Begét and Limke (1988) modeled flow rheology and kinematics, and Allen and Zies (1923), Zies (1929), Keith (1984), and Kodosky (1989) studied the Valley of Ten Thousand Smokes fumaroles. Geophysical surveys have become an important part of Katmai research, with the work of Kubota and Berg (1967), Kienle (1969; 1970; 1991), and Matumoto (1971) being only a small sampling of the whole. A possible future step in Katmai study is a proposed drilling project near Novarupta which may yield important new information on vent morphology and the complicated series of events transpiring in 1912 (Eichelberger and Hildreth, 1986; Eichelberger and others, 1990; 1991).

Despite the overwhelming volume of research on the Valley of Ten Thousand Smokes, there are a number of other important aspects of Katmai research. In addition to the Katmai/Novarupta system, Muller and others (1954), Kienle and others (1981), Kosco (1981a; 1981b), and Kienle and Swanson (1983) examined the distribution and character of other volcanic centers in the area. Muller (1952; 1953) also addressed Pleistocene glaciation on the Alaska Peninsula, as did Detterman and Reed (1973) and Detterman (1986). Archaeological studies in the area, beginning with Hrdlicka in 1931 (Dumond, 1981), yielded important dates and stratigraphic information as well as palynological and tephrochronological data (Clark, 1977; Dumond, 1980; 1981; Heusser, 1963). The large number of Holocene tephras and their value as stratigraphic marker horizons in Dumond's Naknek River drainage project led to the tephrochronology study of Nowak (1968).

A large volume of material has been published on the research carried out at Katmai, and the above constitutes only a fraction of the literature available. There nevertheless remains a great deal that is poorly or incompletely understood, particularly with respect to the 1912 eruption. Katmai and its Valley of Ten Thousand Smokes continues to be a priceless natural laboratory in which to study the mechanisms and effects of large silicic volcanic eruptions. This project was undertaken to describe and interpret the largely unstudied pre-1912 surficial deposits of the Katmai area and further refine the Quaternary geologic history of the region.

1.4 PRESENT INVESTIGATION

Fieldwork for the Windy Creek project was carried out over three field seasons: July 18-August 10, 1987; June 4-15, 1988; and August 22-30, 1989. Transportation to the study area was accomplished by commercial airline from Anchorage to King Salmon (Mark Air), and then by Peninsula Air/Katmailand floatplane to Brooks Lodge. A bus operated by Katmailand runs daily from Brooks Lodge to Three Forks Overlook, beyond which all travel is by foot. Supplies and equipment were limited by what could by be packed in, although permission was given by the Park Service to store a few items in the cabin at Three Forks Overlook. Base camps in 1987 and 1988 were located approximately 2 km south of Three Forks. A spike camp established during the 1987 season some 5 km farther up Windy Creek had to be abandoned for two days due to violent winds, but survived with only minor damage. Fieldwork in 1989 was based out of Three Forks Overlook cabin.

The presence of bears required that all food, soap, and other strong-smelling materials be carefully packaged and cached some 100 m from the tents. At the base camps the lack of trees in which to store these supplies posed a problem which was ultimately solved by discrete burial in the 1912 ashflow deposit. Although bears and bear sign were common, there were no negative encounters. Indeed, Windy Creek's resident large bruin, affectionately dubbed "Big Windy", generally pointedly avoided human haunts.

Fieldwork was a accomplished exclusively by foot traverse. Mapping was done on enlargements of 1:63,360 U.S.G.S. topographic maps and was refined by comparison with black-and-white and color-IR aerial photographs at four different scales. Notes were transcribed into a second notebook every 2 to 4 days to provide a backup copy that remained in camp. Exposures were cleared by shovel and trowel and measured using a tape measure where possible. Some dangerous canyon walls required visual estimation of deposit thicknesses. At certain key exposures, rope and harness were used to enable closer study. Samples were collected in plastic "Ziploc" sandwich bags labeled twice with a permanent marking pen.

Sample preparation and analysis were carried out following the end of each field season. Radiocarbon samples were oven-dried and hand-picked for obvious modern rootlets before being sent to Beta Analytic for dating. Tephras were cleaned, sieved, and separated into glass and mineral components using heavy-liquid methods at the Alaska Center for Tephrochronology of the University of Alaska, Fairbanks (Appendix I). Glass separates were analyzed by electron microprobe at the X-Ray Analysis Laboratory of Washington State University using the routines described in Appendix I.

CHAPTER 2: MAPPING AND STRATIGRAPHY

2.1 GENERAL

The geologic map of the Windy Creek study area (Fig. 2.1) was constructed from aerial photographs and verified by foot traverse and field mapping on enlargements of topographic maps. The area is approximately 40 km^2. Mappable deposits fall into three main categories: pre-Quaternary "bedrock"; late Quaternary and early Holocene glacial and volcanic deposits; and late Holocene to Recent volcanic and minor surficial deposits. A number of linear features observed on the aerial photographs may be major joints or faults of unknown displacement. Locations of measured sections and surface collection sites are shown in Figure 2.2.

2.2 NAKNEK FORMATION (Jn)

Bedrock in the Windy Creek study area consists exclusively of the Upper Jurassic Naknek Formation. This unit was first described and named by Spurr (1900) and has been subsequently studied by Smith (1925), Keller and Reiser (1959), Burk (1965), and Riehle and others (1987). The following description is derived largely from their work.

Present on virtually the entire Alaska Peninsula, the marine Naknek Formation consists of sandstones, siltstones and shales sandwiched between two conglomerate units. Total thickness ranges from 1,500 m to more than 3,000 m locally, and it is topped by an unconformity. Igneous dikes are common. The

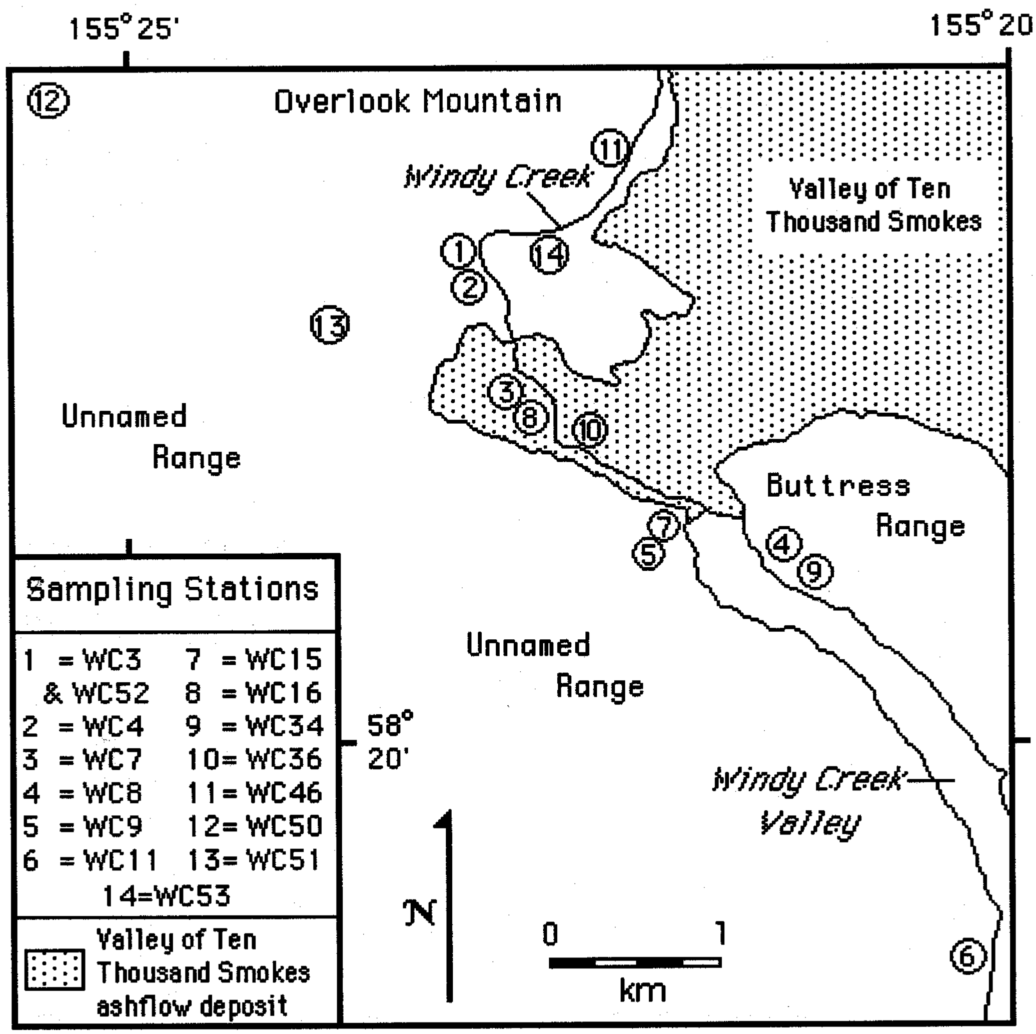


Figure 2.2 Sampling station location map.

Upper Jurassic age was determined from locally abundant fossil assemblages consisting primarily of marine pelecypods of the genus *Buchia* (formerly *Aucella*), but also including belemnites, ammonites, gastropods, and rare brachiopods (Keller and Reiser, 1959). Carbonaceous plant remains are locally present. The Naknek Formation was laid down as marine shelf deposits derived in part from Lower and/or Middle Jurassic intrusive rocks in the northeast. Strata in the study area are primarily horizontal with a few gentle dips on the order of 3° to 5°. Outcrops in the Buttress Range are an exception with southwest dips to 12°.

The most prominent landforms in the Windy Creek study area, including the Buttress Range and Overlook Mountain (Fig. 1.2 and Fig. 2.3), are composed of rocks of the Naknek Formation. The dominant lithology is fossiliferous siltstone and shale with a pronounced greenish tint. Bedding is prominent and forms

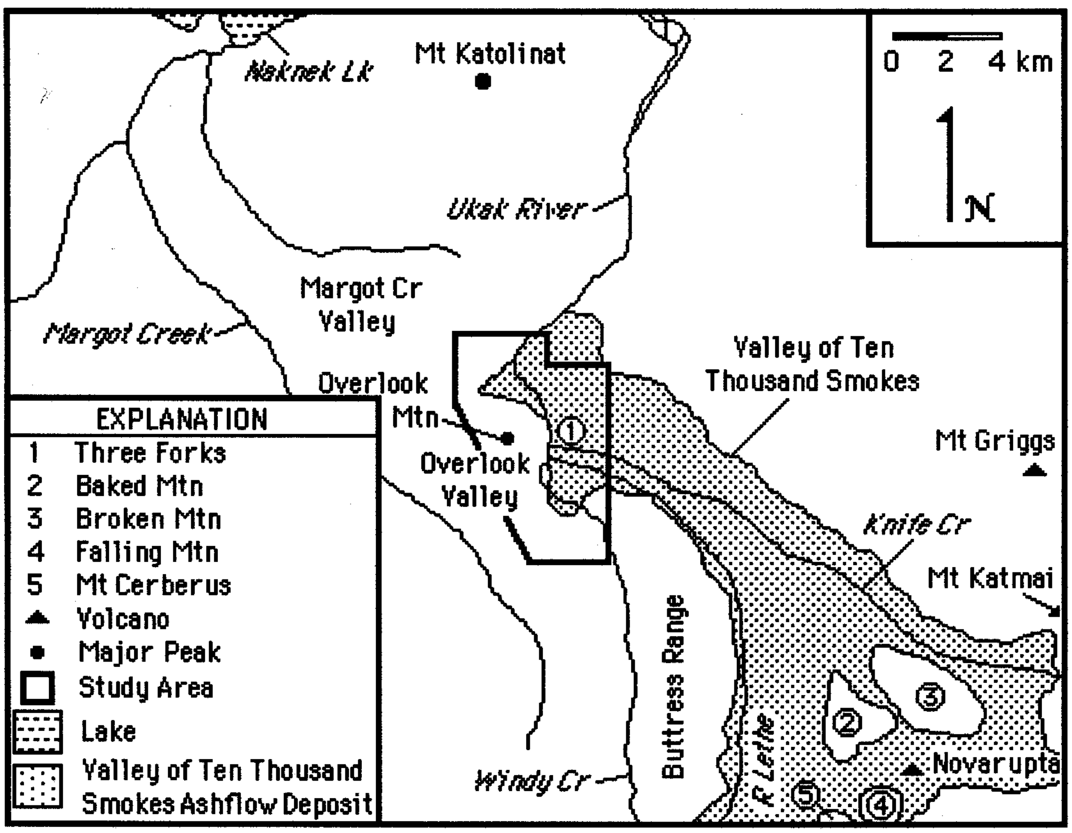


Figure 2.3 Map of the Windy Creek area showing principle geographic features referred to in the text..

numerous small benches apparent even under vegetative cover. Steep slopes are common and talus and colluvium are ubiquitous along the lower slopes. A rock slide extending about 1 km from the base of the Buttress Range was recognized south of the mapped area in upper Windy Creek valley. Naknek Formation lithologies form the dominant clast type in most surficial deposits.

2.3 WINDY CREEK ASHFLOW DEPOSIT (Qwa)

2.3.1 Description of Windy Creek Ashflow Deposit

Deposits of the Windy Creek ashflow are exposed for 200 m on the west side of lower Windy Creek valley (Fig. 2.1). The ashflow is under- and overlain by till, and believed to be of late Wisconsin age (see Chapter 3 for a detailed discussion of these tills). The underlying till deposit is known only from the Windy Creek ashflow exposure and is not laterally traceable The overlying till is preserved locally as a cap on the ashflow deposit, but is not sufficiently extensive to form a mappable unit. The Windy Creek ashflow deposit consists of a lower alluvially reworked pumice unit (unit "A") and the overlying ashflow deposit (unit "B")(Fig. 2.4).

The alluvial unit "A" is 2.5 to 5.0 m thick and composed of stratified white-to-pinkish pumice, ash and lithic pebbles. Pumice clasts reach 5 cm in diameter and are extremely friable. The lower meter consists of pale pumice with planar clay/silt interbeds, and is overlain by 50 cm of coarse stratified silt, sand, pumice and lithic pebbles. Topping this is 1.5 m or more white-to-pink pumice in a dark silt matrix. This unit is very indurate and forms resistant, near-vertical slopes. Bedding in unit "A" dips approximately 8^{o} downvalley, at least twice the local gradient.

Unit "B", the primary ashflow deposit, immediately overlies unit "A". The basal layer is a bed of lithic-rich coarse sand and pebbles 5 to 10 cm thick (subunit "Ba" on Fig. 2.4). In sharp contact with the lithic layer is an approximately 20-cm-thick zone of fine-grained pink ash and pumice foreset beds with low-angle cross-stratification dipping downvalley (subunit "Bb" on Fig. 2.4). This is overlain by more than 6 m of massive pink-to-white ash and pumice with diffuse horizontal zones of coarser pumice (subunit "Bc" on Fig. 2.4). This upper ashflow unit is extremely well-indurated, forming steep slopes incised by numerous shallow rills.

The ashflow deposit is extensively cut by fractures filled with laminated dark grey-green clay and silt. The largest fracture bulges to more than 20 cm wide where it contains sandy fill and angular fragments of the ashflow tuff. The upper portions of some fractures are bent, and many that intersect the upper contact are injected by the overlying till with clasts aligned parallel to fracture walls. The largest fracture shows 20 to 30 cm of apparent vertical displacement, and another exhibits 10 cm of apparent overthrust. These fractures may have resulted from compaction, or possibly from deformation by an overriding glacier.

2.3.2 Ashflow Depositional Processes

The Windy Creek ashflow deposit can be divided into lower and upper units based on differences in depositional processes. Unit "A" represents

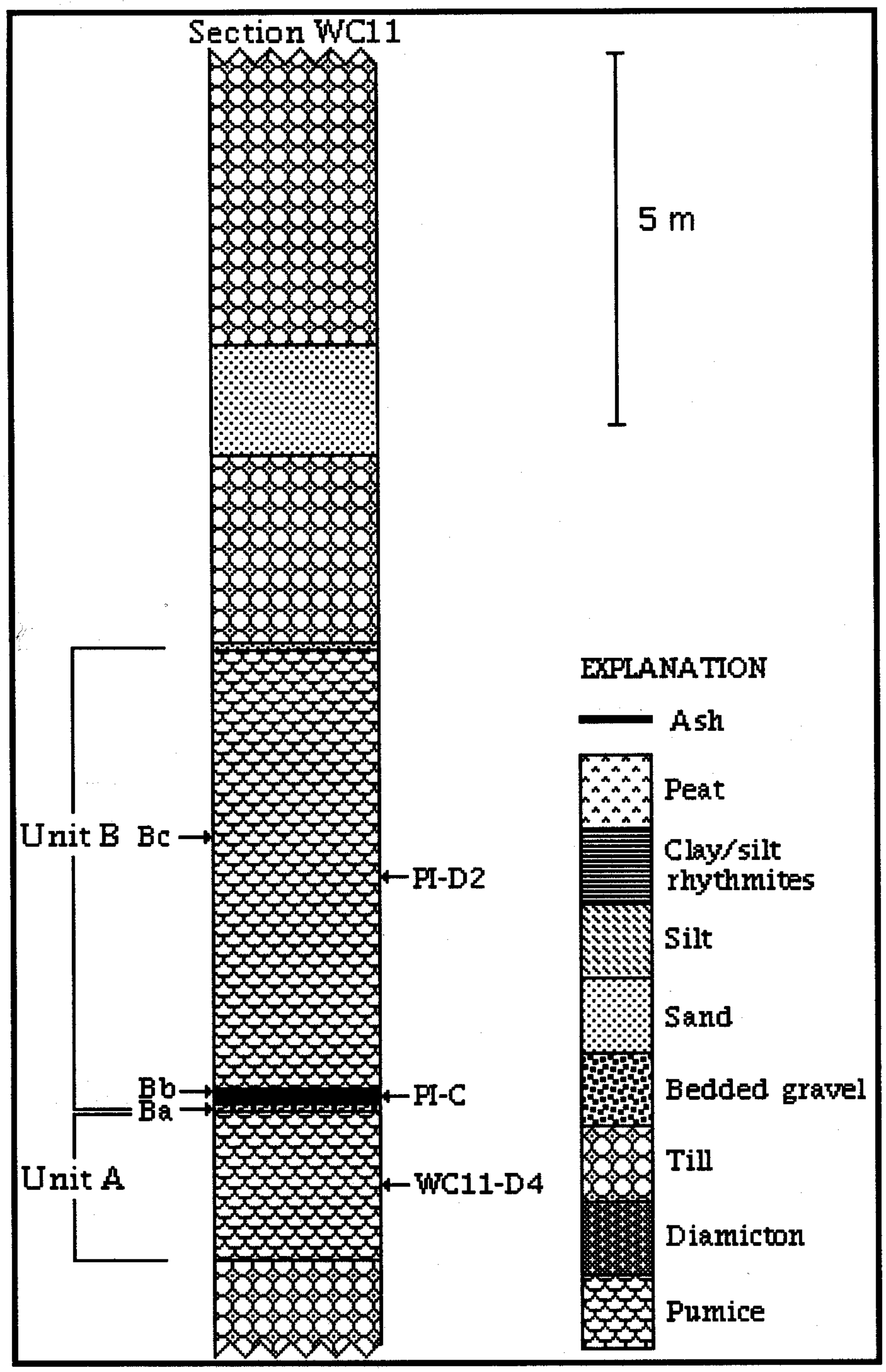


Figure 2.4 Measured stratigraphic section WC11 of the Windy Creek ashflow deposit.. Ba, Bb, and Bc are subunits, as explained in the text. Number-letter designations on right side of column are sample numbers indicated at level of collection..

Plinian airfall pumice generated in an initial, high eruption column. This airfall material was reworked by water prior to the onset of pyroclastic flow deposition in the area. The three parts of unit "B" were directly deposited by pyroclastic flow processes and correspond to layers that are typical of many ashflow deposits (Froggatt, 1981; Sparks et al, 1973; Valentine and Fisher, 1986; Walker et al, 1981; Walker and Wilson, 1983; Wilson, 1985; Wilson and Walker, 1982; 1985).

Terminology describing ashflow deposits has undergone change reflecting changes in ideas regarding their origin. The thin, lithic-rich deposit represented in the Windy Creek ashflow deposit by subunit "Ba" has been variously termed the "ground layer" (Sparks et al, 1973; Walker et al, 1981), "lithic lag layer" (Froggatt, 1981), and "layer 1H" (Wilson and Walker, 1982; Walker and Wilson, 1983) deposit. The distinctive attributes of fines-depletion, heavy-constituent enrichment, and separation from the main body of the ashflow deposit by a sharp, near-planar contact best fit the descriptions of the ground layer of Walker and others (1981). This kind of deposit is believed to be generated by sedimentation of heavy constituents in the strongly fluidized head of a pyroclastic flow, and the layer is then overridden by the remainder of the flow in a shearing relationship (Froggatt, 1981; Valentine and Fisher, 1986; Walker et al, 1981; Walker and Wilson, 1983; Wilson, 1985; Wilson and Walker, 1982; 1985).

The concept of the standard flow unit of Sparks and others (1973) can be applied to the other two ashflow subunits of the Windy Creek ashflow deposits. The fine-grained deposit (subunit "Bb") is interpreted as "layer 2a", representing the laminar-flowing part of the flow where shear stress exceeds yield strength and results in reverse grading (Wilson and Walker, 1985; Valentine and Fisher, 1986). The bulk of the flow deposit (subunit "Bc") corresponds to "layer 2b", which moves as a plug over the layer 2a zone (Valentine and Fisher, 1986). "Layer 3" of this system, also known as the "co-ignimbrite air-fall deposit" (Wright et al, 1980), is not represented in the Windy Creek deposits and may have been removed by overriding glaciers.

2.4 UNDIFFERENTIATED DRIFT (Qu)

Glacial deposits that are not readily assignable to a specific glacial advance are mapped as "undifferentiated drift" (Fig. 2.1). Primary surface morphology on these deposits has been significantly altered, and vegetative cover is commonly dense and extensive. This Wisconsin-age drift was probably laid down in large part by Iliuk ice, although it may well include a component of older material. The deposit floors Margot Creek valley (Fig. 1.2 and Fig. 2.3) and reaches approximately 100 m up the valley walls, where it is characterized by numerous kame terraces from ice-marginal streamflow.

2.5 ILIUK DRIFT (Qid)

Iliuk drift (Fig. 2.1) is best displayed in Overlook valley (informal name), a hanging valley south of Overlook Mountain which once was occupied by Windy Creek (Fig. 1.2 and Fig. 2.3). A lateral moraine from glaciers in the ancestral Valley of Ten Thousand Smokes blocked drainage and dammed a lake in Windy Creek valley. This moraine can be traced some 5 km west of the mouth of Windy Creek, and its counterpart extends about 3 km along the south side of Overlook Mountain. Maximum moraine height exceeds 50 m at the mouth of Windy Creek valley.

Surficial morphology of the moraines is only slightly modified by thin coverings of loess and tephra in protected areas. Ventifacts are locally common. Degree of vegetation is not a useful tool for characterizing surficial deposits in this area due to the effects of the cataclysmic 1912 eruption on plant life. Airfall and redeposited airfall pumice and at least one pyroclastic flow associated with the Lethe volcaniclastic deposits are present over many of the Iliuk surfaces. Drift flooring Overlook valley has been extensively fluvially reworked into a now-abandoned floodplain.

Exposures of Iliuk drift unobscured by float, vegetation, or younger deposits are comparatively rare in the study area. Till in the moraines is boulder- and gravel-rich with a generally coarse silt-sand matrix. Clast lithology is predominantly sedimentary rocks derived from the Naknek Formation and andesitic volcanic rocks. No sedimentary structures were observed in the exposures. Overlying soil-forming deposits are extremely variable, ranging from nonexistent to several tens of centimeters thick.

2.6 ILIUK GLACIOLACUSTRINE DEPOSITS (Qil)

2.6.1 Description of Iliuk Glaciolacustrine Deposits

"Glacial Lake Windy" (informal name) was an ice-marginal ice-contact lake, abutting Iliuk ice at the mouth of the valley and very likely in contact with another local Windy Creek glacier upvalley. Glaciolacustrine deposits occur in bluffs up to 40 m high along the margins of the river floodplain (Fig. 2.1). These deposits form an approximately level surface up to 0.5 km wide on either side of the valley at an elevation of about 400 to 430 m, and extend more than 6 km upvalley. Water seepages are common at several levels and numerous springs and streams drain from the bluffs. Slopes tend to be unstable and are mantled with slumped and sliding material. Some of the upper surfaces have been stripped of their eolian and vegetative cover, revealing nearly level platforms of yellow-brown clay and silt strewn with angular to subangular pebbles and cobbles. The surface is commonly cut by numerous small runoff rills, and mudcracks were observed in some localities.

The glaciolacustrine deposits overlie Newhalen(?)-age till (see Chapter 3 for a discussion of this buried deposit) and consist of well-bedded dark blue-grey clay that dries to yellow, yellowish-brown to grey silt and sand, and fine to coarse gravel and cobbles. Many exposures are mantled with minor mudflow deposits where clay beds are abundant and water-saturated. Dried mudflow deposits are yellow. Vague horizontal structure due to water seepages along contacts of the impermeable clay is often apparent in the bluffs, even where covered by mudflow debris and float. Deposits in the central parts of the lake basin are primarily massive to laminated clay and silt, commonly rhythmically bedded, with lower portions consisting of stony mud diamicton. In lower Windy Creek valley the clearly lacustrine deposits thicken and grade into coarser ice-proximal deposits of bedded sand and silt with subordinate amounts of gravel and clay that merge with till of the Iliuk lateral moraine. No clear contact exists between till and proximal glaciolacustrine deposits.

2.6.2 Glaciolacustrine Depositional Processes

Deposition in glacial lakes is controlled in large part by proximity to ice margins, which exerts a strong influence on the character of the deposits. Ice-deposited material may take the form of lacustrotill or flowtill, generated by mass movement and flow directly off the glacier snout, or waterlaid till deposited beneath the floating glacier or beneath icebergs. The shallow water depths do not allow appreciable size separation during settling (May, 1977; Eyles and Eyles, 1983; Booth, 1986; Ashley, 1989). Meltwater streams entering the lake discharge their sediment load in prograding deltas or subaqueous fans where deposition results from sedimentation in the standing water, as well as traction from grainflow (Theakstone, 1976; Smith and Ashley, 1985; Ashley, 1989; Donnelly and Harris, 1989). Density underflows (subaqueous continuations of meltwater streams into the basin) can carry entrained material beyond the margin of the delta or fan (Smith and Ashley, 1985; Ashley, 1989). Unstable slopes on these prograding deposits give rise to cascading sediments that can trigger episodic surge currents which continue downslope and far into the basin (Eyles and Eyles, 1983; Smith and Ashley, 1985; Ashley, 1989). Suspension settling from the water column and meltout from floating ice are also components of ice-proximal deposition.

Ice-proximal deposits such as those in Windy Creek section WC34 (Fig. 2.5) reflect a wide range of depositional processes. As a result of changing local conditions at any given time (proximity to ice, water depth, location relative to inflowing streams), this exposure includes everything from the coarsest of diamictons to the finest of clays. Diamictons and poorly stratified sand and gravel suggest proximity to the ice margin where mass-movement can dominate

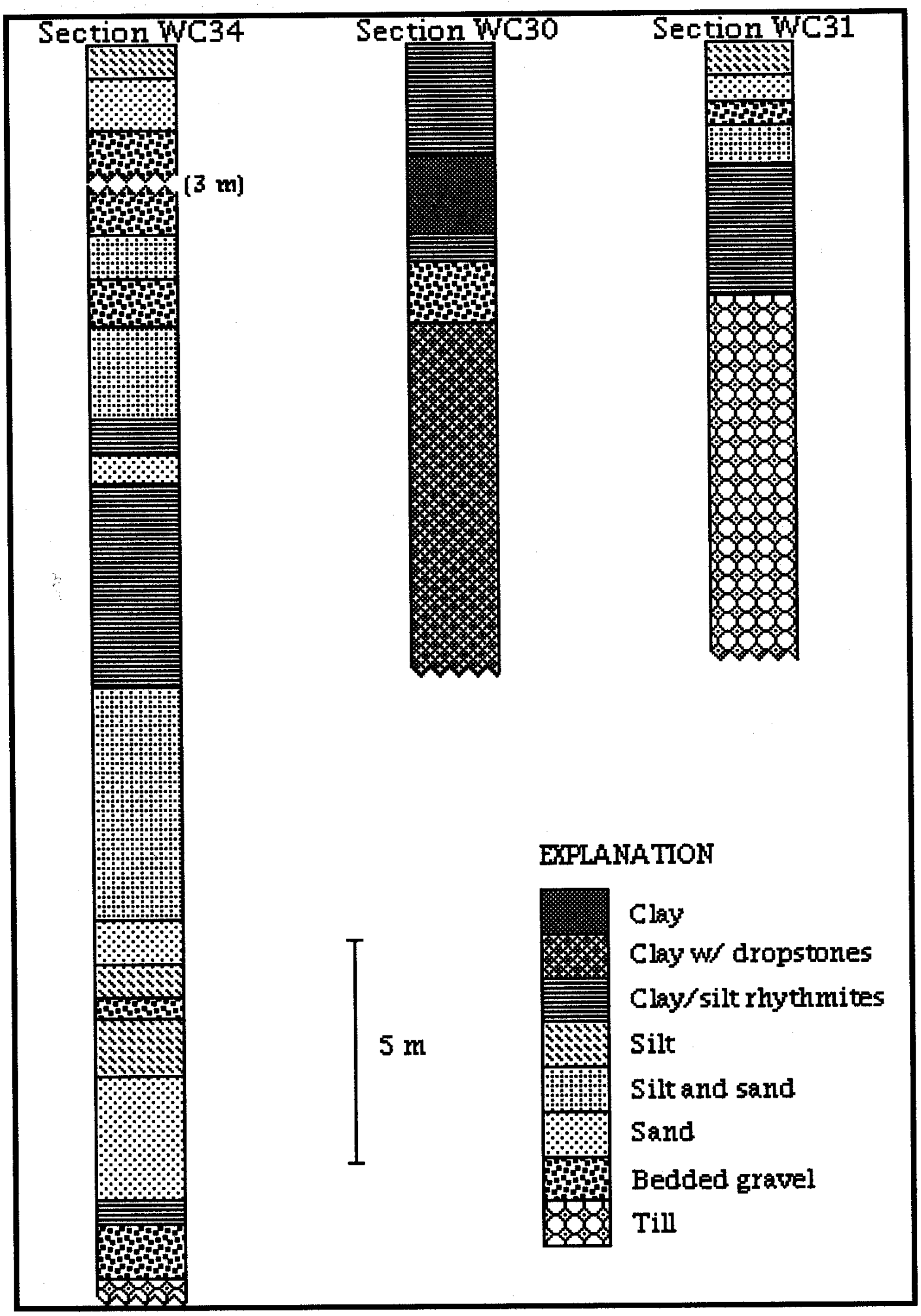


Figure 2.5 Measured stratigraphic sections of Iliuk glaciolacustrine deposits.

depositional processes. Massive to horizontally bedded sand units that may be cross-bedded, trough-bedded, or exhibit ripple lamination and climbing ripple sequences were probably deposited as prograding fans. Massive and horizontally laminated silt is present, as well as laminated and rhythmically bedded fine sand, silt, and clay. These are likely the result of deposition from suspension and density currents. Ice-rafted debris includes fine sediment and dropstones deposited by melting icebergs. Fluidization structures are locally well-developed and seem especially prevalent at silt/sand contacts where silt units are overlain by sand. This phenomenon is apparently common in glaciolacustrine deposits (Theakstone, 1976; Eyles and Eyles, 1983; Ashley, 1989; Donnelly and Harris, 1989).

The distal glaciolacustrine environment, represented by Windy Creek sections WC30 and WC31 (Fig. 2.5), is characterized by a much more limited array of depositional processes. Slump-generated underflows (surges or density currents) from basin margins can deposit considerable thicknesses of sediment across the lake bottom, particularly during the summer months when meltwater streams are most actively depositing. During other times suspension settling of clay from the water column can dominate. When both processes occur repeatedly at a given location, the resulting deposits are rhythmically bedded silts and clays such as those seen in the two distal sections (Fig. 2.5) (Theakstone, 1976; May, 1977; Eyles and Eyles, 1983; Smith and Ashley, 1985; Ashley, 1989). An additional component of distal glaciolacustrine deposition is ice-rafted material, which can include anything from fine clay to sizeable boulders. Ice-rafted pebbles form a significant proportion of the lower parts of the Windy Creek sections, where dropstones may constitute over 50 percent of the deposit.

2.7 LETHE VOLCANICLASTIC DEPOSITS (Qvl)

2.7.1 Overview of Lethe Deposits

The informally named Lethe volcaniclastic deposits (Pinney and Begét, 1990; 1991; 1992) (Fig. 2.1) are composed of an extensive suite of dacitic deposits, including pyroclastic flows, lahars, lahar-runout flows, and primary and reworked fallout tephra. These deposits are exposed in river gorges in the Valley of Ten Thousand Smokes as far as 1.5 km upvalley from the mouth of Windy Creek and they extend about 5 km past Windy Creek in Overlook valley (Fig. 2.6), where they thinly mantle Iliuk moraines. Reworked pumice equivalent to the Lethe volcaniclastic deposits has been identified over 20 km away in latest Pleistocene delta deposits that appear to be graded to a former Brooks Lake shoreline. Lethe deposits overlie Iliuk drift of late Wisconsin age in the Windy Creek area and are overlain by and incorporated into latest Pleistocene Ukak and early Holocene Katolinat drifts (Pinney and Begét, 1991). Organic silt immediately underlying these later drifts yields a younger limiting date of 12,640 ± 100 yr B.P. (Beta-33666) for Lethe deposits (Pinney and Begét, 1991). Lethe tephra is thus a potentially important late Pleistocene marker horizon for the Alaska Peninsula. The source of this tephra is presently unknown, but exposures of Lethe volcaniclastic deposits in deep stream cuts along River Lethe more than a kilometer south of the confluence of the Valley of Ten Thousand Smokes and Windy Creek valley indicate an origin at the head of the Valley of Ten Thousand Smokes, as does the lack of significant primary Lethe deposits in Windy Creek

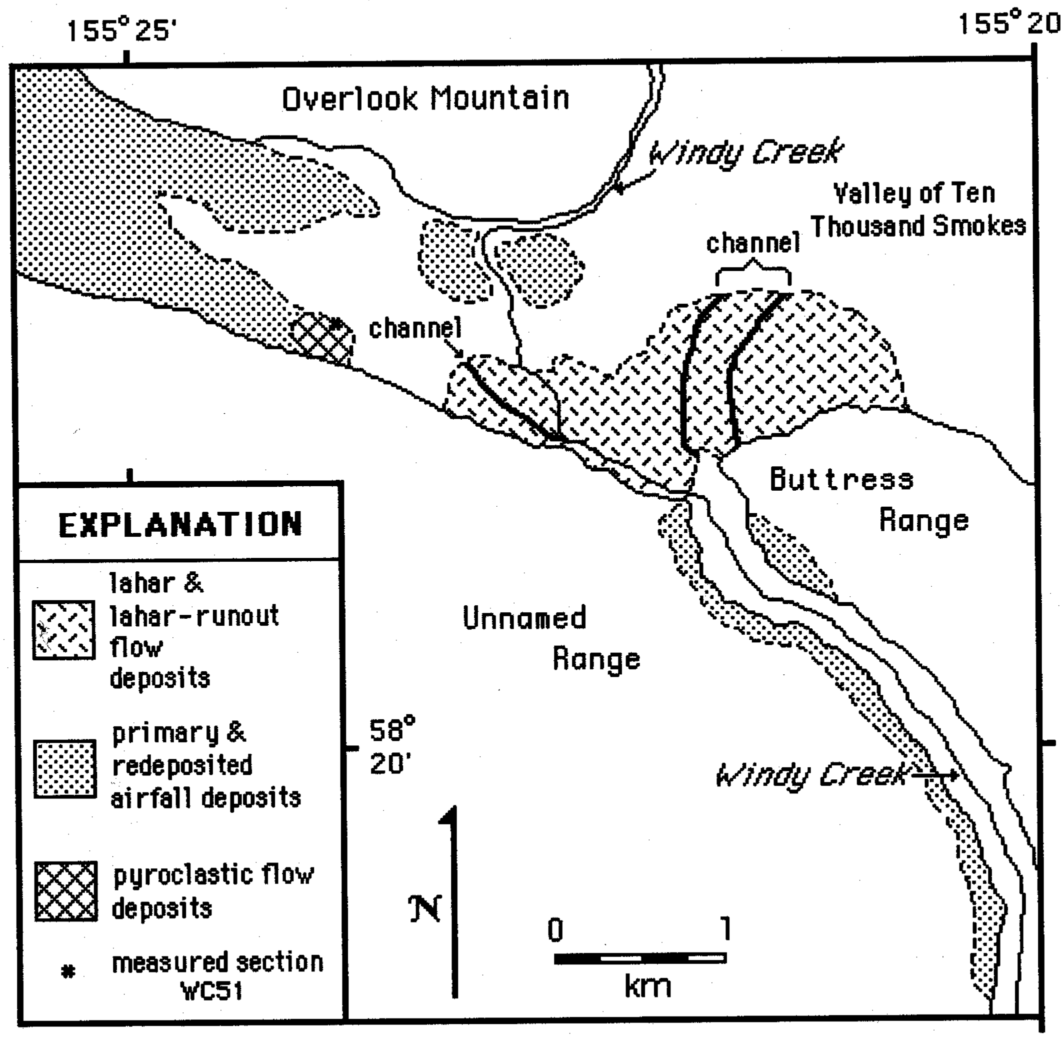


Figure 2.6 Distribution map of Lethe volcaniclastic deposits. Airfall deposits shown here were not shown in figure 2.1 as they form only a thin veneer on underlying glacial deposits.

valley. Possible sources include Mt. Mageik and dacite domes surrounding Novarupta (for example, Mt. Cerberus and Falling Mountain).

2.7.2 Lethe Lahar and Lahar-Runout Flow Deposits

2.7.2a Description of Lethe Lahar and Lahar-Runout Flow Deposits

Sediments from lahar and lahar-runout flows of the Lethe volcaniclastic deposit commonly occur together and are the dominant unit in the Windy Creek area (Fig. 2.6). Lahar deposits consist predominantly of fairly well-rounded, buff-to-yellow, coarse , bedded pumice up to 10 cm in diameter in a coarse sandy matrix. Beds are 1 to 3 m thick and are reversely graded in the lowest part of each flow unit. Scattered, prismatically-fractured pumice clasts and discoloration of pumice and surrounding sediments indicate that these lahars were emplaced while still hot. Rare sintered, glassy blocks associated with possible fumarolic activity are also found in the lahar deposits.

The sandy matrix of these pumiceous lahars is compositionally and texturally very similar to the sandy lahar-runout flow deposits with which they are usually interbedded. The coarse, yellow-brown lithic sands of the runout deposits approach thicknesses of 30 m in some stream cuts, where they form near-vertical, indurated cliffs. A volcanic origin for the lahar-runout flow deposits is confirmed by the fine fraction composed of almost pure glass with geochemistry indistinguishable from that of the pumice in the associated lahars. The lower 10 to 15 m of the thickest lahar-runout flow deposits are planar beds up to 2 m thick, and the upper 15 to 20 m have climbing ripple beds 10 to 30 cm thick, which are typical of high-concentration flow deposits. Water-escape dish-and-pillar structures are locally very abundant and are present throughout many meters of section in some areas.

Large isolated clasts of sedimentary and volcanic lithologies up to 0.5 m in diameter are present in the sand, and a possible rip-up block of till was also identified. Smaller clasts are abundant and are usually distributed in chains or zones of concentration. Rare gravel-filled channels are present near the base of the lahar-runout flow sands.

Overlying lahar-runout flow deposits in erosional contact are 0.5 to 4 m thick waterlaid, crossbedded pumice and gravel bodies, sometimes in channels. The presence of rare, intact, breadcrust bombs in these deposits indicates that they were associated with volcanic activity that continued after emplacement of lahars and related deposits.

The surface of the valley fill composed of volcaniclastic deposits is largely buried by the 1912 ignimbrite, but exposures in banks along Windy Creek and River Lethe demonstrate that it is fairly flat and slopes gently to the northwest, confirming that the material was derived from the upper Valley of Ten Thousand Smokes. The Lethe-age surface is incised by at least two abandoned channels of Windy Creek (Fig 2.6). A smaller, gravel-filled western channel may reflect diversion of flow by glaciers during latest Pleistocene or earliest Holocene time, and the larger eastern channel was likely the course of Windy Creek immediately before the 1912 eruption.

2.7.2b Lahar-Runout Flows: Deposition and Characteristics

The definitive studies of lahars and their associated runout flows were carried out by Scott (1988; 1989) on lahars of the recent eruption of Mt. St. Helens, and on several older St. Helens debris flows. He identified four primary mechanisms for generating lahars: 1) debris avalanches; 2) catastrophically ejected surges and avalanches; 3) eruption-induced snowmelt surges; and 4) lake-breakout flood surges. In each case the addition of either water (for "1"or "2" above) or sediment (for "3" or "4" above) can produce lahars. The incorporation of additional water caused further flow transformation into lahar-runout flows in the distal phases of most flows (Scott, 1988; 1989). The following discussion on the generation of and deposition from lahar-runout flows is summarized from Scott's work.

The transformation of lahars into runout flows involves debulking, or decrease of sediment concentration, through progressive incorporation of overrun streamflow. Hyperconcentrated streamflow, reiterated by Scott (1988) as flow containing 40 to 80 percent sediment by weight or 20 to 60 percent by volume (400,000 to 800,000 ppm), results when the increased water content causes a significant drop in yield strength. The change from lahars to runout flows is thought to be facilitated by low clay content in the lahar and thus low cohesiveness that allows greater miscibility with streamflow. When this transition threshold is reached, coarse clasts are deposited due to loss of yield strength and fine silt and clay may be removed by drainage of interstitial water as the flow continues downstream. Poorly sorted, generally matrix-supported debris flow deposits give way to particle-supported, granular runout sands in an inversely graded transition facies. In the transition facies, runout deposits appear as a thickening wedge at the base of the flow, overlain by debris flow deposits that thin and disappear downstream (Scott, 1988; 1989). Continued addition of water can eventually dilute lahar-runout flow to normal streamflow. The runout phases of some lahars at Mt. St. Helens were sufficiently large to bury entire floodplains more then 80 km from the volcano (Scott, 1988).

Lahar-runout flow deposits generated at Mt. St. Helens were generally massive to crudely stratified silt and granular (2 to 4 mm diameter) sand with particle or clast-supported texture (Scott, 1988; 1989). Modal size is in the sand range, commonly 0.2 to 2.0 phi (0.25 to 0.9 mm). The granularity is thought to reflect inclusion of sediments subject to previous selective sorting by explosive or hydraulic means. Sorting is characteristically 1.1 to 1.6 phi, in a range intermediate between that of debris flow deposits and most normal streamflow deposits (Fig. 2.7). Clay content is low, commonly less than 3 percent.

Grain-size analysis using nested sieves was performed on samples of Lethe lahar-runout flow sediments for comparison with Mt. St. Helens deposits. Two samples of generally massive, particle-supported Lethe sands have virtually identical grain size distributions and are within the range indicated for Mt. St. Helens lahar-runout flow deposits (Scott, 1988) (Fig. 2.7). Sorting is 1.08 phi, and modal grain size, at 0.70 phi, is also well within the range of Mt. St. Helens deposits. Lethe clay contents are much less than 3 percent, typical of lahar-runout flow deposits (Scott, 1988).

Stratification in Mt. St. Helens lahar-runout deposits, if present at all, is better developed in lateral and backwater areas (Scott, 1988). This lack of stratification reflects rapid and uninterrupted deposition from runout flood pulses. Inverse grading dominates in the transition units but generally disappears downstream. The top surfaces of the deposits are nearly planar and basal erosion is common. Wood debris and pumice can occur on the surface, and low-density clasts are sometimes embedded within the flow deposits. Pumice layers are also seen near lateral flow boundaries and locally along the base. Lahar-runout flow deposits at Mt. St. Helens are up to 2.5 m thick and might be mistaken for normal fluvial sand except for their massive appearance (Scott, 1988).

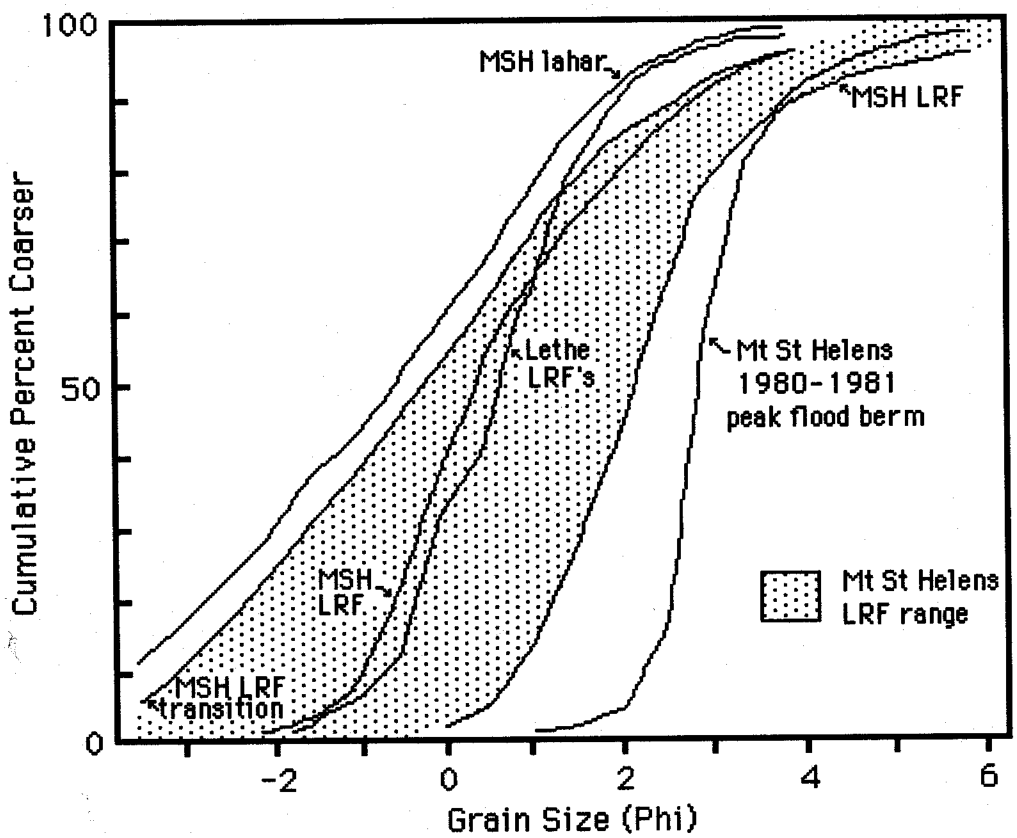


Figure 2.7 Particle size distributions in Lethe lahar-runout flows (LRF) plotted against curves for Mt. St. Helens (MSH) deposits, including lahar-runout flows, lahars, deposits from the lahar- to lahar-runout flow transition, and flood deposits. Lethe curve represents analyses of two samples that plot virtually identical and fall in the range of Mt. St. Helens LRF deposits. Mt. St. Helens data from Scott (1988).

Water escape structures have not been reported at Mt. St. Helens, but given the water-saturated, high sediment-concentration depositional environment, it was no surprise to find them in the Windy Creek deposits. Pillars formed between the upward-curving margins of dishes represent fluidization channels developed through permeable sediment (Lowe, 1975). These "Type A" pillars are infrequent and irregularly spaced where dewatering has occurred relatively slowly and tend to be common and regularly spaced where consolidation has involved near-complete sediment liquefaction (Lowe, 1975). Water escape structures probably developed at Windy Creek and not at Mt. St, Helens due to the much greater thickness (hence greater overburden pressure) of lahar-runout flow deposits at Windy Creek (30 m) compared to 2.5 m at Mt. St. Helens.

2.7.3 Lethe Pyroclastic Flow Deposits

Pyroclastic flow deposits represent only a small part of the section in the Lethe deposits (Fig. 2.6). Their presence indicates that active volcanism accompanied formation of the Lethe deposits and was of sufficient vigor to send pyroclastic flows many kilometers from any possible source. Table 2.1 gives approximate travel distances from possible source volcanos and domes. Lethe pyroclastic deposits are best described as unwelded pumice flow deposits (Fischer and Schmincke, 1984) composed of abundant pumice blocks and lapilli and less than 50 percent ash. Pyroclastic flow deposits have morphologic characteristics

Table 2.1 Approximate Travel Distances for Lethe Pyroclastic Flows from Possible Volcanic Sources

Volcanic Center	Distance (km)
Mount Katmai	25
Mount Mageik	23
Trident Volcano	21
Mount Cerberus	19
Falling Mountain	19
Mount Griggs	17

(flat top, base that follows underlying topography, sedimentary structures such as cross bedding in the lee of obstacles, graded bedding, and massive beds) indicative of primary pyroclastic flow deposition.

Exposures of several pyroclastic flows in a long gully cut across a morainal crest (sampling station WC51, Fig. 2.2) display angular to sub-rounded blocks and bombs of prismatically fractured, buff-colored dacitic pumice (Fig. 2.8). The deposits are locally clast-supported and openwork. A pumice-flow deposit up to 6 m thick, including several well-developed fossil fumaroles, extends more than 90 m to the mouth of the gully where it thins over an 8 m thickness of exposed late Wisconsin-age Iliuk till. In most places, beds of pyroclastic-flow pumice are topped by variable thicknesses of wind-reworked Lethe tephra and soil-forming silts. Pumice blocks and bombs exceed 60 cm diameter. Flow units up to 5 m thick are normally graded. In one 3 m-thick exposure, 50 cm of 10 to 20 cm diameter pumice at the top grades downward into more than 2.5 m of larger pumice and bombs. Baked contacts are present locally, and fossil fumaroles are common.

2.7.4 Primary and Reworked Lethe Fallout Deposits

Lethe airfall pumice overlying deposits of Iliuk age and older in the Windy Creek study area are locally preserved on level surfaces. Buff -colored pumice lapilli up to 2 cm in diameter are scattered on exposed Iliuk moraines. Smaller lapilli of about 1 cm diameter are dispersed in a paleosol overlying Iliuk glaciolacustrine deposits. Finer-grained, crystal-rich sandy ash equivalent to the pumice lapilli is over 1.25 m thick on the floor of Overlook valley (Fig. 2.3). These exceptional thicknesses are likely due in part to eolian concentration in protected

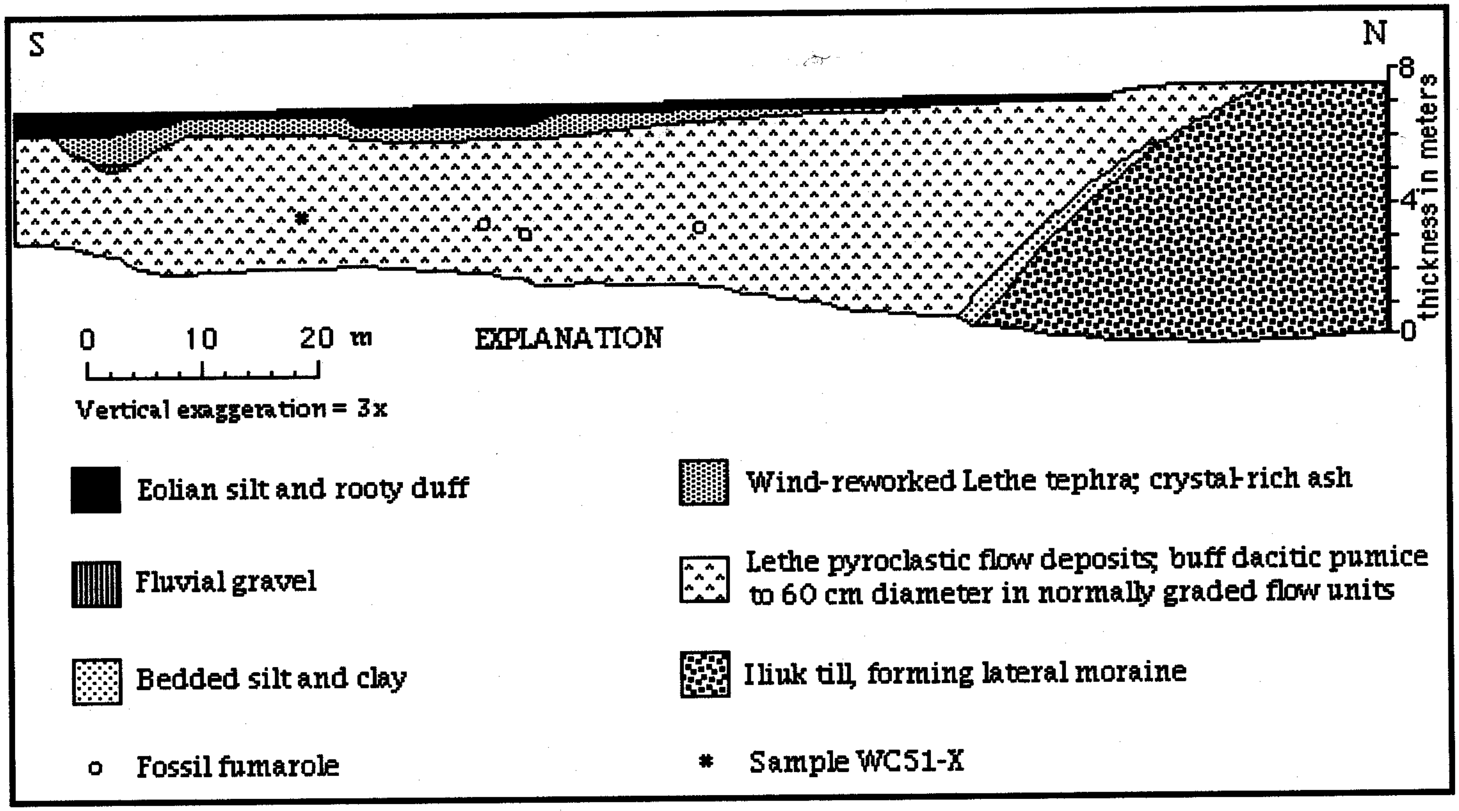


Figure 2.8 Geologic cross section through Lethe volcaniclastic deposits exposed in a natural gully west of lower Windy Creek (WC51). Volcaniclastic deposits override a lateral moraine of the late Wisconsin Iliuk glaciation.

areas. Sedimentary structures observed in the Lethe ash deposits are analogous to those seen in cross-sections through 1912 tephra dunes. It is uncertain how much of this ash can be attributed to an airfall source, and how much was derived by eolian winnowing of the sandy lahar and lahar-runout flow deposits.

Fluvially reworked Lethe airfall pumice is widely distributed in the study area and has been identified in latest Pleistocene delta deposits overlain by outwash near Brooks Lake. Redeposition of slopewash material along the flanks of Windy Creek valley has produced deposits of bedded pumice and sand that locally reach thicknesses of 6 m. The typical Lethe buff-to-yellow pumice clasts are in a coarse sandy matrix, are very well-rounded, and up to 15 cm in diameter. Rare brownish pumice clasts are sometimes dispersed among the lighter ones. Bedding can be planar to cross-bedded, and bed thickness varies from 1 to 30 cm. Interbedded with the pumice units are coarse sand and, locally, fluvial gravel beds composed of Naknek Formation sedimentary rocks and andesitic volcanic rocks. The sand is typically composed of distinct dark and light mineral grains, giving it a characteristic "salt and pepper" appearance. Small siltstone and shale pebbles of the Naknek Formation are common throughout the Windy Creek valley deposits. Extensive reworking of Lethe pumice is also evident west of Overlook Mountain where Overlook valley intersects the Margot Creek drainage. Fine-grained, thinly bedded pumice and lapilli are exposed in this location in sections more than 2 m thick.

2.8 UKAK DRIFT (Qud)

A latest Wisconsin-age drift preserved in the study area was informally named "Ukak drift" (Pinney and Begét, 1991) (Fig. 2.1). Based on the excellent preservation of Iliuk glacial and glaciolacustrine deposits in Windy Creek valley and the lack of identifiable moraines, ice from the Ukak advance does not appear to have extended far down Windy Creek itself. In the Valley of Ten Thousand Smokes, glaciers advanced several kilometers beyond Overlook Mountain and a tongue of ice extended past the mouth of Windy Creek. Windy Creek was probably diverted around the margin of the ice to flow westward in Overlook valley and continued to drain, for there is no evidence of an ice-dammed lake in Windy Creek valley during this time. Extensive dead-ice terrain formed by in-place melting of stagnant glacial ice in Margot Creek valley (Fig. 1.2 and Fig. 2.3) is the best-preserved Ukak drift. Moraine surfaces are of typical kettle-and-kame topography, being irregular, pitted, and studded with ponds and low-lying marsh between high mounds and ridges of till. The surface is well-vegetated, primarily with long grasses and thick brush. Ukak drift is also found in Overlook valley. Although considerably less extensive and subjected to more reworking due to its proximity to Windy Creek, it still exhibits the distinctive till mounds (kames) that serve to differentiate Ukak drift from other glacial deposits in the area.

2.9 KATOLINAT DRIFT (Qkd)

The youngest glacial deposits recognized in the lower Windy Creek area are informally named the "Katolinat drift" (Pinney and Begét, 1991), and form a nested pair of well-formed, modestly-sized terminal moraines (Fig 2.1). Katolinat-age glaciers advanced down the Valley of Ten Thousand Smokes almost as far as glaciers during Ukak time. As with the Ukak advance, ice does not appear to have extended far down Windy Creek valley itself. Windy Creek drainage was diverted by the ice margin and dammed to form a small lake in Overlook valley. It is unclear if this lake drained via ice-marginal streams into the Valley of Ten Thousand Smokes, via the abandoned channels formed by Windy Creek during Ukak time, or a combination of the two. Katolinat drift is best exposed along the 4-to-5 km reach of Windy Creek immediately south of Three Forks, where moraine ridges overrun by the 1912 ashflow can be clearly seen in the canyon walls of Windy Creek. Katolinat moraines extend across the lower Valley of Ten Thousand Smokes and obstructed the flow of the ignimbrite and funneled it against Overlook Mountain. Katolinat drift in the study area tends to be clay-rich with variable concentrations of clasts and is composed in part of a rockfall of volcanic debris transported by ice as an intact block to the glacier terminus. The moraines are associated with up to 20 m of glaciolacustrine silts and clays rich in dropstones and reworked (Lethe-type?) pumice where ice blocked Windy Creek drainage into what is now the Valley of Ten Thousand Smokes. Katolinat drift near Windy Creek is commonly overlain by thick deposits of peat and organic-rich silt.

2.10 OTHER SURFICIAL DEPOSITS (Ql, Qac, Qvk, Qad, Qc, Qaf, Qat, Qal)

Other surficial deposits (Fig. 2.1) mapped in the Windy Creek area may be broadly subdivided into three categories: 1) miscellaneous late Pleistocene and early Holocene deposits; 2) the 1912 ashflow and related deposits; and 3) Holocene-to-Recent minor surficial deposits.

The first group includes lacustrine deposits and abandoned channel deposits. Lacustrine deposits (Ql) are found in small drained kettle ponds on the surface of latest Pleistocene Ukak drift. The abandoned channel deposits (Qac) were probably left by Katolinat - and/or Ukak -age drainages.

The 1912 ashflow forms the most prominent surficial deposit of the Valley of Ten Thousand Smokes and nearby areas, and is associated with a wide variety of related deposits. The ashflow (Qvk) buried pre-existing surfaces near lower Windy Creek beneath up to 20 to 30 m of ash and pumice. Much of the material west of Windy Creek consists of 1912 mudflow debris that ran beyond the margins of the ashflow. Most surfaces are littered with airfall pumice showing a rapid decrease in size and number away from the vent. Thick sequences of ash up to 20 cm thick are preserved in most soil sections, with locally redeposited ash adding 50 cm or more material. The ashflow briefly dammed Windy Creek to form a lake into which tributary streams built prograding deltas (Qad). The largest of these is almost a kilometer wide and over 2 m thick, and is composed almost entirely of redeposited 1912 pumice and ash with well-developed top-, fore-, and bottom-set beds.

The Holocene-to-Recent minor surficial deposits include an assortment of fluvially- and mass movement-generated materials. Colluvium (Qc) in the form of talus cones and talus slopes universally mantle the lower slopes of ridges and peaks underlain by Naknek Formation siltstone and shale. Alluvial fans (Qaf) form in the lower reaches of most small tributary streams in places where they undergo abrupt decreases in slope as they leave the higher valleys. Fans at the base of Mt. Katolinat are quite large, in some cases up to over a kilometer across. In the upper reaches of Windy Creek (south of the mapped area), an immense coalescing fan complex composed of alluvially redeposited 1912 airfall material flanks the western base of the Buttress Range for over 5 km. Alluvial terraces (Qat) of lower Windy Creek were formed by stepwise down-cutting of the stream channel through 1912 material and into the underlying glacial deposits. The upper, braided reaches of the river form a broad floodplain up to 0.5 km wide in Windy Creek valley (Qal).

CHAPTER 3: GLACIATION

3.1 INTRODUCTION

If volcanoes form the backbone of the Alaska Peninsula, then glacial deposits are the tendons and muscles binding that skeleton together. Prior to the Quaternary the southern end of the Peninsula below Port Heiden was nothing more than a string of islands (Detterman, 1986), much like today's Aleutians (Fig. 3.1). The Pleistocene saw these islands connected first by ice, then by glacial drift. Detterman (1986) indicates that at least 50 percent of the peninsula was constructed during the Quaternary by the combined forces of volcanoes and glaciers. Immediately adjacent to a moisture source in the Gulf of Alaska (Péwé, 1975; Detterman, 1986), the Alaska Peninsula was ideally situated to produce exceptionally large glaciers. North of its mountain crest glaciers filled valleys and spread as piedmont lobes to the Bering Sea (Atwood, 1911; Péwé, 1975), while the south side was virtually buried by ice (Péwé, 1975). During times of maximum glaciation an ice cap in Shelikof Strait, one of several on the peninsula, sent outlet glaciers north through passes in the Aleutian Range to form piedmont lobes on the coastal plain along Bristol Bay and south into valleys on southwest Kodiak Island (Péwé, 1975). The southern coast of the Alaska Peninsula today rises almost directly into mountains, hence most glacial deposits of any great extent are preserved in the northwestern lowlands fringing Bristol Bay (Atwood, 1911).

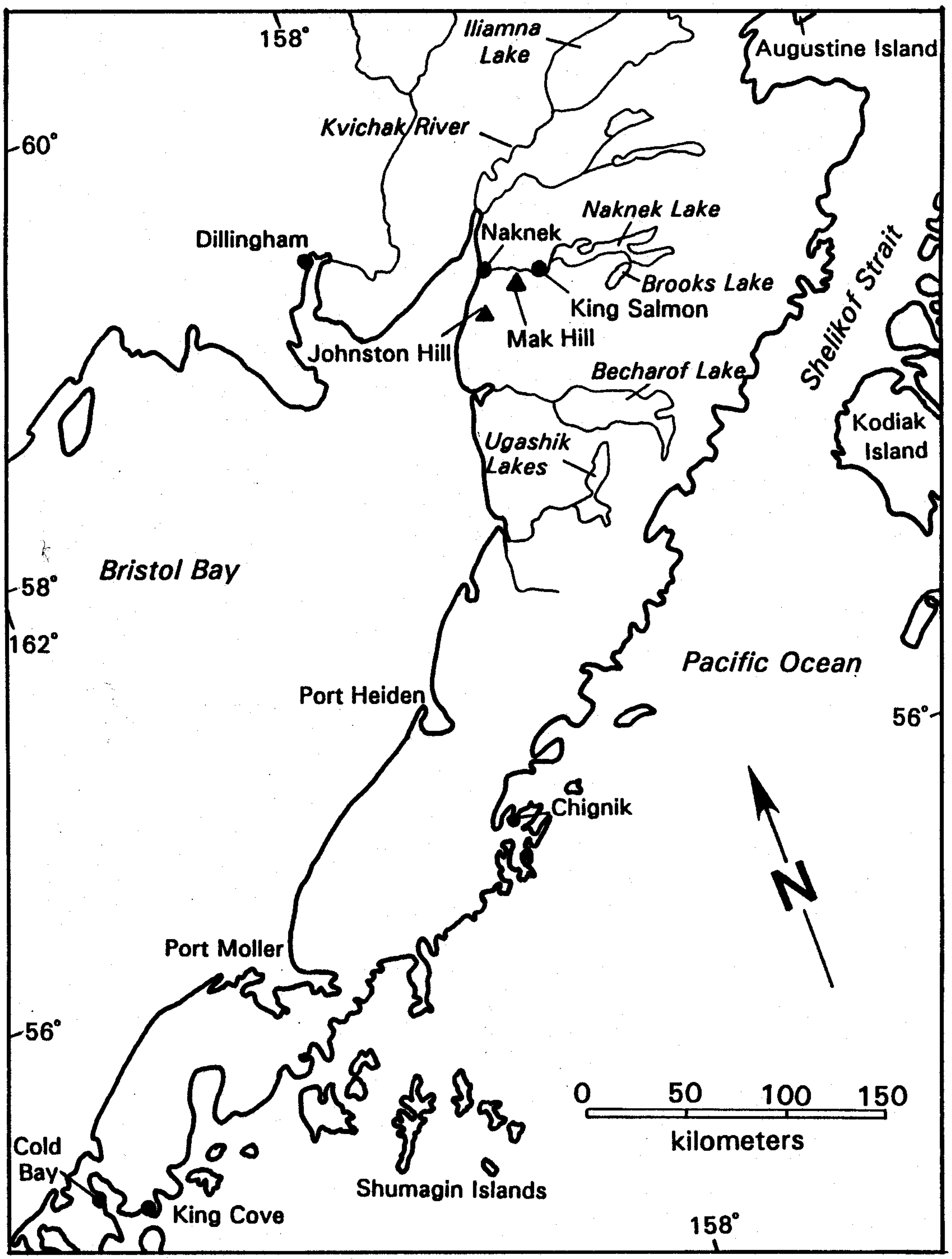


Figure 3.1 Map of the Alaska Peninsula showing locations referred to in text.

3.2 ALASKA PENINSULA GLACIAL SUCCESSION

Study of the Alaska Peninsula began with Josiah Spurr's landmark 1898 U.S.G.S. expedition in southwest Alaska (Spurr, 1900). This journey traversed approximately 1,425 miles (2,280 km) by boat and on foot, beginning at Cook Inlet, curving north and west along the Kuskokwim River, south along the Bering Sea coast, and concluded with a crossing of the Alaska Peninsula by way of Naknek Lake and Katmai Pass. Spurr commented on the large, well-developed glaciers on the northwest side of Katmai Pass, but concluded primarily on the basis of valley morphology that there had been no general glaciation of southwest Alaska. He felt glaciers had extended no farther in the past than they did in his time. To explain the origin of the numerous large lakes in the region he invoked crustal warping and damming by elevated bay bars. Other than a brief mention of glacial debris at the lower end of the Valley of Ten Thousand Smokes by Smith (1925), it would be more than fifty years before the glacial history of the Alaska Peninsula would again be addressed.

E.H. Muller (1952) was the first to recognize the true extent of Pleistocene glacial deposits on the northwestern lowlands of the Alaska Peninsula, and that there are no fewer than four distinct episodes of glaciation recorded therein. The oldest till preserved on the peninsula has been found near Halfmoon Bay (Muller, 1952), Kvichak Bay (Muller, 1953), and exposed in coastal bluffs along Bristol Bay near Naknek (Detterman, 1986). It is believed to be pre-Wisconsin in age (Detterman, 1986). Johnston Hill drift, first recognized in a moraine remnant 19 km south of Naknek named Johnston Hill (Abrahamson, 1949; Muller, 1953; Muller and others, 1954), is also thought to be of pre-Wisconsin age (Detterman, 1986). All remains of this drift sheet are found within a few kilometers of Bristol

Bay (Detterman, 1986). Mak Hill, 8 km west of King Salmon, is a till knob of what came to be called Mak Hill drift (Muller, 1952; 1953). Dated at >40,000 yr B.P. (I-13056), this may represent an early Wisconsin event (Detterman, 1986). The Mak Hill drift sheet forms much of the Bristol Bay coastline (Detterman, 1986), where ice coalesced to form piedmont lobes (Detterman and Reed, 1973). Detterman and Reed (1973) suggest that Mak Hill drift may correlate with moraines in the Kotzebue Sound area that have been dated at greater than 34,000-38,000 yr B.P. The last major episode of glacial expansion on the Alaska Peninsula was recorded by the ubiquitous presence of large moraine-dammed lakes in the foothills of the Aleutian Range, including Brooks, Naknek, Iliamna, Ugashik, Grosvenor, and Becharof Lakes (Muller, 1952; 1953; Keller and Reiser, 1959; Detterman and Reed, 1973; Henn, 1978; Dumond, 1981; Detterman, 1986). The Brooks Lake drift, named for its type occurrence, covers most of the lowland areas of the Alaska Peninsula (Detterman, 1986), its moraines controlling drainage and recording minor fluctuations of the ice margin during protracted stillstands. Detterman and Reed (1973) and Detterman (1986) correlate this event with the late Wisconsin Glaciation of the counterminous United States.

Four stades have been identified within the Brooks Lake Glaciation: the Kvichak, Iliamna, and Newhalen, named by Detterman and Reed (1973), and the Iliuk, named by Muller (1952; 1953). The Kvichak and Iliamna Stades were large, piedmont-lobe-forming events separated by a considerable period of time from the smaller, alpine valley advances that marked the Newhalen and Iliuk Stades (Detterman and Reed, 1973). Kvichak ice margins reached some 10 to 30 km beyond those of the Iliamna and lay 60 to 120 m higher on mountainsides. One of the Kvichak moraines was the first to dam Iliamna Lake (Detterman and Reed, 1973). Iliamna glaciers advanced 30 to 100 km farther downvalley than Newhalen glaciers and experienced at least three stillstands and possibly one minor readvance (Detterman and Reed, 1973). The present size and shape of Iliamna Lake is controlled by Iliamna moraines. Detterman and Reed (1973) dated material recovered from an Iliamna Lake terrace 21 m lower than maximum lake stand at 8,520±350 yr B.P. (W-179), providing a distant upper limiting date for the Iliamna Stade. The recession of Iliamna glaciers marked the end of the the last major glacial event on the Alaska Peninsula.

Subsequent ice advances saw glaciers generally confined to their alpine valleys, with Newhalen and Iliuk ice barely extending into the Aleutian Range foothills. Newhalen glaciers only advanced some 30 to 50 km from their source and experienced at least three recessional readvances (Detterman and Reed, 1973). Ugashik Narrows, the object of several archaeological studies, is a Newhalen-age moraine (Detterman, 1986). Sites at the Narrows were occupied by about 9,000 yr B.P., as evidenced by numerous radiocarbon dates (Henn, 1978), and provide an upper, albeit distant, limiting age for Newhalen deposits. Approximately 20 km behind the Newhalen moraine enclosing Brooks Lake, the type Iliuk moraine (Muller, 1952) encloses Iliuk Arm and represents a readvance of the ice front at the Close of the Brooks Lake Glaciation. Muller (1953) was the first to recognize that moraines occupying similar positions in adjacent basins and separating upper lakes and arms from the main lake also mark the Iliuk advance, and other authors followed (Keller and Reiser, 1959; Detterman and Reed, 1973; Detterman, 1986). It is unclear whether Iliuk deposits represent a separate advance or merely a readvance of Newhalen-age glaciers (Detterman, 1986), but ice extended 15 to 30 km from the source cirques and experienced at least one brief stillstand during retreat (Detterman and Reed, 1973). The end of the Iliuk Stade is considered to mark the end of the Pleistocene on the Alaska Peninsula. Table 3.1 summarizes the Alaska Peninsula glacial chronology.

Table 3.1 Late Quaternary Glacial Chronology of the Alaska Peninsula

Name		Age
Brooks Lake Glaciation	Iliuk Stade	Latest Wisconsin
	Newhalen Stade	
	Iliamna Stade	
	Kvichak Stade	Late Wisconsin
Mak Hill Glaciation		Early Wisconsin
Johnston Hill Glaciation		Pre-Wisconsin
(Unnamed Glaciation)		Pre-Wisconsin

3.3 WINDY CREEK GLACIAL DEPOSITS

3.3.1 Overview of Windy Creek Deposits

A minimum of four late Quaternary glacial advances are recorded in the deposits of the Windy Creek study area. Three sets of late Pleistocene deposits may be stratigraphically assigned to the Iliamna, Newhalen, and Iliuk stades of the Brooks Lake Glaciation. An additional latest Pleistocene glacial deposit, the Ukak drift, represents a final Pleistocene readvance. Glaciers in the area experienced another period of expansion during the early Holocene to deposit the Katolinat drift. Neoglacial ice advances may be recorded by buried hummocks beneath the Valley of Ten Thousand Smokes ashflow and by sharp-crested moraines fronting alpine glaciers on the major peaks of the area. Stratigraphy, tephrochronology, and radiocarbon dates well constrain the ages of the Ukak and Katolinat deposits, which consequently provide upper limiting ages for the youngest three stades of the Brooks Lake Glaciation that are approximately 4,000 years older than those previously reported (Pinney and Begét, 1991).

3.3.2 Pre-Iliuk Drift

The oldest glacial deposits in the Windy Creek study area are known from only one exposure in the valley of Windy Creek (Fig. 3.2). Underlying an ashflow deposit of unknown age (the Windy Creek ashflow) is an indurated diamicton of which only the upper 10 to 15 cm are exposed above the modern streambed of Windy Creek. Overlying the ashflow deposit is 2.5 m of diamicton with boulders up to at least 60 cm in diameter. This unit is almost clast-supported by clasts of well- to moderately well-rounded local lithologies. The upper unit is overlain by 1.5 m of wavy- to parallel-bedded pale pumice pebbles and dark sands in beds 0.5 to 2.0 cm thick, giving it a distinctive striped appearance. Cross-bedding is evident locally and beds thin over a 20 cm-diameter pumice clast. Capping the sequence is more than 4 m of diamicton, virtually clast-supported, with boulders up to at least 40 cm in diameter. Median clast size is somewhat larger than that of the lower diamicton. Clasts are well- to moderately rounded Naknek Formation lithologies.

The two upper diamictons are interpreted as tills, primarily on the basis of thickness, large grain size, lack of sorting, and location. The intervening unit is interpreted as a lacustrine or fluviolacustrine deposit composed almost entirely of pumice derived from the underlying ashflow unit. It is uncertain whether this

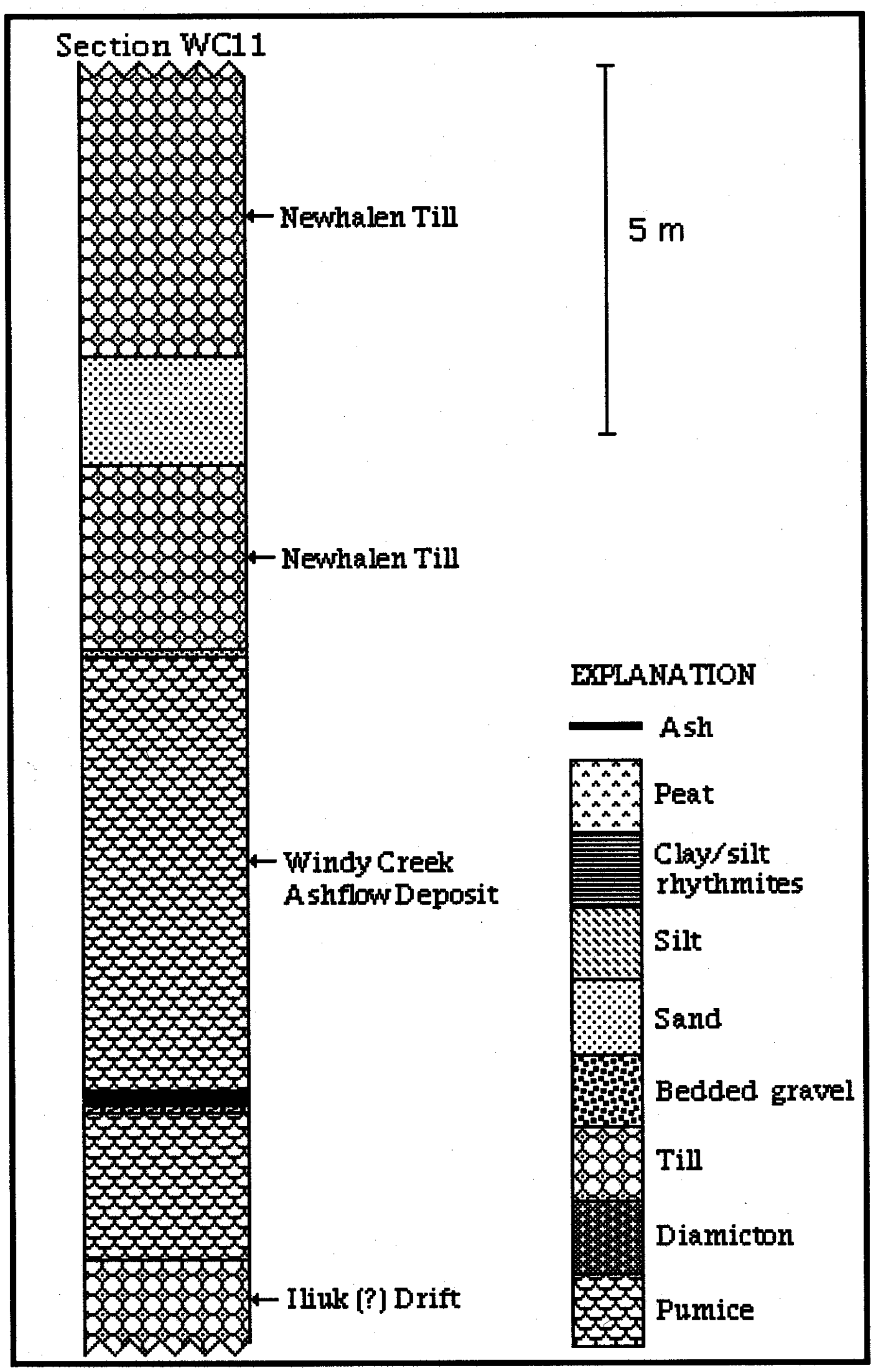


Figure 3.2 Measured stratigraphic section of pre-Iliuk glacial deposits.

tripartite sequence represents two discrete glaciations or records a single glacial event that included a brief oscillation of the ice front. Relationships to other glacial deposits in the study area, discussed below, indicate that this sequence is stratigraphically pre-Iliuk. If this is indeed the case, the large time interval separating the Iliamna and Newhalen advances would tend to preclude the first possibility, ie, that the tills represent both of these two events, for there is no evidence of a significant time hiatus. The sequence was probably deposited by pulses of Newhalen ice, which is believed to have experienced at least three recessional readvances (Detterman and Reed, 1973). The presence of the ashflow deposit less than 9 km from the glacier's source cirque at the head of Windy Creek valley demonstrates that the valley was largely ice-free when the ashflow was erupted. This ice-free condition may represent an oscillation of the ice front during Newhalen time, in which case the lowermost diamicton is also of Newhalen age. If this hiatus is interpreted as an interstadial event of longer duration than a simple ice-front oscillation, the lowermost diamicton may be assigned a pre-Newhalen age, possibly Iliamna. A positive determination can not be made with the available evidence.

3.3.3 Iliuk Drift

The type Iliuk moraine is located approximately 20 km downvalley from the study area, where it partially separates Iliuk Arm from the rest of Naknek Lake (Fig. 3.1). Iliuk lateral moraines and associated deposits, identifiable because they can be traced into the Iliuk terminal moraines on Naknek Lake, dominate the landscape of lower Windy Creek and constitute far and away the largest volume of glacial material in the study area. Glaciers of Iliuk age at the head of Windy Creek were of insufficient size to fill the valley, the mouth of which became blocked by ice extending from the Valley of Ten Thousand Smokes. A single radiocarbon date of 8,410±140 yr B.P. (Beta-29520) (Table 3.2) was obtained from a paleosol formed 6 m above the resulting glaciolacustrine deposits in Windy Creek valley (Fig. 3.3), giving a distant upper limiting date for damming of the valley by Iliuk ice (radiocarbon dates relating to the younger Ukak drift, described below, actually indicate an age exceeding 13,000 yr B.P. for Iliuk deposits). Iliuk glaciolacustrine deposits overlie the till of probable Newhalen age, discussed above, and are the basis for its pre-Iliuk age assignment. Lethe volcaniclastic deposits overlie both Iliuk drift and Iliuk glaciolacustrine deposits throughout the area.

Table 3.2 Radiocarbon Dates

Field No.	Lab No.	Loc.*	Material	Significance	Date (yr B.P.)
WC3-90	Beta-29519	1	peat	Maximum age for Tephra WC3-91	1,540 ± 80
WC4-80	Beta-24783	2	woody peat	Maximum age for Tephra WC4-90	3,320 ± 70
WC4-60	Beta-25632	2	woody peat	Minimum age for Three Forks Ash	3,600 ± 120
WC4-30	Beta-24782	2	peaty silt	Maximum age for Three Forks Ash	4,300 ± 70
WC4-10	Beta-24784	2	peaty silt	Minimum age for Katolinat drift	4,760 ± 90
WC34-X	Beta-29520	9	organic soil	Minimum age for Iliuk drift	8,410 ± 140
89K-Md	Beta-33668	11	peat	Minimum age for Katolinat drift	8,530 ± 100
WC3-20	Beta-25631	1	organic silt	Minimum age for Katolinat drift	8,680 ± 170
89K-13A	Beta-33667	14	platy peat	Minimum age for Katolinat drift	9,850 ± 90
89K-3-1	Beta-33665	1	organic silt	Maximum age for Katolinat drift	10,200 ± 140
89K-3-2	Beta-33666	1	organic silt	Dates Ukak drift	12,640 ± 100

* Location number; refers to sampling station numbers in Figure 3.3

3.3.4 Ukak Drift

Ukak drift in the study area characteristically forms ice stagnation terrain

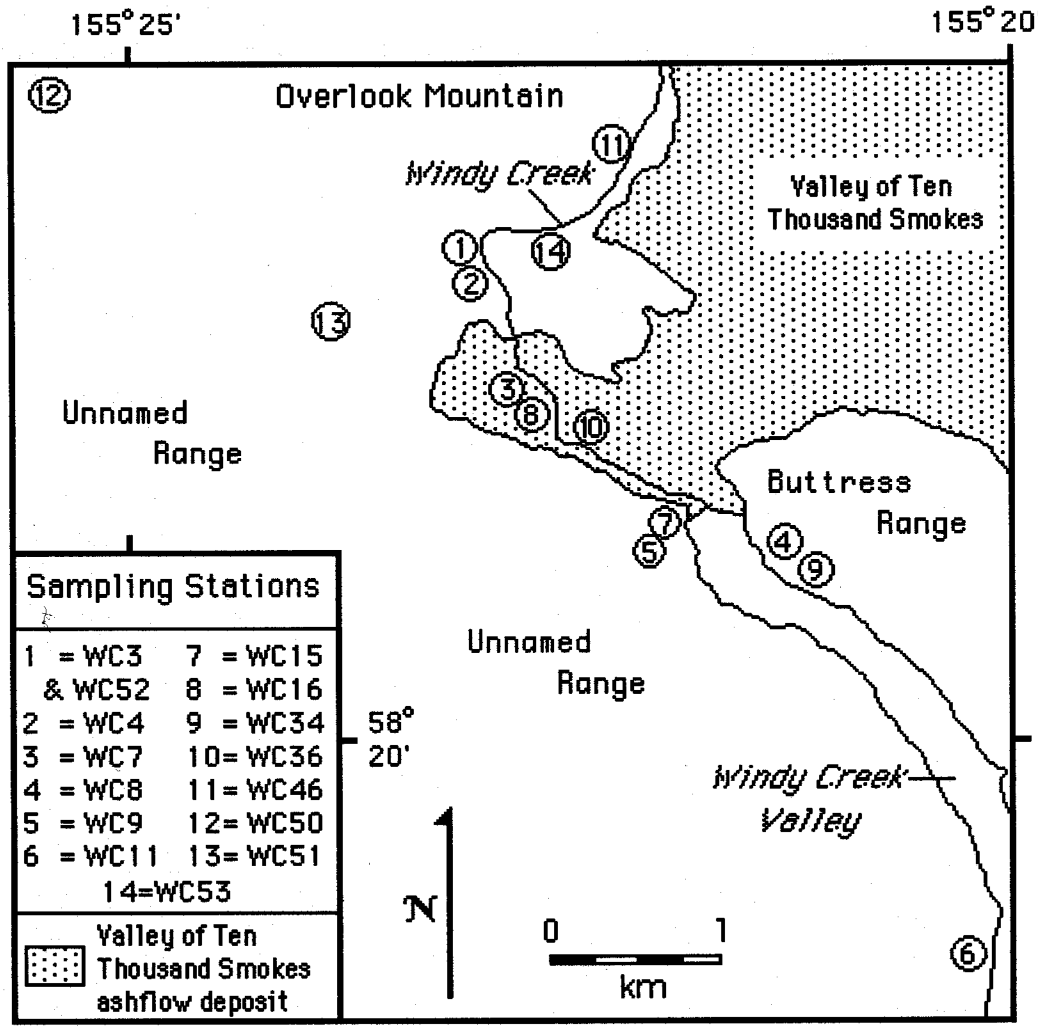


Figure 3.3 Sampling station location map.

dominated by extant and drained kettle lakes and extensive kame deposits. The Ukak ice terminus extends approximately 25 km beyond the termini of the modern Knife Creek glaciers at the head of the Valley of Ten Thousand Smokes which, along with Mt. Mageik glaciers, are the remnants of the ice stream that once filled the valley. Ice in the Valley of Ten Thousand Smokes dammed a small lake in the eastern part of Overlook valley. Windy Creek drained into this lake, which in turn emptied westward through Overlook valley into Margot Creek valley.

Radiocarbon samples recovered from organic-rich lacustrine silts and clays deposited in the Overlook valley lake (Fig. 3.4) yielded dates of 12,640±100 yr B.P. and 10,200±140 yr B.P. (Beta-33665, Beta-33666) for the lake (Pinney and Begét, 1991), giving a latest Pleistocene age for the ice advance which agrees well with the timing of the Allerød-Bølling cooling trend (11,000 yr B.P. to 13,000 yr B.P.) and Younger Dryas cold period (10,000 yr B.P. to 11,000 yr B.P.) recorded in Europe and some parts of North America (Paterson and Hammer, 1987). Ukak drift overlies and incorporates Lethe volcaniclastic deposits, which were deposited under ice-free conditions in lower Windy Creek, and thus represents a *minimum* 2 km readvance of Valley of Ten Thousand Smokes glaciers (the extent to which Lethe deposits have been traced upvalley in the Valley of Ten Thousand Smokes) near the Pleistocene-Holocene boundary between *ca.* 10,000 and 12,000 yr B.P. (Pinney and Begét, 1991).

3.3.5 Katolinat Drift

Katolinat drift, the youngest glacial deposit in lower Windy Creek, forms prominent moraines across the Valley of Ten Thousand Smokes approximately 5 km behind Ukak ice limit deposits (Fig. 2.1). Radiocarbon dates obtained from organic deposits associated with Katolinat drift (Fig. 3.5) provide upper and lower limiting dates for this advance (Table 3.2). A soil pod contained within morainal till yielded an age of 9,850±90 yr B.P. (Beta-33667) which, in conjunction with the 10,200±140 yr B.P. minimum date of the older Ukak drift, clearly places Katolinat deposits into the Holocene (Pinney and Begét, 1991). Extensive peat kettle-fills on

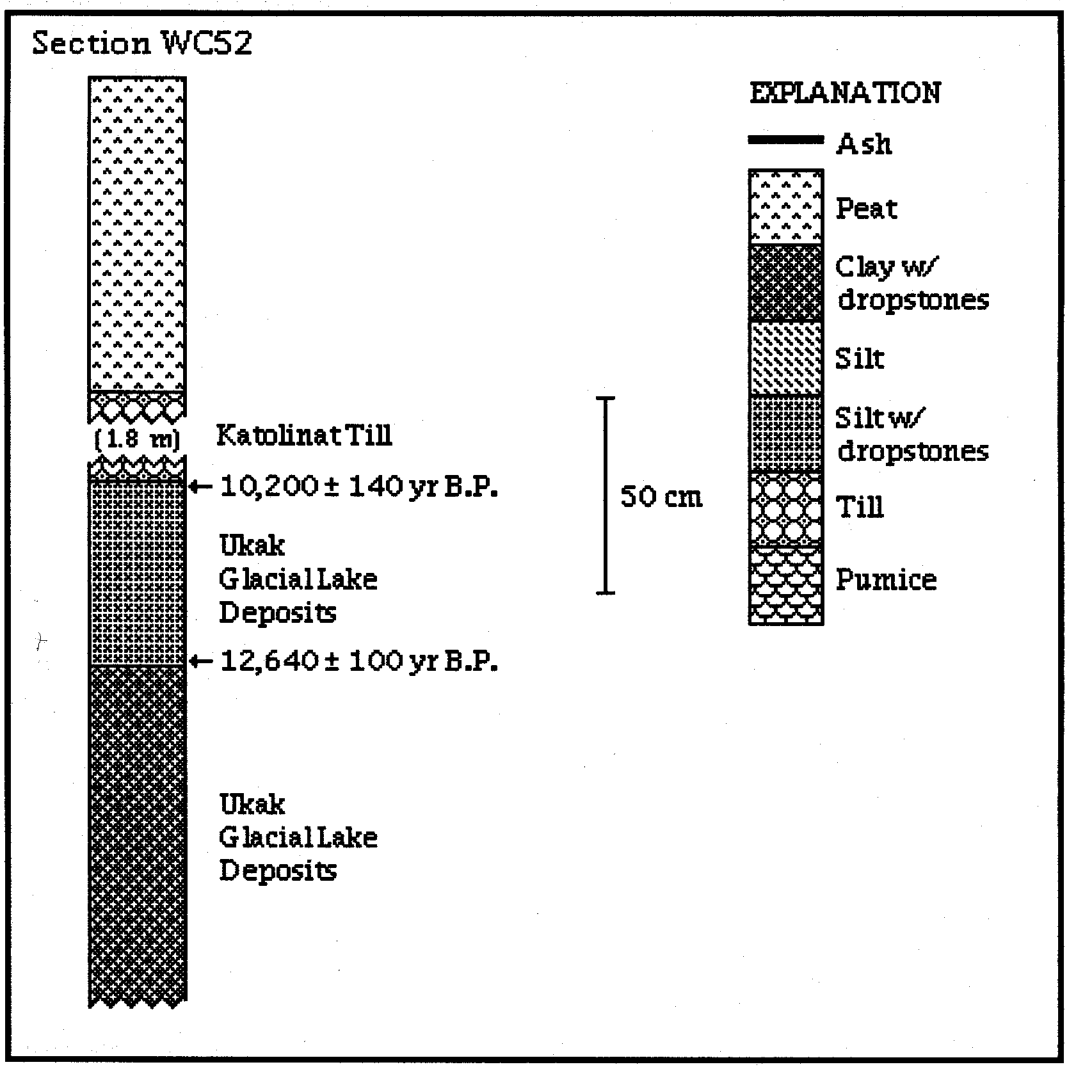


Figure 3.4 Measured stratigraphic section of Ukak glacial lake deposits. Radiocarbon dates are shown to right of column.

Katolinat drift (Fig. 3.5) give firm upper limiting dates of 8,680±170 yr B.P. and 8,530±100 yr B.P. (Beta-25631, Beta-33668) (Table 3.2) (Pinney and Begét, 1991). These peat deposits also yielded a sequence of six dates through the remainder of the Holocene (Table 3.2) and contained several widespread ash

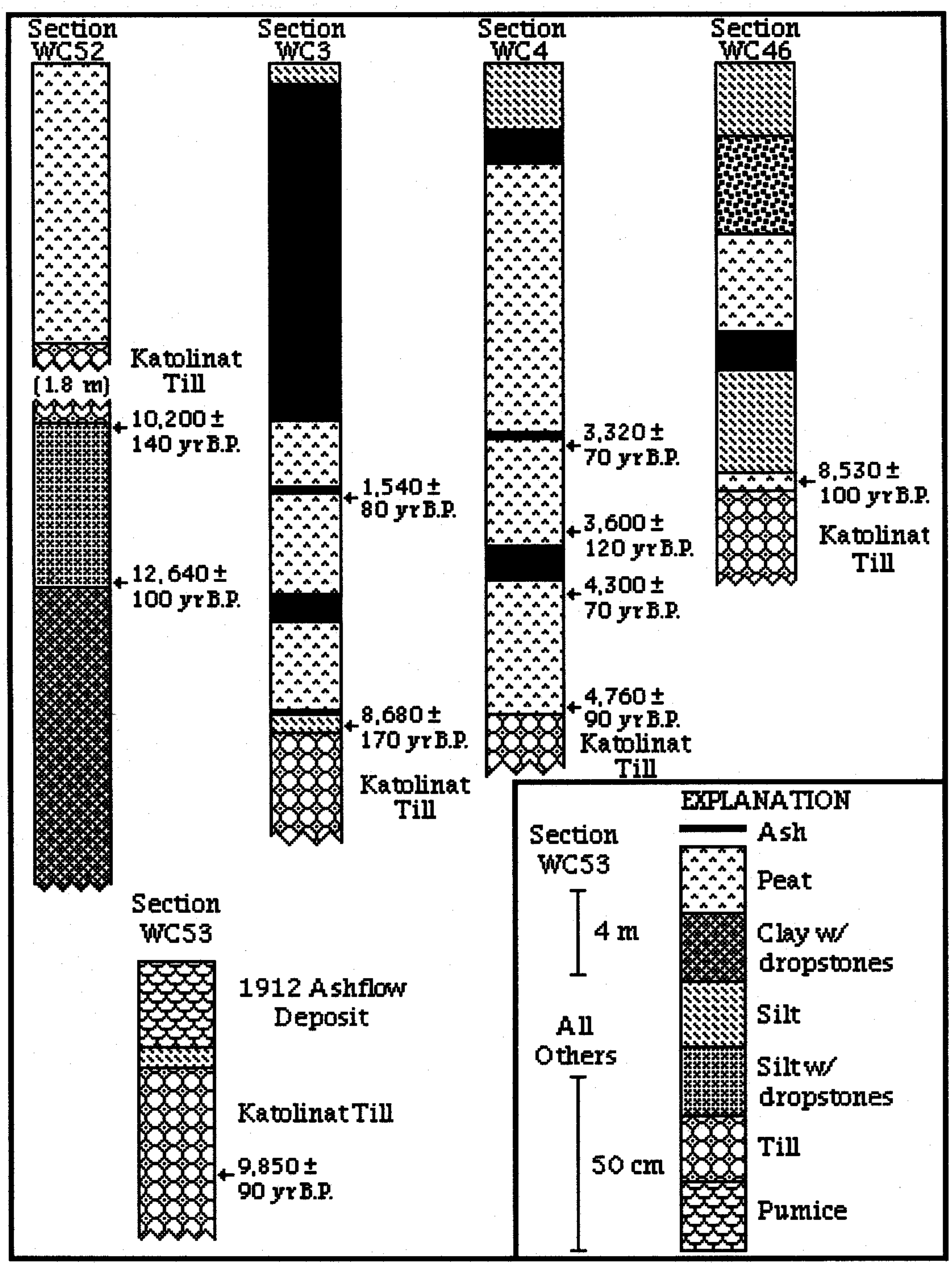


Figure 3.5 Measured stratigraphic sections of Katolinat drift. Radiocarbon dates are shown to right of each column. Note scale difference of Section WC53.

layers, including the informally named Three Forks tephra dated between 5,000 and 3,480 yr B.P. (see Chapter 4 for a detailed discussion of these tephras). Katolinat drift records a brief expansion of alpine glaciers in the Valley of Ten Thousand Smokes at the beginning of the Holocene between *ca.* 8,500 and 10,000 yr B.P. (Pinney and Begét, 1991).

3.4 SUMMARY AND REVISED ALASKA PENINSULA GLACIAL SUCCESSION

Pleistocene glacial deposits recognized on the Alaska Peninsula include an unnamed pre-Wisconsin drift, pre-Wisconsin Johnston Hill drift, early Wisconsin Mak Hill drift, and late Wisconsin Brooks Lake drift (Muller, 1952; 1953; Detterman and Reed, 1973; Detterman, 1986). The Brooks Lake Glaciation has been subdivided into four stades: the Kvichak, Iliamna, Newhalen, and Iliuk (Muller, 1952; 1953; Detterman and Reed, 1973; Detterman, 1986). Windy Creek and its environs provide an outstanding record of latest Wisconsin glacial events on the Alaska Peninsula. Drift of probable Iliamna and Newhalen age is exposed in Windy Creek valley, which was later dammed by Iliuk ice to confine a proglacial lake. A soil overlying lacustrine deposits resulting from this damming was dated at 8410±140 yr B.P., providing an upper limiting date for the Iliuk advance just 25 km from the type Iliuk moraine at Iliuk Arm. Ukak drift, representing a latest Pleistocene ice readvance, is preserved in the wide valley bottom between Mt. Katolinat and Three Forks Mountain, and also near lower Windy Creek. The upper part of Ukak glaciolacustrine deposits has been radiocarbon dated between *ca.* 10,000-12,000 yr B.P., providing an upper limiting date older than any previously reported for the Brooks Lake Glaciation and its four stades (Pinney and Begét, 1991). Katolinat drift forms two distinct moraine loops that partially obstructed the flow of the 1912 ignimbrite. The early Holocene Katolinat drift has been radiocarbon dated between *ca.* 8,500 and 10,000 yr B.P. (Pinney and Begét, 1991).

Figure 3.6 is a time-distance plot of late Pleistocene glacier advances on the northern Alaska Peninsula measured from the termini of the modern Knife Creek glaciers, and includes three volcanic deposits that form distinctive markers in the

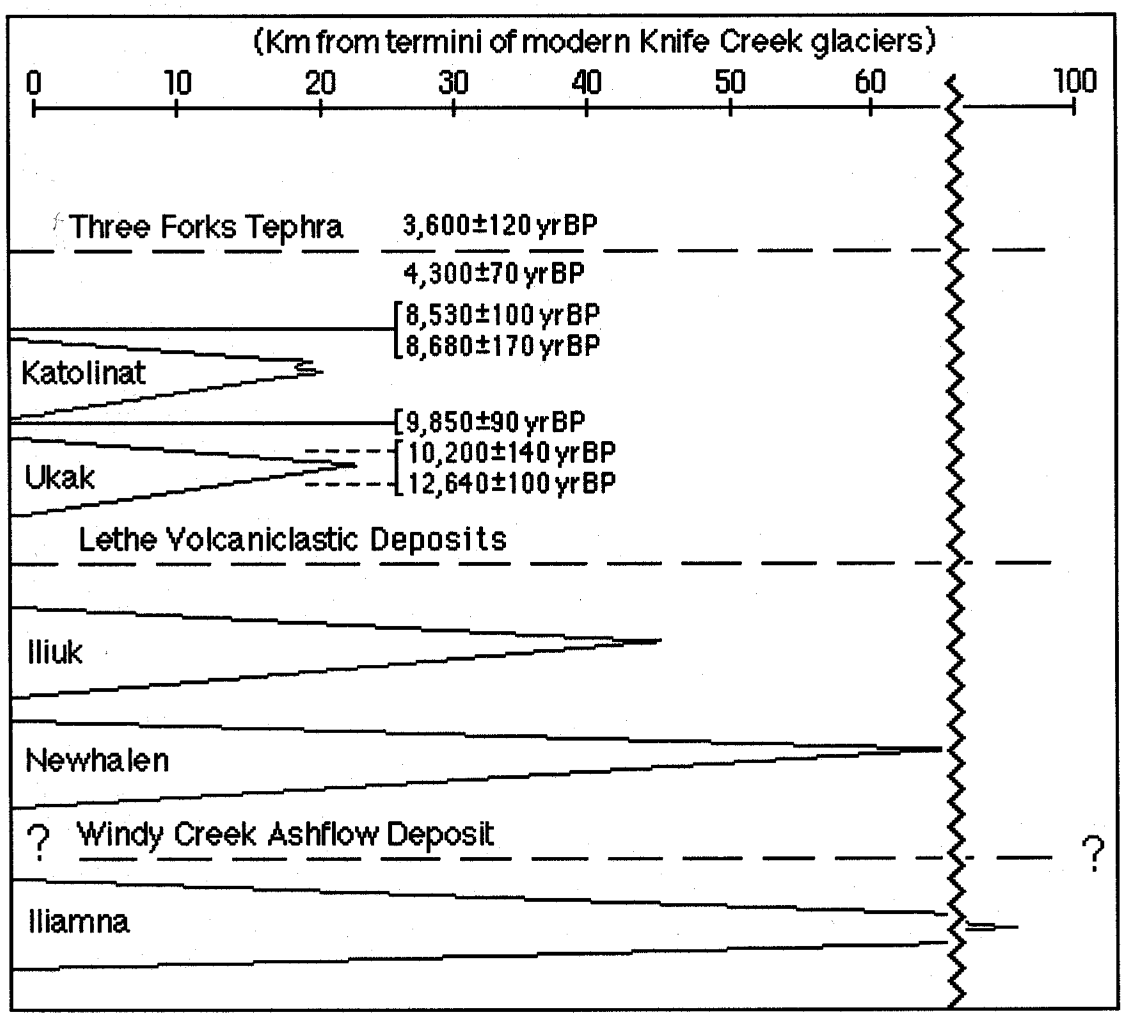


Figure 3.6 Time-distance plot of glacier advances with radiocarbon dates and major volcanic horizons.

Windy Creek section. Ice of the Iliamna stade extended approximately 100 km downvalley from modern glaciers. Thirty kilometers behind the Iliamna ice margin are Newhalen moraines, and 20 km farther upvalley the type Iliuk moraine forms the narrows separating Iliuk Arm from Naknek Lake. Prior to this study the ages of these alpine valley glacier advances, like that of the major Iliamna advance, were poorly constrained by upper limiting dates of *ca.* 9,000 yr B.P. (Detterman and Reed, 1973). The Windy Creek study has pushed these limits back some 4,000 years to greater than *ca.*13,000 yr B.P. Lethe volcaniclastic deposits overlie all these deposits and underlie all younger glacial deposits, forming an important marker horizon that may traceable to the Kenai Peninsula, over 250 km away (Pinney and Begét, 1992). The Ukak readvance of alpine glaciers near the Pleistocene-Holocene boundary *ca.* 10,000 to 12,000 yr B.P. (Pinney and Begét, 1991) extended about 25 km downvalley from modern glaciers and terminated approximately 25 km behind the Iliuk ice margin. Moraines of the early Holocene Katolinat ice expansion *ca.* 9,000 yr B.P. (Pinney and Begét, 1991) are found 1 to 5 km upvalley from Ukak deposits in the Valley of Ten Thousand Smokes. The *ca.* 4,000 yr B.P. Three Forks tephra shown in Figure 3.6 (see Chapter 4 for a more detailed discussion of this ash layer) is a mid-Holocene marker horizon that may prove valuable in separating the aforementioned groups of deposits from subsequent Neoglacial deposits. Table 3.3 is a revision of Table 3.1 to include Ukak and Katolinat deposits.

Table 3.3 Revised Late Quaternary Glacial Chronology of the Alaska Peninsula

<table>
<tr><th colspan="2">Name</th><th>Age</th></tr>
<tr><td>(Unnamed Glaciation)</td><td>Katolinat Stade</td><td>Holocene</td></tr>
<tr><td rowspan="5">Brooks Lake Glaciation</td><td>Ukak Stade</td><td>Latest Wisconsin</td></tr>
<tr><td>Iliuk Stade</td><td></td></tr>
<tr><td>Newhalen Stade</td><td></td></tr>
<tr><td>Iliamna Stade</td><td></td></tr>
<tr><td>Kvichak Stade</td><td>Late Wisconsin</td></tr>
<tr><td colspan="2">Mak Hill Glaciation</td><td>Early Wisconsin</td></tr>
<tr><td colspan="2">Johnston Hill Glaciation</td><td>Pre-Wisconsin</td></tr>
<tr><td colspan="2">(Unnamed Glaciation)</td><td>Pre-Wisconsin</td></tr>
</table>

CHAPTER 4: WINDY CREEK TEPHRA STUDY

4.1 INTRODUCTION

The fundamental principles of tephrochronology were developed in Iceland by Sigurdur Thorarinsson (Self and Sparks, 1981). His research in the 1940's and 1950's showed that tephra layers, each representing an instant in geologic time, could be correlated over large areas of Iceland, and could thus be regarded as isochronous stratigraphic markers. Reliable correlation of tephra layers is essential in tephrochronology and this requires a multiple-criteria approach to tephra characterization. Westgate and Gorton (1981) identified three major requirements that must be fulfilled for tephra layers to be correlated to one another: 1) the ages of the layers, relative and/or absolute, must be compatible; 2) the physico-chemical properties of glass and primary phenocrysts must agree; and 3) the combination of these characteristics must be distinct from other tephra layers in the area.

The Windy Creek area preserves a remarkably detailed record of Alaska Peninsula volcanism and is thus well suited to the use of tephrochronology. A total of thirty-eight tephra samples were collected for analysis from nine measured sections and three surface collections near Windy Creek (Fig. 4.1), and two measured sections near Brooks Lake. These samples span a variety of deposits ranging from proximal, meters-thick pyroclastic flows containing half-meter pumice blocks, to distal, fine, fallout ash barely thick enough to sample. Correlation among Windy Creek tephras and with other documented Alaskan tephras was attempted by combining stratigraphic information with petrographic

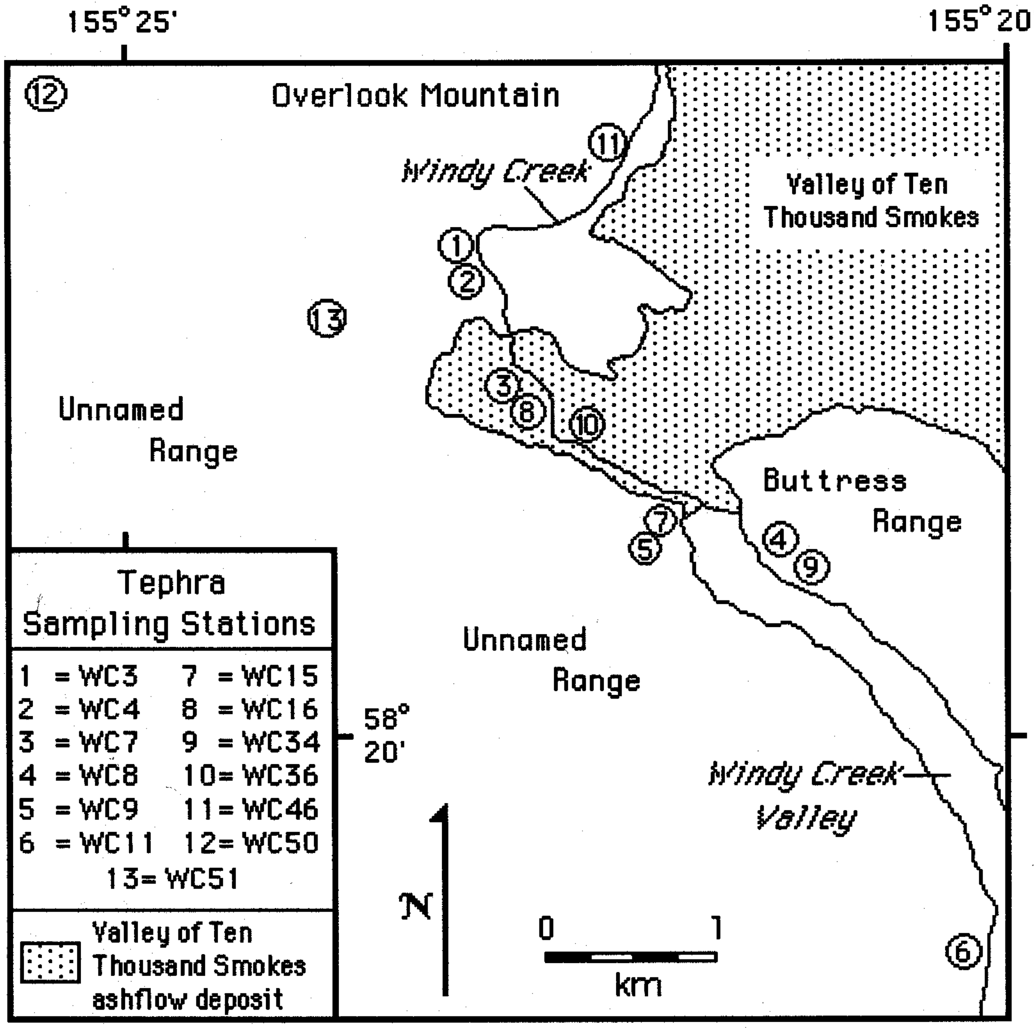


Figure 4.1 Tephra sampling station location map.

and geochemical data. These efforts met with moderate success, allowing four tephras to be traced through multiple localities in the study area, one to be traced to the Kenai Peninsula, one to be traced to west-central Alaska, and two to be correlated with proximal deposits at Mt. St. Augustine and Aniakchak. The majority of the samples proved uncorrelatable with any other tephras, and many showed evidence suggesting mixing, reworking and/or contamination.

4.2 TEPHRA STRATIGRAPHY

4.2.1 Overview of Windy Creek Tephra Sites

Measurement of stratigraphic sections was the first step in unraveling the tephrochronology of the Windy Creek area. Except for surficial collection site WC50 and the Brooks Lake gravel pit sites BL-1 and BL-2, all measured sections were in natural streamcuts. Thirty-eight tephra samples were collected from fifteen sites for tephrochronologic study.

4.2.2 Section WC3

Section WC3 (Fig. 4.2) was measured through the deepest part of a peat-filled kettle lake developed on Katolinat till that is exposed in a cut bank of Windy Creek. A basal clay-rich organic silt was radiocarbon-dated at 8,680 ± 170 yr B.P. (Beta-25631)(Table 3.2). Three tephras were collected at this locality: WC3-26, a 1-to-2 cm-thick, very fine brown ash; WC3-55/62, a 7 cm-thick, coarse grey-brown sandy ash with lenses of finer brown-to-grey ash; and WC3-91, a 1 cm-thick, fine brown ash extensively mixed with silty sediment. Peat immediately below tephra WC3-91 yielded a radiocarbon date of 1,540 ± 80 yr B.P. (Beta-29519)(Table 3.2).

4.2.3 Section WC4

Section WC4 (Fig. 4.3) is a cut through a shallower part of the same kettle lake approximately 20 meters upstream from Section WC3. Basal peaty silt,

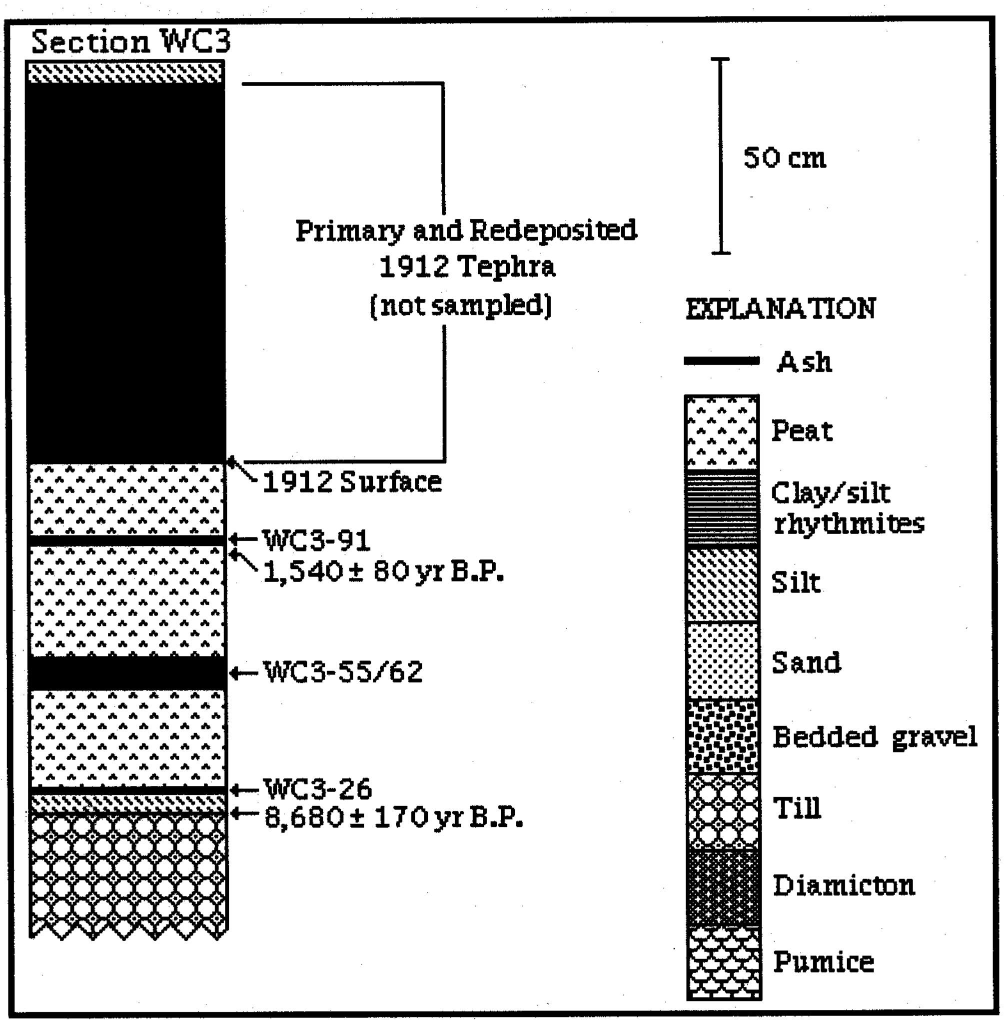


Figure 4.2 Measured stratigraphic section WC3. Tephra sample numbers and radiocarbon dates are shown to right of column.

dated at 4,760 ±90 yr B.P. (Beta-24784)(Table 3.2), was younger than that at WC3, possibly reflecting temporal differences in inception of peat accumulation between the central part and margins of the basin. Two tephras were collected from this section: WC4-50, a 10 cm-thick, pinkish-to-buff or grey, coarse, sandy ash containing lenses of pink-to-buff or grey fine ash; and WC4-90, a 1 cm-thick,

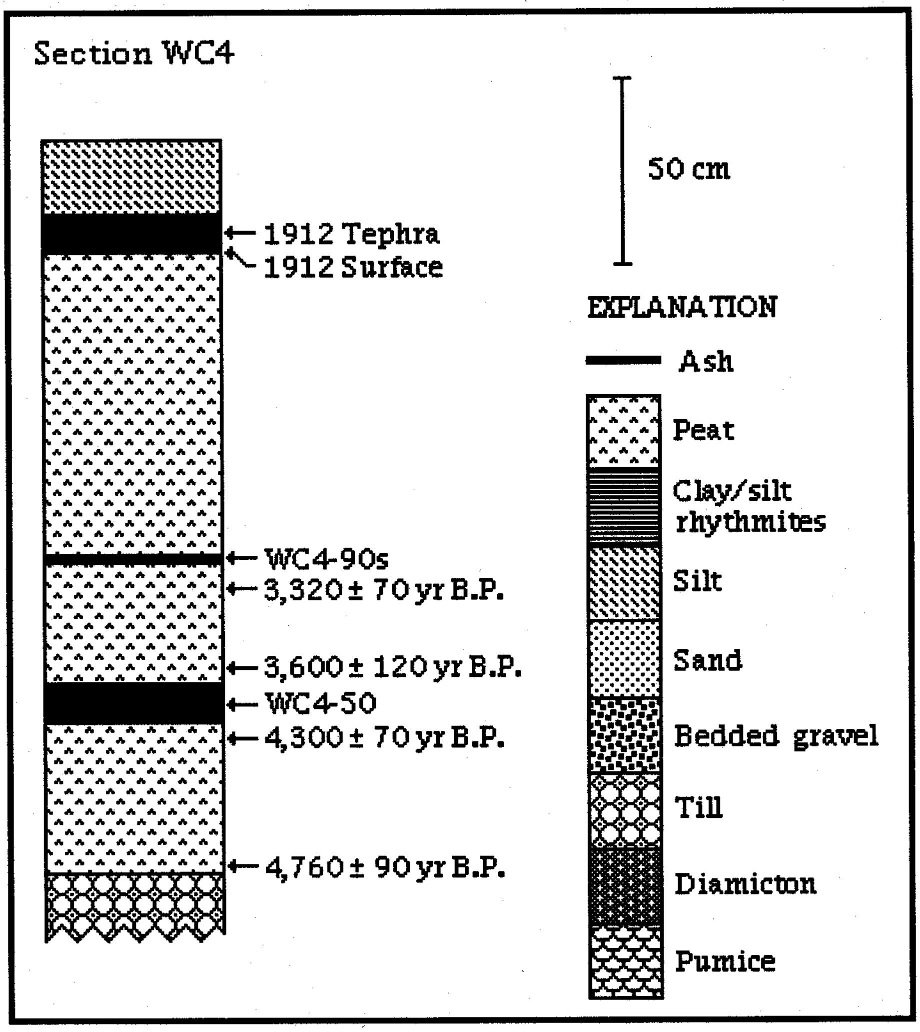


Figure 4.3 Measured stratigraphic section WC4. Tephra sample numbers and radiocarbon dates are shown to right of column.

grey, sandy ash. Peat samples immediately below and above tephra WC4-50 were dated at 4,300 ± 70 yr B.P. (Beta-24782) and 3,600 ± 120 yr B.P. (Beta-25632), respectively (Table 3.2). Peat directly beneath WC4-90 was dated at 3,320 ± 70 yr B.P. (Beta-24783) (Table 3.2).

4.2.4 Section WC7

Section WC7 (Fig. 4.4) is located in the 20-to-30 meter deep gorge cut by Windy Creek into Lethe lahar-runout flow deposits. Two tephras were collected from 1.3 m of silt overlying the volcaniclastic deposits: WC7-40, a thin, diffuse, very fine brownish-orange ash; and WC7-55, a 5 cm-thick, coarse, reddish-brown, sandy ash with some finer ash. No radiocarbon material was present in this section.

4.2.5 Section WC8

Section WC8 (Fig. 4.5) is located near the mouth of Windy Creek valley and forms a cap over thick Iliuk-age glaciolacustrine deposits. Five tephras were collected from a 2.3 meter thick eolian silt and sand sequence: WC8-0, a 2 cm-thick, brown-to-pink, fine ash; WC8-19, a diffuse, dark brown, fine ash; WC8-30, consisting of diffuse lenses and pods of fine, light grey ash; WC8-60, a fine, pinkish-grey ash occurring in minute lenses and pods; and WC8-70, an irregular 2-to-4 cm-thick, dark grayish-brown, fine ash. A dark, organic-rich silt layer 17 cm above tephra WC8-30 and 18 cm below tephra WC8-60 yielded a radiocarbon date of 660 ± 70 yr B.P. (Beta-25633)(Table 3.2).

4.2.6 Section WC11

Section WC11 (Fig. 2.4) is on the west wall of lower Windy Creek valley where the Windy Creek ash flow deposit is exposed. This section has been discussed in detail in Chapter 2. Three tephra samples were collected at this locality: fluvially redeposited pre-ashflow fallout pumice WC11-D4, consisting of 2.5-to-5 m of coarse, rounded, white-to-pale pink pumice up to 5 cm in diameter;

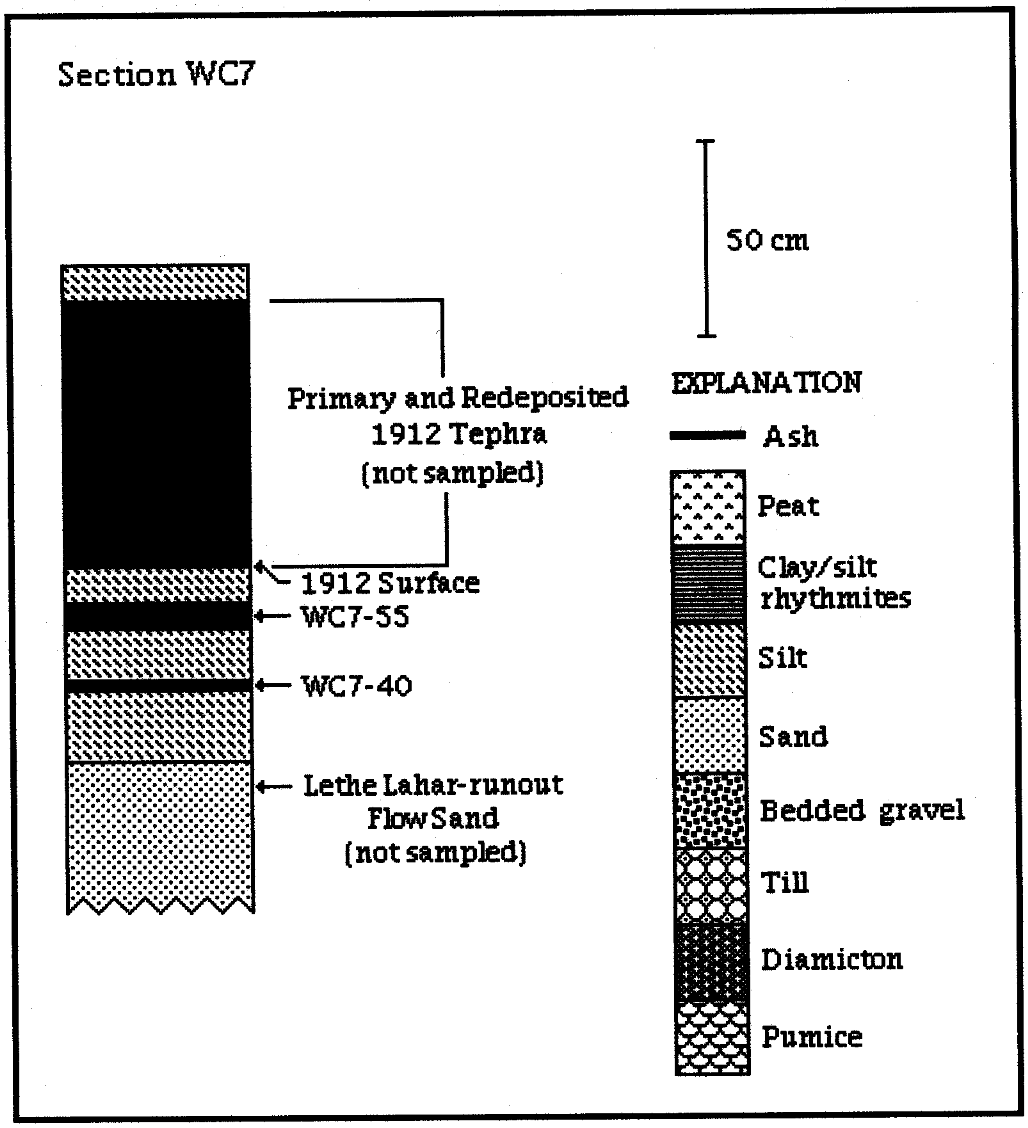


Figure 4.4 Measured stratigraphic section WC7. Tephra sample numbers are shown to right of column.

PI-C, a 20 cm-thick deposit of fine, pink ash and pumice lapilli; and PI-D2, consisting of pale pink-to-white, fine ash and pumice up to 2 cm in diameter from the 6 m-thick main body of the ash flow.

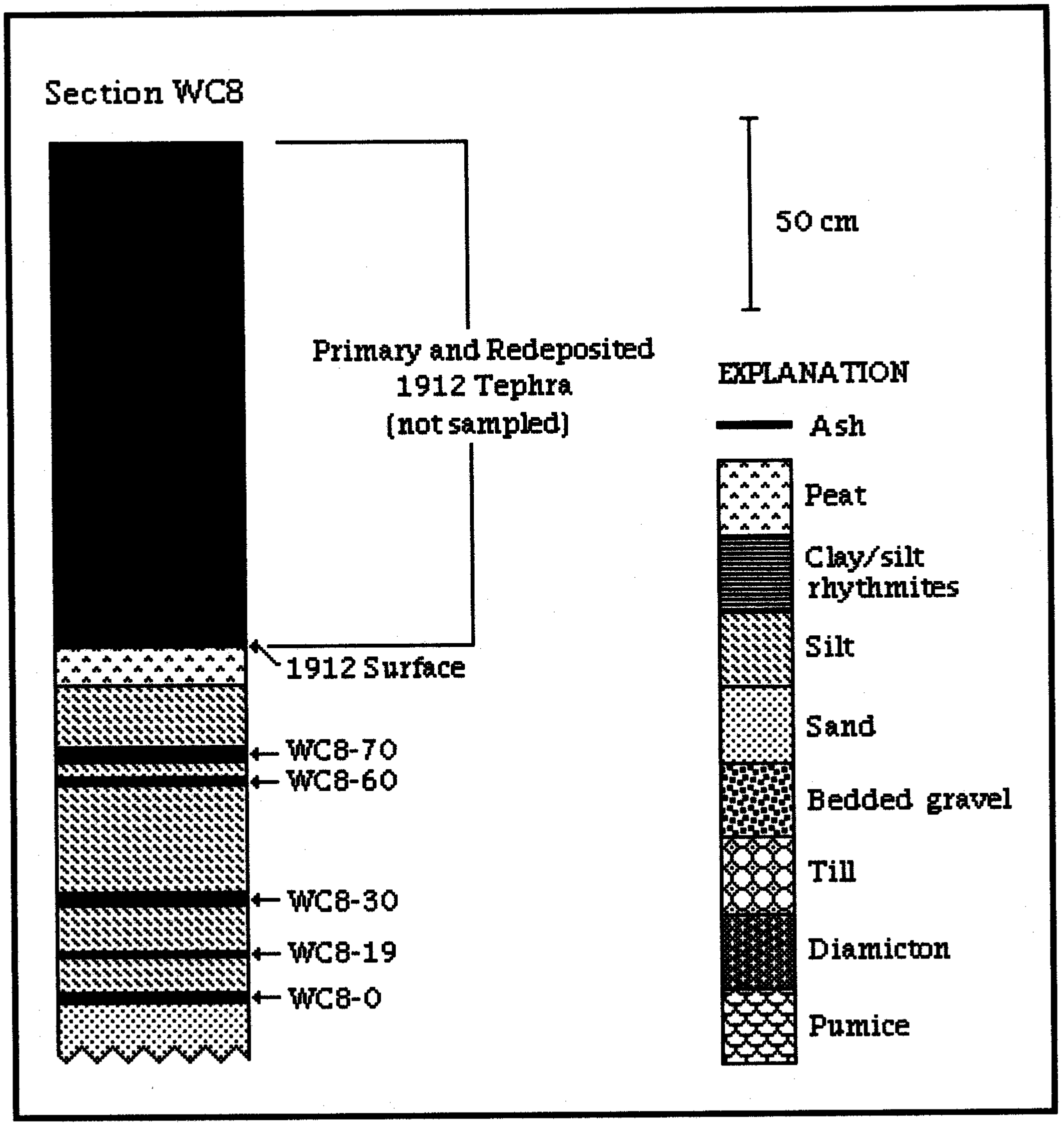


Figure 4.5 Measured stratigraphic section WC8. Tephra sample numbers are shown to right of column.

4.2.7 Section WC15

Section WC15 (Fig. 4.6) is located along a tributary stream of Windy Creek near the mouth of the valley. Naknek Formation bedrock at this site is overlain by

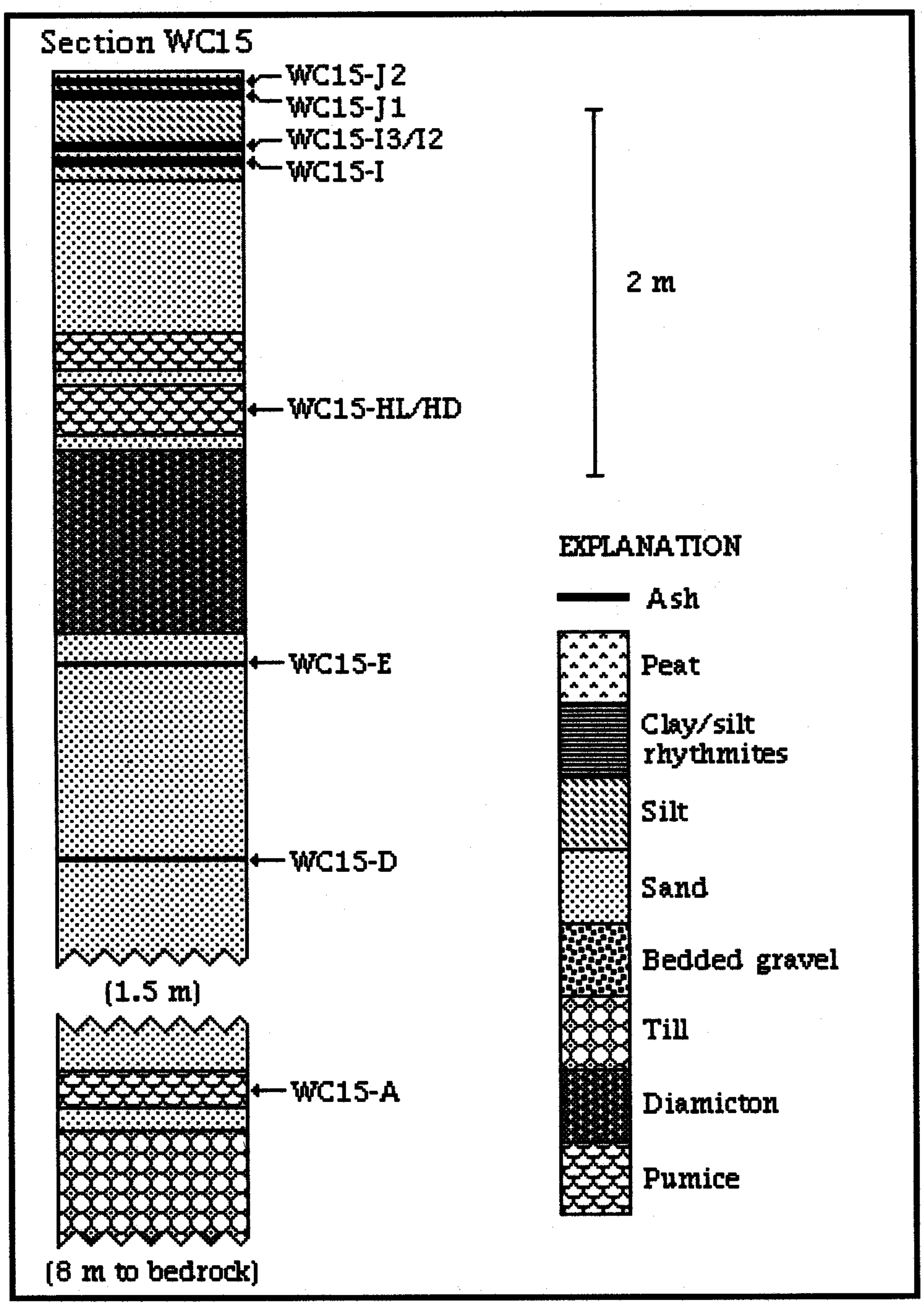


Figure 4.6 Measured stratigraphic section WC15. Tephra sample numbers are shown to right of column.

8 m of till and 7 m of fluvially reworked Lethe fallout pumice and ash containing an intercalated mudflow deposit. Five tephra samples were collected from the bedded Lethe deposits: WC15-A, a 20 cm-thick bed of buff-to-pink-to-grey, rounded pumice up to 5 cm in diameter; WC15-D, a thin (< 1 cm) horizontal stringer of fine, yellowish-brown ash; WC15-E, a thin stringer of buff pumice lapilli from a 0.5 m-thick bed of reworked, oxidized, pumiceous sand directly underlying a mudflow deposit; and WC15-HL, a 25 cm-thick bed of buff-to-yellow pumice up to 15 cm in diameter in which are dispersed rare, smaller, dark brown pumice clasts of WC15-HD. The capping meter of the exposure consists of eolian silt from which five tephras were collected: WC15-I, a 0.5 cm-thick, dark brown, fine ash; WC15-I2, a discontinuous, fine, red ash up to 2.5 cm thick, interbedded with WC15-I3, a discontinuous, fine, red-to-yellow ash up to 1.5 cm thick; WC15-J1, a 0.5-to-2 cm-thick, fine, orange and grey ash; and WC15-J2, a 0.5-to-1 cm-thick, fine, reddish-orange ash.

4.2.8 Section WC34

Section WC34 (Fig. 4.7) is located approximately 50 m upvalley from section WC8. Six tephras were collected from a 2.35 m-thick eolian silt and sand sequence overlying Iliuk glaciolacustrine deposits: WC34-X, numerous pale pumice lapilli dispersed in a paleosol; WC34-Z2, a fine, grey ash occurring in discontinuous lenses; WC34-Z5, a 2 cm-thick diffuse, fine, grey ash immediately overlain by WC34-Z6, a 3 cm-thick, diffuse, fine, light orange ash; WC34-Z8, a 1-to-4 cm thick fine, pale orange ash with a thin basal zone of very small pumice lapilli; and WC34-Z9, a diffuse, fine, grey ash near the top of the soil horizon buried by primary and redeposited 1912 tephra. The 10 cm-thick, dark brown

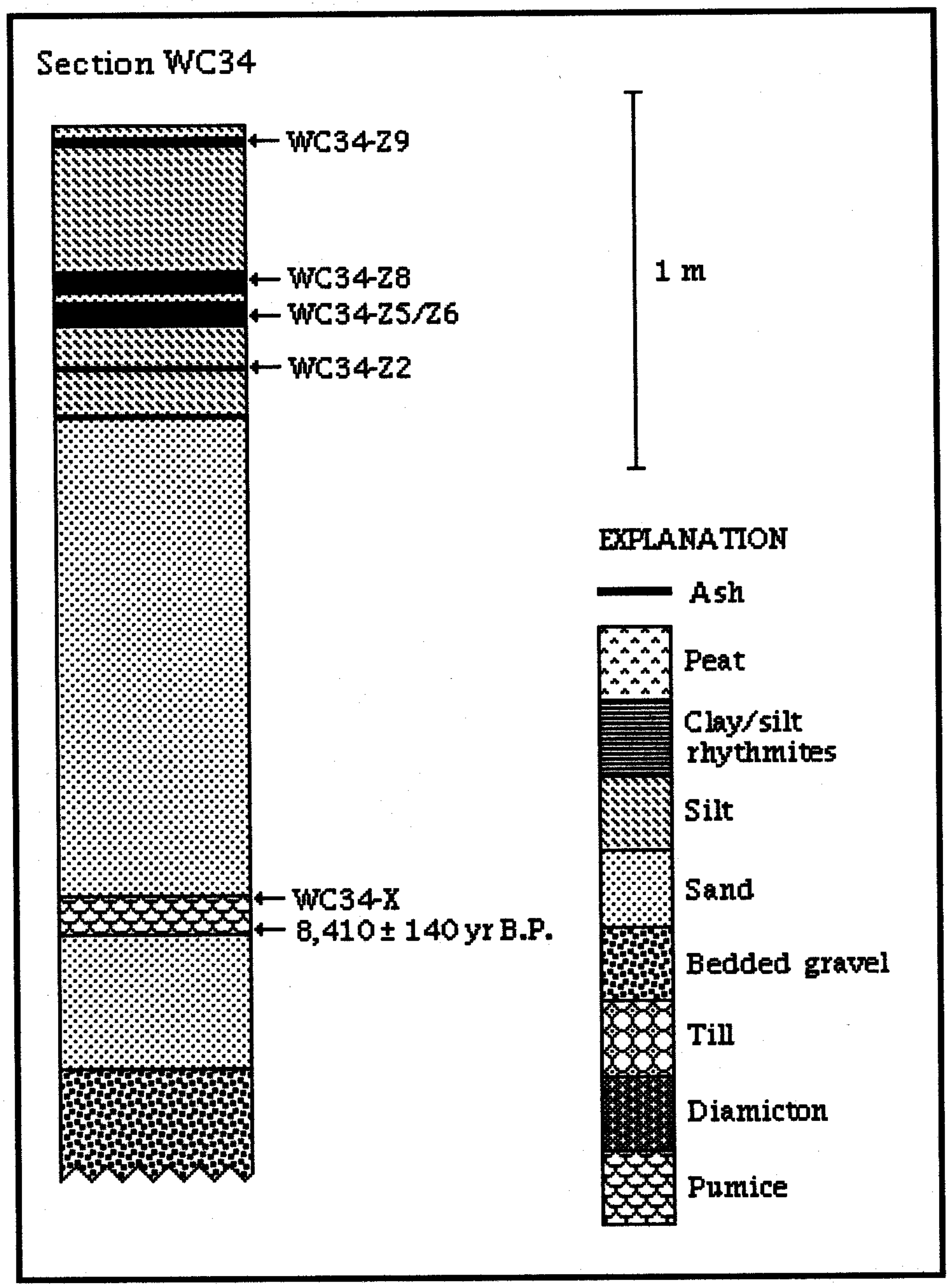


Figure 4.7 Upper, tephra-containing part of measured section WC34. Tephra sample numbers and radiocarbon dates are shown to right of column.

paleosol containing lapilli WC34-X was radiocarbon dated at 8,410 ± 140 yr B.P. (Beta-29520) (Table 3.2).

4.2.9 Section WC36

Section WC36 (Fig. 4.8) is located in the Windy Creek gorge through Lethevolcaniclastic deposits. The section consists of approximately 6 m of interbedded fluvial and lahar deposits overlying a thick sequence of lahar-runout flow deposits. A large (>50 cm diameter) welded pumice bomb contained in highly discolored fluvial sand and gravel was sampled for analysis (WC36-SI).

4.2.10 Section WC46

Section WC46 (Fig. 4.9) is in the Windy Creek cut through a Katolinat terminal moraine just south of Three Forks. A 1.25 m-thick sequence of eolian silt over clay-rich till contained three tephras: a 1 cm-thick, fine, grey ash (not sampled); a 1 cm-thick, fine, yellow-orange ash (not sampled); and WC46-X, a coarse, yellow-to-pink, sandy ash up to 10 cm thick containing layers of finer ash. Basal peat immediately above the till was dated at 8,530 ± 100 yr B.P. (Beta-33669) (Table 3.2).

4.2.11 Sections BL-1 and BL-2

Sections BL-1 (Fig. 4.10) and BL-2 (Fig. 4.11) are in gravel pits approximately 1.5 km apart located near Brooks Lake. Both sections are in fluvial gravel and sand that contain pumice. Pumice BP-1 was collected from delta foresetbeds at BL-1, where rounded pumice clasts approached 4 cm in diameter. Pumice BP-2 was collected at BL-2 from a 5 cm-thick, very clean horizon of

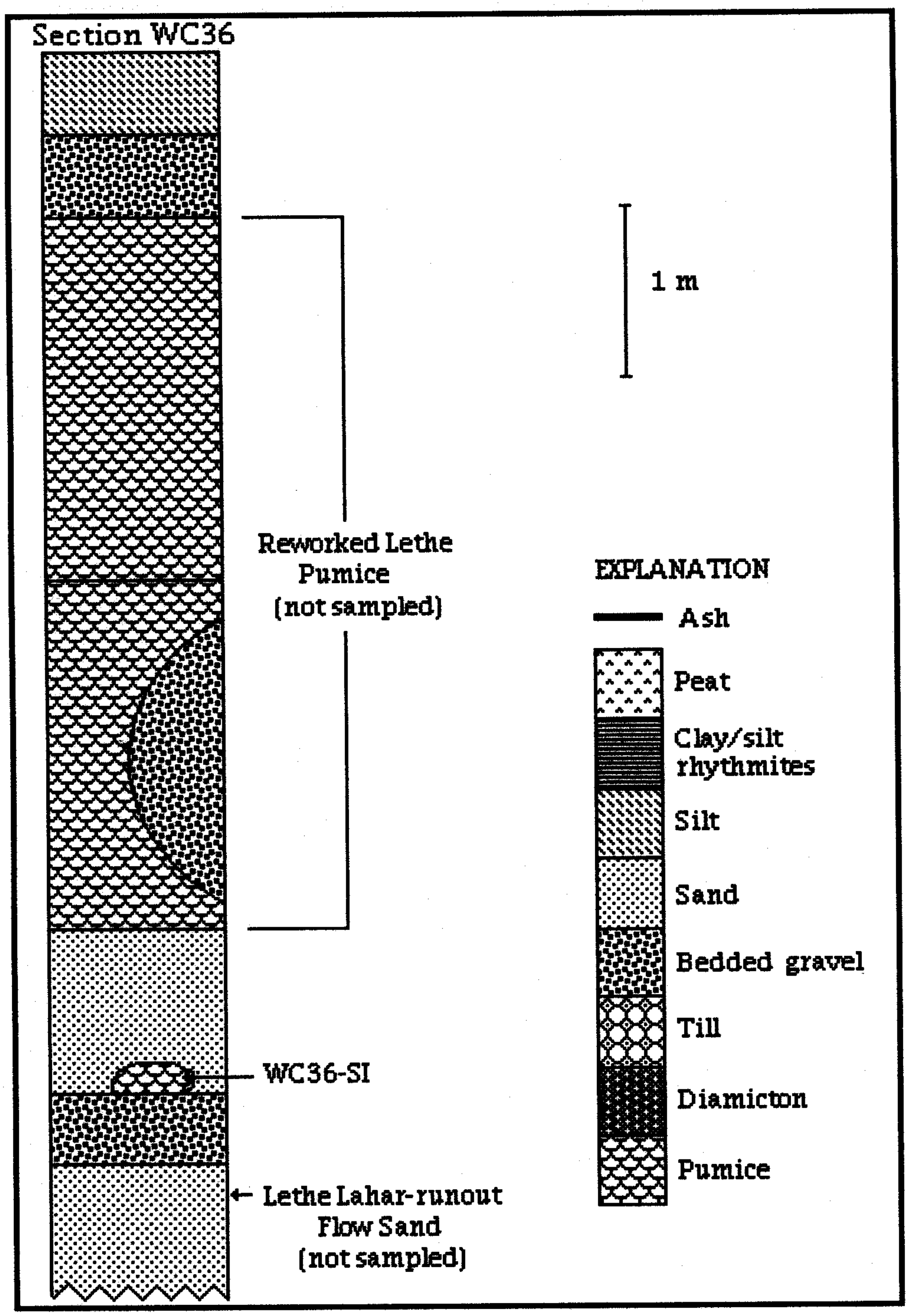


Figure 4.8 Measured stratigraphic section WC36. Tephra sample numbers are shown to right of column.

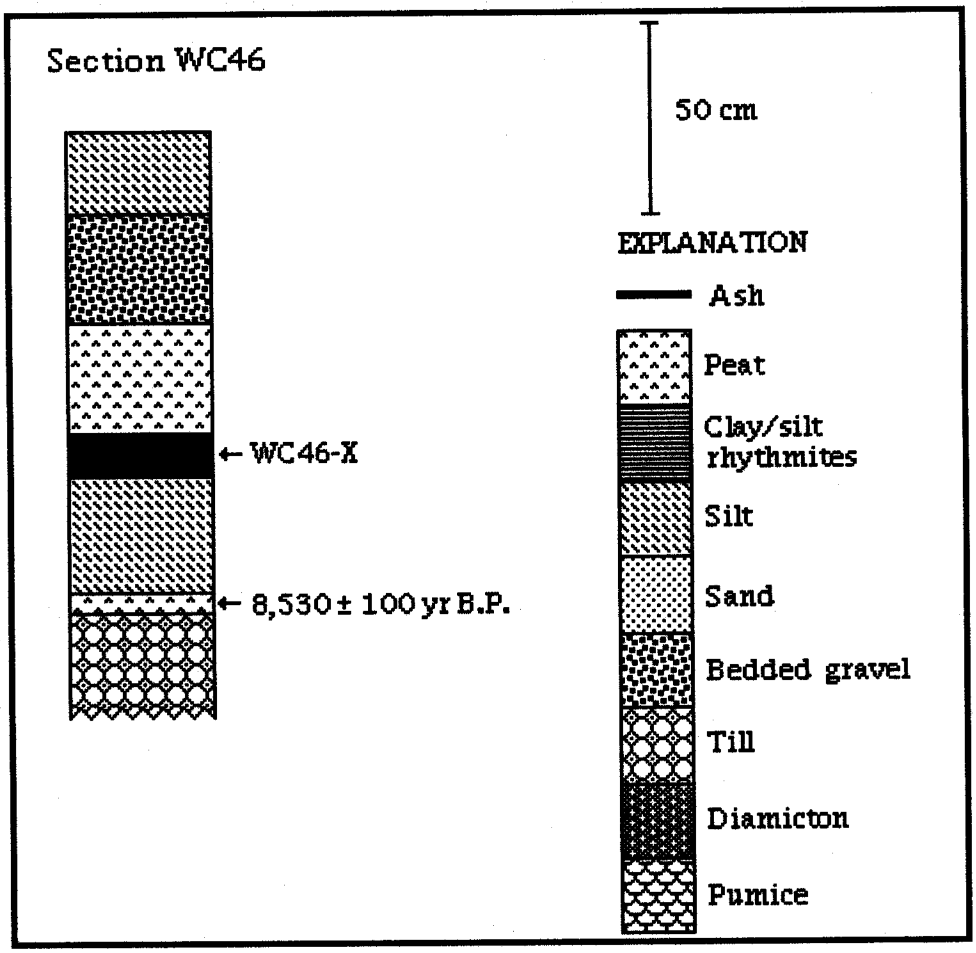


Figure 4.9 Measured stratigraphic section WC46. Tephra sample numbers and radiocarbon dates are shown to right of column.

rounded, granule-size pumice.

4.2.12 Additional Tephra Sampling Localities

Three additional tephra samples were spot-collected in the Windy Creek area to better characterize the distribution and nature of the Lethe tephra (Fig. 4.1). Tephra WC9-X is coarse, well-rounded, buff pumice from bedded,

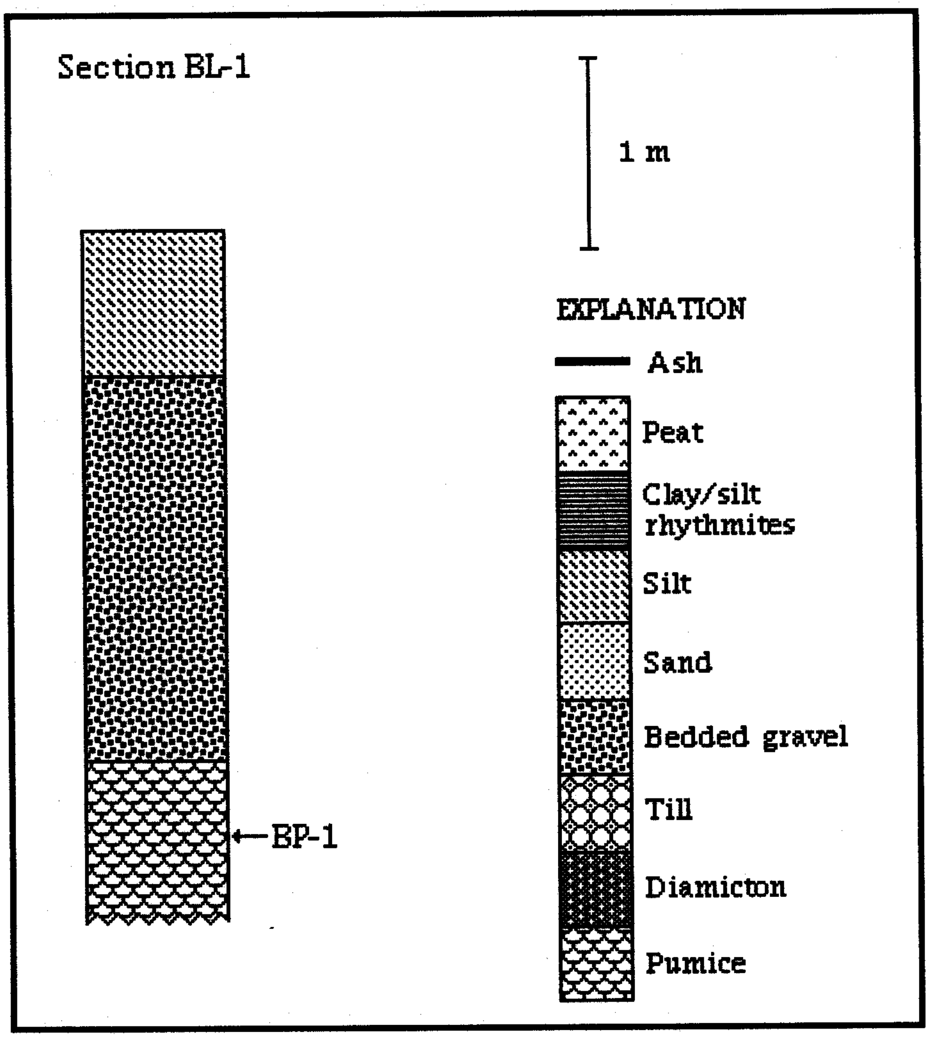


Figure 4.10 Measured stratigraphic section BL-1. Tephra sample numbers are shown to right of column.

redeposited fallout tephra exposed adjacent to section WC15. Tephra WC16-X is lahar-runout flow granular sand collected at the base of Windy Creek gorge approximately 50 m downstream of section WC7. Tephra WC50-X was collected on the saddle west of Overlook Mountain and consists of well-rounded, buff-to-orange pumice up to 15 cm in diameter that occurs as an eolian lag on the surface

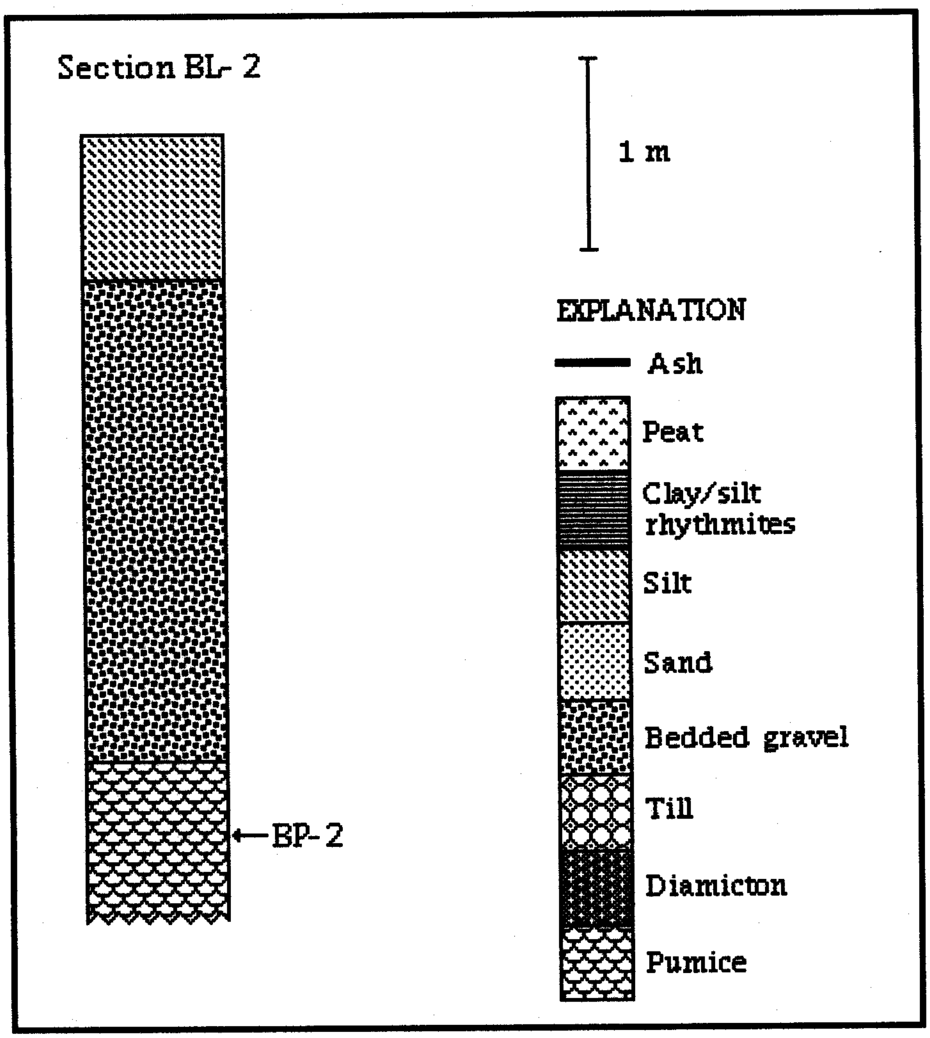


Figure 4.11 Measured stratigraphic section BL-2. Tephra sample numbers are shown to right of column.

of reworked Lethe volcaniclastic deposits.

4.3 PETROGRAPHY

Petrographic analysis was carried out on the tephra samples as the next step in characterization. Mafic phenocryst assemblages are frequently used in tephrochronology as an aid in correlation, particularly in the form of ratios of certain mineral species, but are usually not grounds in themselves for firm correlations. Magmas of similar composition are likely to contain similar phenocrysts, so that phenocryst mineralogy may be of limited value. Contaminating grains can be common and may be impossible to distinguish from primary minerals, leading to erroneous results if included in counts. This problem can be circumvented by counting only those mineral grains with attached glass, but this may lead to the additional difficulty of locating sufficient grains to make a meaningful count. Rare cases exist in which a single distinctive mineral is characteristic of a certain tephra layer, as is cummingtonite in Mt. St. Helens tephra set Y (Westgate and Gorton, 1981) and biotite in tephras from Hayes volcano in Alaska (Riehle, 1985). In such instances mineralogy may be a powerful tool to correlate tephra layers.

Windy Creek tephras were cleaned and sieved as described in Appendix I, and petrographic examinations were carried out on the -60-to-+230-mesh fraction. Table 4.1 shows the results of the petrographic examinations. Mafic phenocrysts were categorized as orthopyroxene (OPX), clinopyroxene (CPX), green amphibole (GAMP), blue amphibole (BAMP), and other minerals (OTHER). The number of mafic mineral grains counted ranged from 1 to 80 per sample due to the variable abundances of glass-coated grains. Although the results are presented below, this is too little data for a meaningful analysis.

Raw counts were converted into percentages for comparison (Table 4.1). Orthopyroxene is the dominant mineral in almost every sample, with clinopyroxene present in subordinate amounts and green amphibole generally appearing in only minor amounts. Riehle found the ratio CPX/OPX/AMP useful in

Table 4.1 Petrographic Results

Sample No.	OPX	CPX	GA	BA	OT	TOT	CPX/OPX/AMP	Shard Morphology	Inc	Ves
BP-1	30	7	0	0	0	37	81/19/0	-	-	-
BP-2	47	19	2	0	0	68	69/28/3	-	-	-
PI-C	23	5	21	1	0	50	46/10/44	-	-	-
PI-D2	22	6	7	1	0	36	61/17/22	-	-	-
WC3-26	7	13	0	0	0	20	35/65/0	BL,PU*	Y	Y*
WC3-55/62	25	6	0	0	0	31	81/19/0	BL,ST,PL,TJ*	Y	Y*
WC3-91	40	4	0	0	0	44	91/9/0	PU,BL,ST	Y	Y
WC4-50	16	4	0	0	0	20	80/20/0	PL,BL,ST,SP*	Y*	Y*
WC4-50s	37	16	1	0	0	54	69/29/2	PU,ST	Y	Y
WC4-90s	6	4	0	0	0	10	60/40/0	PU,ST	N	Y
WC8-0	38	6	1	0	0	45	85/13/2	PU,ST,BL	Y	Y
WC8-19	6	0	1	0	0	7	86/0/14	PU,ST,BL	Y*	Y
WC8-30	9	2	0	0	0	11	82/18/0	BL,ST,PU*	Y*	Y*
WC8-60	6	0	0	0	0	6	100/0/0	PU	Y	Y
WC8-70	23	10	0	0	0	33	70/30/0	PU, ST	Y	Y
WC9-X	49	29	1	0	1	80	62/37/1	-	-	-
WC11-D4	26	2	9	2	0	39	67/5/28	-	-	-
WC15-A	32	9	2	0	0	43	74/21/5	-	-	-
WC15-D	1	0	0	0	0	1	100/0/0	PU,BL,ST,TJ*,SP*	Y*	Y*
WC15-E	31	8	3	0	0	42	74/19/7	-	-	-
WC15-HD	39	15	1	0	0	55	71/27/2	-	-	-
WC15-HL	41	14	5	0	0	60	68/24/8	-	-	-
WC15-I	16	7	0	0	0	23	70/30/0	BL,ST,TJ*	Y	Y
WC15-I2	41	8	0	0	0	49	84/16/0	ST,BL,PU,PL	Y	Y
WC15-I3	31	5	0	0	0	36	86/14/0	BL,PU,PL,ST	Y*	Y*
WC15-J1	34	27	0	0	0	61	56/44/0	BL,ST/SP	Y	N
WC15-J2	34	13	0	0	0	47	72/28/0	BL,PL,ST	Y	Y*
WC16-X	25	7	0	0	0	32	78/22/0	-	-	-
WC31-E	42	15	2	0	0	59	71/26/3	-	-	-
WC34-X	42	24	10	0	0	76	55/32/13	-	-	-
WC34-Z2	28	4	0	0	0	32	88/12/0	PL,ST,PU,BL,SP*	Y	Y
WC34-Z5	40	8	0	0	0	48	83/17/0	PU,BL,ST,SP*,PL*	Y*	Y*
WC34-Z6	46	28	0	0	0	74	62/38/0	PU,BL,ST	Y*	Y
WC34-Z8	23	2	0	0	0	25	92/8/0	ST,BL,SP,PL,PU	Y*	Y
WC34-Z9	16	0	0	0	0	16	100/0/0	BL,ST,PU,TJ*	N	Y
WC36-SI	52	26	0	0	0	78	67/33/0	-	-	-
WC50-OCRSP	46	28	1	0	0	75	61/38/1	-	-	-
WC46-X	58	7	0	0	0	65	89/11/0	PU,ST	N	Y

EXPLANATION:
OPX=orthopyroxene
CPX=clinopyroxene
GA=green amphibole
BA=blue amphibole
OT=other
TOT=total grains counted
Inc=inclusions
Ves=vesicles
BL=blocky
PU=pumiceous
ST=stretched vesicles
PL=platy
TJ=triple junctions
SP=spicular
*=very rare

his studies of Holocene tephras in Upper Cook Inlet, Alaska, and the Windy Creek data set was expressed in that format and examined for trends (Table 4.1). Samples of the Windy Creek ashflow deposit have ratios that are different from the other tephras, but the data set as a whole remains without any other obvious groups. The data were than plotted on a ternary diagram using clinopyroxene, orthopyroxene, and total amphibole (green + blue) as vertices, also following the methodology of Riehle (1985) (Fig. 4.12). There are some apparent groupings, such as that of the Windy Creek ashflow samples, but no clear correlations can be made due to the low number of grains counted. Glass shard morphology characteristics of non-pumice Windy Creek tephra samples are included in Table 4.1. Shard shapes are listed in visually-estimated, decreasing order of abundance

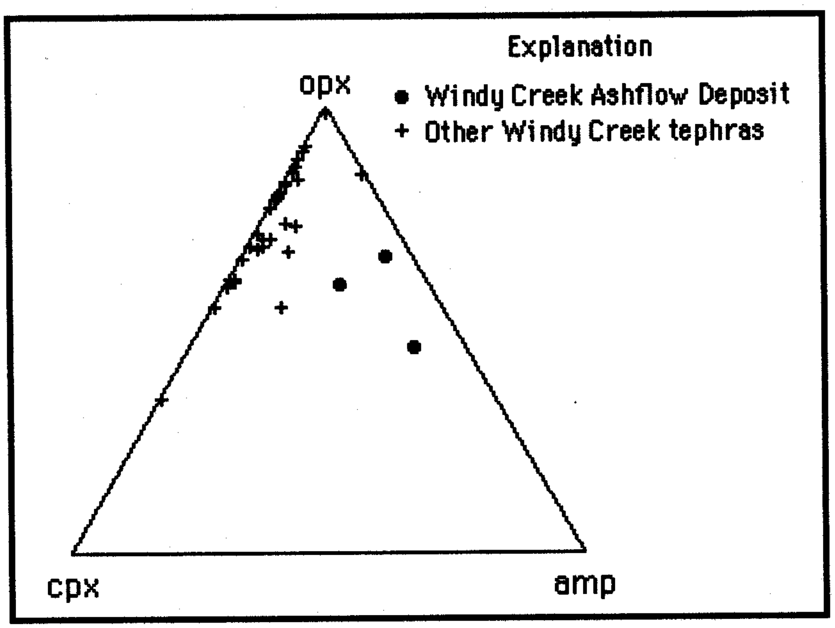


Figure 4.12 Mafic phenocryst contents of Windy Creek tephras. Plot vertices are orthopyroxene (opx), clinopyroxene (cpx), and total amphibole (amp).

for each sample. The presence or absence of microlitic mineral inclusions and vesicles in the glass shards was also noted. Asterisks beside entries indicate that the characteristic is very uncommon, occurring only once or twice in the examined grain mounts. As with phenocryst assemblages, glass shard characteristics proved unhelpful for correlating tephras of the Windy Creek sample set.

4.4 GEOCHEMISTRY

4.4.1 Overview of Geochemical Techniques as Applied to Tephras

Geochemical analysis became crucial in deciphering the tangle of late Quaternary tephras in the Windy Creek area when stratigraphy and petrographic analysis alone failed to support even tentative correlations among most of the tephra samples.

Tephras in other studies have been variously characterized using bulk chemistry, refractive indices of glass shards and bulk glass chemistry, but each of these methods is fraught with problems. Bulk chemical analysis is subject to error arising from post-depositional changes in chemistry due to alteration and weathering, contamination due to reworking and mixing with detrital materials, and the possible sorting effects of long transport distance during deposition (Smith and Westgate, 1969). The refractive index of volcanic glass varies with chemistry, and this trait has been used with limited success by some tephra workers (Nowak, 1968). Unfortunately, the relatively small differences in glass chemistries of many tephras may not be sufficient to produce a detectable change in refractive index (Smith and Westgate, 1969). Bulk glass analysis eliminates the problem of contaminating mineral grains or concentrated primary mineral grains, but not that of detrital glass contamination. Mineral, vapor, and fluid inclusions will also introduce error, as will coatings of weathering products on shard surfaces. Grain-discrete analytical methods using single glass shards avoid most of the above problems, with electron microprobe analysis being the most common analytical technique.

Looking to this last option as potentially the most fruitful, Windy Creek tephras were analysed by electron microprobing glass separates using the analytical routine of Begét and others (1991). See Appendix I for a detailed description of the analytical procedures used to prepare and analyze Windy Creek tephras.

4.4.2 Methodology

Major element data for each sample (Appendix II), expressed as normalized oxide weight percent, was first assessed by plotting histograms of silica content. Anomalous analyses in each sample could be identified by their distinctly high or low silica contents when compared to the bulk of the analyses, and it was also possible to recognize samples with multiple glass-shard populations. The outliers in each data set were discarded and standard deviations were then calculated for each oxide of each population. More statistically rigorous methods of identifying outliers and populations (such as cluster analysis) were considered, but rejected as being too time-consuming for the purposes of the present study.

Removing outlying analyses from the data sets was considered justifiable for a number of reasons. Some analyses proved to be of minerals (usually feldspars) rather than glass and were easily identified as such due to their distinctive chemical compositions. Poor analysis totals could indicate shards that were too small or thin and that burned up during analysis, possessed high water contents due to alteration, or were highly vesicular. Contamination by foreign glass shards was most often observed in very thin, fine-grained ash layers, with shards often appearing distinctly different from primary glass under the microscope in terms of grain size, color and morphology. These scattered foreign shards may have resulted from mixing with other tephras, although they may be the result of a single eruption that produced mixed products. If the latter case were true, the low percentage of anomalous shards would suggest that the secondary component is a very minor one. Other differences in glass shard composition could be accounted for by microlites and small vesicles that were virtually impossible to avoid in some samples. Hydration and alteration products lining interior vesicles would not have been removed in the pre-analysis treatment process and may have also led to inconsistencies in some analyses. It is possible, indeed likely, that some valid analyses reflecting geochemical endmembers of the magma system were discarded because they differed too far from the dominant composition. It was deemed essential , however, that each tephra be characterized by its *dominant* composition (or compositions, for tephras with multiple populations) for correlation to be successful across large areas. Many of the "mean" compositions used in the calculations below can thus be viewed as weighted compositional averages of heterogeneous tephras.

Table 4.2 shows Windy Creek mean glass compositions expressed as normalized weight percent of nine major oxides analysed, the number of analyses per sample, and standard deviations for each oxide. Of the thirty-nine samples collected, twenty-seven were homogeneous, single-population tephras, ten had

Table 4.2 Glass Compositions of Windy Creek Tephras
Major oxides in glass separates given in normalized weight percent. Total Fe expressed as FeO*. One standard deviation in weight percent is given below each oxide concentration. Number of analyses per sample = n.

Sample No.	n	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
WC50-X	16	72.44	13.85	3.99	3.24	2.61	2.40	0.70	0.64	0.14	100.00
		0.50	0.18	0.25	0.17	0.20	0.06	0.06	0.06	0.06	0.00
PI-D2	18	75.38	13.64	4.91	1.67	1.45	2.22	0.31	0.25	0.17	100.00
		0.30	0.08	0.10	0.21	0.17	0.10	0.04	0.06	0.03	0.00
PI-C	18	75.40	13.66	4.92	1.70	1.38	2.15	0.29	0.25	0.23	100.00
		0.33	0.17	0.12	0.15	0.05	0.08	0.03	0.07	0.03	0.00
WC11-D4	27	75.44	13.78	4.88	1.69	1.42	2.07	0.28	0.26	0.18	100.00
		0.57	0.27	0.18	0.27	0.13	0.09	0.05	0.05	0.05	0.00
WC15-A	10	71.89	14.10	4.21	3.17	2.75	2.36	0.76	0.64	0.13	100.00
		0.22	0.19	0.15	0.11	0.09	0.07	0.05	0.04	0.01	0.00
WC15-D	35	77.04	12.12	3.67	1.92	1.26	3.19	0.28	0.37	0.14	100.00
		1.62	0.70	0.23	0.45	0.48	0.28	0.13	0.13	0.07	0.00
WC15-E	13	72.24	13.97	4.17	3.03	2.66	2.41	0.73	0.65	0.14	100.00
		0.47	0.19	0.25	0.23	0.22	0.09	0.08	0.07	0.02	0.00
WC15-HD	11	71.90	14.04	4.29	3.18	2.66	2.40	0.77	0.62	0.13	100.00
		0.30	0.11	0.10	0.19	0.13	0.06	0.05	0.05	0.03	0.00
WC15-HL	10	72.06	14.00	4.23	3.20	2.58	2.40	0.75	0.67	0.11	100.00
		0.24	0.12	0.09	0.12	0.12	0.07	0.03	0.07	0.02	0.00
WC15-I	21	72.84	13.62	4.26	3.09	2.34	2.49	0.64	0.59	0.14	100.00
		1.24	0.43	0.17	0.39	0.44	0.30	0.17	0.11	0.05	0.00
WC15-I2-P1	10	76.68	12.50	3.76	1.87	1.17	3.26	0.25	0.39	0.11	100.00
		0.92	0.39	0.28	0.34	0.32	0.28	0.09	0.15	0.05	0.00
WC15-I2-P2	16	72.86	13.88	3.90	3.10	2.38	2.45	0.66	0.61	0.15	100.00
		0.75	0.30	0.44	0.25	0.35	0.17	0.09	0.06	0.03	0.00
WC15-I3-P1	14	76.16	12.70	3.75	2.06	1.38	3.07	0.33	0.42	0.13	100.00
		0.98	0.55	0.28	0.34	0.49	0.40	0.09	0.11	0.05	0.00
WC15-I3-P2	15	72.87	13.92	4.00	2.91	2.51	2.46	0.61	0.60	0.12	100.00
		0.73	0.40	0.25	0.57	0.26	0.12	0.17	0.13	0.05	0.00

Table 4.2 Glass Compositions of Windy Creek Tephras (continued)

Sample No.	n	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
WC15-J1-P1	10	77.53	12.47	3.76	1.62	1.82	2.02	0.32	0.28	0.18	100.00
		0.40	0.57	0.18	0.16	0.39	0.65	0.10	0.11	0.07	0.00
WC15-J1-P2	8	75.61	13.08	3.73	2.07	1.68	2.85	0.38	0.45	0.15	100.00
		0.21	0.28	0.52	0.23	0.31	0.53	0.05	0.06	0.04	0.00
WC15-J1-P3	9	71.90	14.47	4.26	3.06	2.12	2.90	0.60	0.55	0.15	100.00
		1.07	0.51	0.38	0.43	0.42	0.48	0.11	0.09	0.02	0.00
WC15-J2	27	74.49	13.21	4.02	2.46	1.81	2.88	0.44	0.52	0.18	100.00
		1.67	0.59	0.46	0.56	0.51	0.37	0.16	0.16	0.13	0.00
WC16-X	18	72.46	13.74	4.35	3.17	2.47	2.38	0.67	0.61	0.15	100.00
		0.65	0.24	0.15	0.20	0.19	0.12	0.06	0.06	0.06	0.00
WC3-26-P1	6	78.41	11.99	4.19	1.14	0.74	3.11	0.11	0.12	0.21	100.00
		0.26	0.08	0.14	0.07	0.04	0.05	0.02	0.05	0.07	0.00
WC3-26-P2	12	73.79	13.52	4.19	2.48	2.14	2.68	0.52	0.54	0.13	100.00
		1.49	0.64	0.40	0.51	0.46	0.36	0.19	0.10	0.03	0.00
WC3-55/62	18	75.86	12.76	3.77	2.06	1.62	2.99	0.36	0.44	0.13	100.00
		0.53	0.20	0.11	0.20	0.14	0.16	0.06	0.06	0.06	0.00
WC3-91-P1	20	67.41	15.08	4.67	4.68	3.17	2.70	1.18	0.94	0.18	100.00
		1.68	0.41	0.17	0.67	0.63	0.32	0.32	0.13	0.09	0.00
WC3-91-P2	11	59.01	16.13	4.28	8.24	6.45	1.67	2.90	1.19	0.13	100.00
		0.59	0.35	0.24	0.34	0.39	0.16	0.37	0.07	0.09	0.00
WC34-X	21	72.77	13.87	4.06	2.94	2.48	2.47	0.68	0.61	0.12	100.00
		0.62	0.20	0.17	0.26	0.16	0.07	0.07	0.06	0.04	0.00
WC34-Z2	18	74.81	13.23	4.04	2.37	1.79	2.76	0.41	0.47	0.12	100.00
		0.81	0.35	0.49	0.43	0.32	0.41	0.11	0.10	0.06	0.00
WC34-Z5-P1	35	76.46	12.56	3.87	1.86	1.32	3.14	0.27	0.37	0.14	100.00
		1.32	0.69	0.56	0.37	0.47	0.79	0.11	0.11	0.08	0.00
WC34-Z5-P2	6	71.79	14.05	4.43	3.21	2.23	2.82	0.63	0.63	0.21	100.00
		0.45	0.78	0.38	0.60	0.51	0.60	0.16	0.08	0.16	0.00

Table 4.2 Glass Compositions of Windy Creek Tephras (continued)

Sample No.	n	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
WC34-Z5-P3	4	66.32	15.33	4.98	5.00	3.31	2.59	1.27	1.07	0.14	100.00
		0.37	0.07	0.13	0.20	0.09	0.10	0.06	0.12	0.03	0.00
WC34-Z6	24	76.62	12.63	3.94	1.78	1.70	2.43	0.34	0.36	0.21	100.00
		0.98	0.40	0.33	0.29	0.43	1.06	0.08	0.11	0.11	0.00
WC34-Z8	16	75.53	12.80	3.81	2.22	1.68	2.97	0.38	0.44	0.16	100.00
		0.33	0.16	0.12	0.11	0.14	0.07	0.05	0.03	0.07	0.00
WC34-Z9-P1	28	75.97	12.88	4.16	1.80	1.32	3.06	0.28	0.36	0.16	100.00
		1.75	0.89	0.64	0.51	0.55	1.00	0.15	0.15	0.09	0.00
WC34-Z9-P2	3	67.53	15.78	4.64	4.28	3.19	2.52	1.12	0.80	0.15	100.00
		0.28	0.12	0.14	0.08	0.14	0.06	0.02	0.12	0.01	0.00
WC36-SI	35	72.34	13.88	4.33	3.13	2.51	2.36	0.71	0.62	0.12	100.00
		0.42	0.13	0.09	0.27	0.10	0.09	0.05	0.07	0.10	0.00
WC4-50	23	75.81	12.77	3.80	2.06	1.60	3.03	0.36	0.42	0.14	100.00
		0.67	0.18	0.12	0.27	0.19	0.13	0.06	0.07	0.06	0.00
WC4-90s-P1	17	71.56	14.98	5.18	2.40	1.69	3.07	0.48	0.48	0.16	100.00
		0.47	0.29	0.23	0.23	0.16	0.27	0.08	0.05	0.04	0.00
WC4-90s-P2	6	59.34	16.46	4.72	7.31	6.30	1.56	2.81	1.34	0.14	100.00
		0.76	0.08	0.16	0.48	0.33	0.10	0.22	0.07	0.03	0.00
WC7-40-P1	18	77.06	12.52	3.98	1.77	1.93	1.91	0.37	0.30	0.17	100.00
		0.48	0.11	0.15	0.18	0.14	0.32	0.04	0.08	0.09	0.00
WC7-40-P2	10	72.85	13.62	4.29	3.00	2.48	2.35	0.65	0.62	0.13	100.00
		0.68	0.30	0.08	0.28	0.22	0.07	0.09	0.05	0.04	0.00
WC7-55	24	75.71	12.72	3.84	2.14	1.71	2.91	0.39	0.45	0.14	100.00
		1.10	0.34	0.21	0.36	0.32	0.21	0.11	0.08	0.06	0.00
WC8-0	16	75.53	12.77	3.84	2.19	1.65	3.02	0.37	0.46	0.17	100.00
		0.42	0.19	0.10	0.17	0.13	0.09	0.05	0.08	0.04	0.00
WC8-19-P1	24	77.15	12.00	3.62	1.98	1.05	3.46	0.22	0.38	0.14	100.00
		1.29	0.55	0.35	0.49	0.44	0.72	0.11	0.10	0.07	0.00

Table 4.2 Glass Compositions of Windy Creek Tephras (continued)

Sample No.	n	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
WC8-19-P2	4	72.11	14.19	4.40	3.08	2.28	2.58	0.61	0.61	0.13	100.00
		0.67	0.65	0.46	0.40	0.39	0.26	0.10	0.09	0.02	0.00
WC8-30-P1	20	76.42	12.56	3.74	2.05	1.29	3.16	0.28	0.36	0.14	100.00
		1.58	0.71	0.28	0.60	0.40	0.46	0.13	0.13	0.07	0.00
WC8-30-P2	7	72.13	13.88	4.23	3.37	2.52	2.39	0.70	0.64	0.14	100.00
		0.36	0.17	0.17	0.10	0.13	0.06	0.04	0.03	0.02	0.00
WC8-60	38	77.20	12.18	3.60	1.78	1.18	3.29	0.24	0.38	0.14	100.00
		1.55	0.76	0.43	0.43	0.45	0.60	0.12	0.12	0.07	0.00
WC8-70-P1	8	69.38	15.02	4.64	3.77	2.62	2.79	0.87	0.79	0.13	100.00
		0.91	0.18	0.32	0.52	0.16	0.15	0.08	0.11	0.06	0.00
WC8-70-P2	14	58.86	16.27	4.43	8.02	6.58	1.63	2.90	1.18	0.12	100.00
		0.83	0.14	0.29	0.43	0.33	0.09	0.19	0.05	0.05	0.00
WC9-X	19	72.47	13.76	4.13	3.27	2.50	2.43	0.67	0.61	0.16	100.00
		0.61	0.28	0.19	0.19	0.20	0.07	0.07	0.03	0.08	0.00
BP-1	24	73.01	13.82	4.18	2.69	2.32	2.72	0.58	0.52	0.16	100.00
		1.07	0.49	0.16	0.55	0.67	0.93	0.24	0.20	0.07	0.00
BP-2	17	72.08	13.99	4.24	3.11	2.70	2.34	0.74	0.66	0.14	100.00
		0.19	0.15	0.13	0.10	0.13	0.05	0.03	0.05	0.03	0.00
WC46-X	22	75.58	12.81	3.94	2.03	1.68	2.95	0.37	0.45	0.19	100.00
		0.39	0.17	0.09	0.13	0.12	0.09	0.05	0.05	0.02	0.00
WC51-X	20	72.39	13.89	4.24	3.03	2.60	2.34	0.73	0.64	0.13	100.00
		0.33	0.13	0.11	0.16	0.10	0.06	0.04	0.06	0.05	0.00

bimodal glass populations, and two had trimodal populations. Secondary and tertiary populations were used only if there were at least three analyses for each population. The resulting fifty-three geochemical compositions were then compared to one another for local correlations and to other documented tephras for regional correlations using the statistical approach of Borchardt and others (1972).

4.4.3 Calculation of Tephra Similarity

The similarity coefficient developed by Borchardt and others (1972) to compare tephras analysed by instrumental neutron activation analysis is a single parameter denoting multivariate similarity derived from the simple equation:

$$d_{(A,B)} = \frac{\sum_{i=1}^{n} R_i}{n}$$

where:

$d_{(A,B)} = d_{(B,A)}$ = similarity coefficient for comparison between sample A and sample B

i = element number

n = number of elements

$R_i = X_{iA}/X_{iB}$ if $X_{iB} \geq X_{iA}$

$R_i = X_{iB}/X_{iA}$ if $X_{iA} > X_{iB}$

X_{iA} = concentration of element i in sample A

X_{iB} = concentration of element i in sample B

The value of $d_{(A,B)}$ is a number between 0.00 and 1.00, with $d_{(A,B)} = 1.00$ denoting perfect similarity. Each sample in a data set may thus be compared with all other samples, and samples pairs having similarity coefficients approaching 1.00 may be considered correlative (Borchardt et al, 1972).

Riehle (1985) made extensive use of similarity coefficients in his study of Cook Inlet tephras. He considered similarity coefficients greater than 0.95 indicative of samples from the same tephrafall, or of samples that were members of a tephra set with a high degree of similarity. Values of 0.93 or 0.94 were thought to represent samples comprising a set or the same tephrafall where "concentrations of one or more elements are unreliable" (Riehle, 1985). Similarity coefficients between 0.90 and 0.93 were considered to indicate samples of the same set but not the same tephrafall, provided that stratigraphy and mineralogy were in agreement.

4.4.4 Tephra Correlations

4.4.4a Local Correlations

A number of distinct groups emerged from the Windy Creek sample set when similarity coefficients were calculated between pairs of analyses. Chlorine was omitted from the calculations due to overall low concentrations and comparatively high analytical error, and because it is generally not analysed for in other, published studies. Analysis pairs with coefficients of 0.90 or greater, and possessing comparable field characteristics, age, and stratigraphic position in relation to other tephras, were considered correlative in this study. Table 4.3 illustrates the range of similarity coefficients resulting from comparisons among ten randomly-chosen tephras. Correlative groups and their similarity coefficients are separated from the other, noncorrelative tephras in tables 4.4 - 4.7. As was to be expected, the three samples of Windy Creek ashflow deposit (mean SiO_2 content 75.55 percent) correlated with one another (Table 4.4). Eleven samples

Table 4.3 Similarity Coefficient Matrix for Randomly Selected Tephras

Sample No.	BP 2	WC15 HD	WC34 Z8	PI C	WC34 Z9 P1	WC15 A	WC8 30 P2	WC15 E	WC8 60	WC3 26 P1
BP-2	1.00									
WC15-HD	0.98	1.00								
WC34-Z8	0.76	0.76	1.00							
PI-C	0.69	0.69	0.80	1.00						
WC34-Z9-P1	0.70	0.70	0.88	0.88	1.00					
WC15-A	0.99	0.98	0.76	0.69	0.70	1.00				
WC8-30-P2	0.97	0.97	0.77	0.70	0.71	0.97	1.00			
WC15-E	0.99	0.98	0.77	0.69	0.71	0.98	0.97	1.00		
WC8-60	0.66	0.66	0.85	0.82	0.93	0.66	0.66	0.67	1.00	
WC3-26-P1	0.56	0.56	0.66	0.68	0.72	0.56	0.56	0.57	0.72	1.00

Table 4.4 Similarity Coefficient Matrix and Mean Composition of the Windy Creek Ashflow Deposit

Sample No.	PI C	WC11 D4	PI D2
PI-C	1.00		
WC11-D4	0.98	1.00	
PI-D2	0.98	0.97	1.00

Mean Composition (n=3)								
	SiO2	Na2O	FeO*	K2O	MgO	CaO	Al2O3	TiO2
avg	75.55	4.91	1.69	2.15	0.30	1.42	13.72	0.25
std dev	0.04	0.02	0.01	0.07	0.01	0.04	0.07	0.01

were confidently identified as Lethe tephra (mean SiO_2 content 72.53 percent), with five other glass populations tentatively interpreted as the result of much later eolian reworking of Lethe ash due to their younger stratigraphic position (Table 4.5). Sample BP-1 had comparatively low similarity coefficients (0.89 to 0.94), but its stratigraphic position and physical characteristics are consistent with a Lethe origin. Another tephra, informally named Three Forks ash (mean SiO_2 content 75.78 percent), was correlated between six sections in the Windy Creek area, and was a component in four other tephra layers (Table 4.6).

Calculations for tephras sometimes resulted in high similarity coefficients for only one population. This may indicate a high degree of similarity between one population and an unrelated tephra, mixing with another tephra at one site but not at the other (resulting in a "multimodal" tephra at the first site and a single-population tephra at the second), or wide compositional variation in a single tephra or set that is preserved *in toto* in one site but manifests as only a single, homogeneous composition at another (for example, via changing wind directions that predominantly deposit the tephra in one area, but for a brief time carry ash to a different area). Dealing with these situations was deemed beyond the scope of this project and further correlations were generally not attempted within these tephras, although a small tephra group consisting of one component in two bimodal glass populations was tentatively distinguished based on its high similarity to Mt. St. Augustine tephras (discussed in the next section). This ash, Tephra "Y" (mean SiO_2 contents 77.36 percent), was correlated between two sections (Table 4.7). Figure 4.13 uses tielines to connect correlative tephra layers in successive measured sections and shows the stratigraphic relations and radiocarbon age control.

Table 4.5 Similarity Coefficient Matrix and Mean Composition of the Lethe Tephra

Sample No.	WC15 I2 P2	WC15 I3 P2	WC7 40 P2	WC15 I	WC34 X	WC9 X	WC16 X	WC50 X	WC51 X
WC15-I2-P2	1.00								
WC15-I3-P2	0.97	1.00							
WC7-40-P2	0.97	0.97	1.00						
WC15-I	0.97	0.96	0.97	1.00					
WC34-X	0.98	0.98	0.98	0.96	1.00				
WC9-X	0.98	0.96	0.97	0.97	0.98	1.00			
WC16-X	0.97	0.96	0.98	0.97	0.97	0.99	1.00		
WC50-X	0.97	0.96	0.96	0.95	0.97	0.98	0.97	1.00	
WC51-X	0.95	0.95	0.97	0.95	0.96	0.96	0.97	0.97	1.00
WC36-SI	0.96	0.95	0.98	0.96	0.97	0.97	0.98	0.97	0.98
WC15-E	0.95	0.95	0.96	0.94	0.96	0.96	0.96	0.97	0.99
WC8-30-P2	0.96	0.95	0.96	0.95	0.96	0.98	0.97	0.98	0.97
WC8-19-P2	0.96	0.96	0.96	0.97	0.95	0.95	0.96	0.93	0.94
BP-2	0.95	0.94	0.96	0.94	0.95	0.96	0.96	0.97	0.99
WC15-HL	0.95	0.94	0.95	0.94	0.95	0.96	0.96	0.97	0.98
WC15-HD	0.95	0.94	0.96	0.94	0.95	0.96	0.97	0.97	0.97
WC15-A	0.94	0.93	0.95	0.93	0.95	0.96	0.96	0.97	0.98
BP-1	0.92	0.94	0.92	0.94	0.93	0.92	0.92	0.90	0.90

Sample No.	WC36 SI	WC15 E	30 P2	WC8 19 P2	WC8 BP 2	WC15 HL	WC15 HD	WC15 A	BP 1
WC36-SI	1.00								
WC15-E	0.97	1.00							
WC8-30-P2	0.98	0.97	1.00						
WC8-19-P2	0.95	0.93	0.94	1.00					
BP-2	0.97	0.99	0.97	0.93	1.00				
WC15-HL	0.97	0.98	0.98	0.93	0.98	1.00			
WC15-HD	0.97	0.98	0.97	0.94	0.98	0.98	1.00		
WC15-A	0.97	0.98	0.97	0.93	0.99	0.98	0.98	1.00	
BP-1	0.91	0.90	0.90	0.94	0.89	0.89	0.89	0.89	1.00

Mean Composition (n=18)								
	SiO2	Na2O	FeO*	K2O	MgO	CaO	Al2O3	TiO2
avg	72.53	4.20	3.10	2.43	0.69	2.52	13.91	0.62
std dev	0.37	0.13	0.15	0.09	0.05	0.13	0.15	0.03

Table 4.6 Similarity Coefficient Matrix and Mean Composition of Three Forks Ash

Sample No.	WC15 I3 P1	WC15 I2 P1	WC34 Z9 P1	WC3 55/62	WC4 50	WC7 55	WC46 X	WC15 J1 P2
WC15-I3-P1	1.00							
WC15-I2-P1	0.95	1.00						
WC34-Z9-P1	0.93	0.93	1.00					
WC3-55/62	0.96	0.92	0.89	1.00				
WC4-50	0.97	0.92	0.90	0.99	1.00			
WC7-55	0.93	0.90	0.87	0.97	0.96	1.00		
WC46-X	0.94	0.91	0.89	0.98	0.97	0.98	1.00	
WC15-J1-P2	0.94	0.91	0.87	0.98	0.97	0.98	0.98	1.00
WC8-0	0.94	0.91	0.88	0.98	0.97	0.98	0.98	0.97
WC34-Z8	0.94	0.90	0.88	0.97	0.97	0.98	0.98	0.98

Sample No.	WC8 0	WC34 Z8
WC8-0	1.00	
WC34-Z8	0.98	1.00

Mean Composition (n=13)								
	SiO2	Na2O	FeO*	K2O	MgO	CaO	Al2O3	TiO2
avg	75.78	3.85	2.10	3.01	0.36	1.59	12.85	0.44
std dev	0.43	0.15	0.16	0.13	0.05	0.17	0.16	0.04

Correlations resulting from similarity coefficient calculations can now be used to separate the geochemistries of the five multi-occurrence tephras from those of the remaining uncorrelative tephras in the data set. Figure 4.14 is a ternary diagram of the entire Windy Creek data set with vertices NaO+K_2O (A), FeO* (F), and MgO (M). There is little of usefulness to be gleaned from this variegated assemblage. Figure 4.15a is a similar diagram for only the four

Table 4.7 Similarity Coefficient Matrix and Mean Composition of Tephra "Y"

Sample No.	WC15 J1 P1	WC7 40 P1
WC15-J1-P1	1.00	
WC7-40-P1	0.94	1.00

Mean Composition (n=2)								
	SiO2	Na2O	FeO*	K2O	MgO	CaO	Al2O3	TiO2
avg	77.36	3.87	1.70	1.97	0.34	1.87	12.50	0.30
std dev	0.43	0.14	0.10	0.08	0.04	0.08	0.01	0.03

correlative tephras and graphically illustrate the degrees of similarity between members of each tephra group. Windy Creek ash and Lethe tephra plot in separate fields, but the remaining tephra groups show a large degree of overlap. Plotting group means (Fig. 4.15b) allows somewhat better distinction between tephra "Y" and Three Forks ash.

4.4.4b Regional Correlations

Regional correlations were attempted to determine possible source areas for distal tephras, as well as extents of tephra falls and to take advantage of any extant dates for tephras that were not directly datable in the Windy Creek area. The fifty-three Windy Creek tephras and tephra populations were reduced to twenty-four by combining each group of correlatable tephras or populations and calculating mean compositions. The resulting data set was then compared to

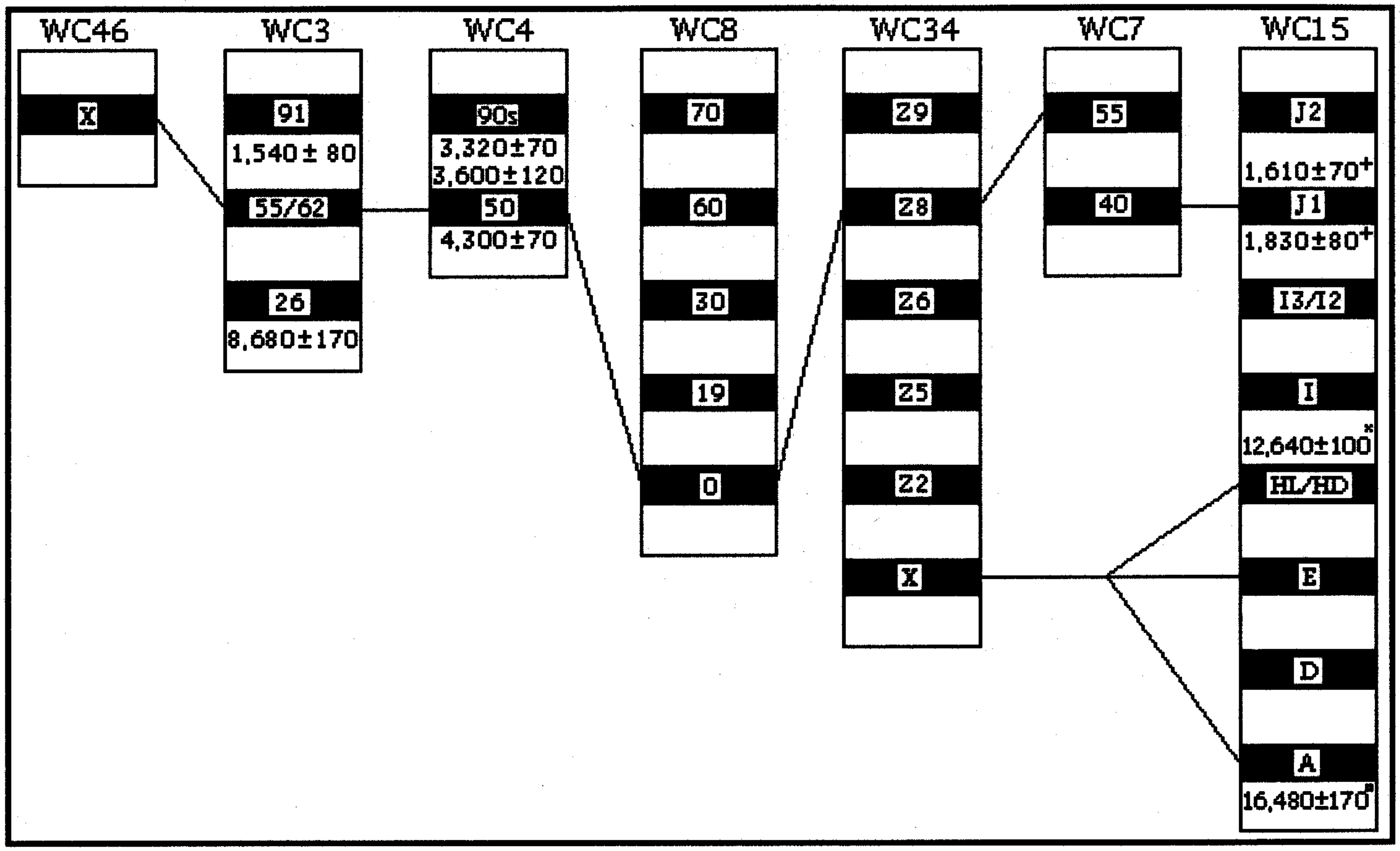


Figure 3.13 Windy Creek tephra correlations. Tielines connect tephras believed to be correlatable between sites based on stratigraphy, age, physical characteristics, and chemistry. Radiocarbon dates are in yr B.P. Dates included from other areas or sections are: "+" Mt. St. Augustine (Beget); "x" WC52; and " " the Kenai Peninsula (Reger). The diagram does not include the Windy Creek ashflow deposit, which occurs at only one site in the study area, or Lethe volcaniclastic deposits from sites WC9, WC16, WC36, WC50, WC51, BL-1, and BL-2.

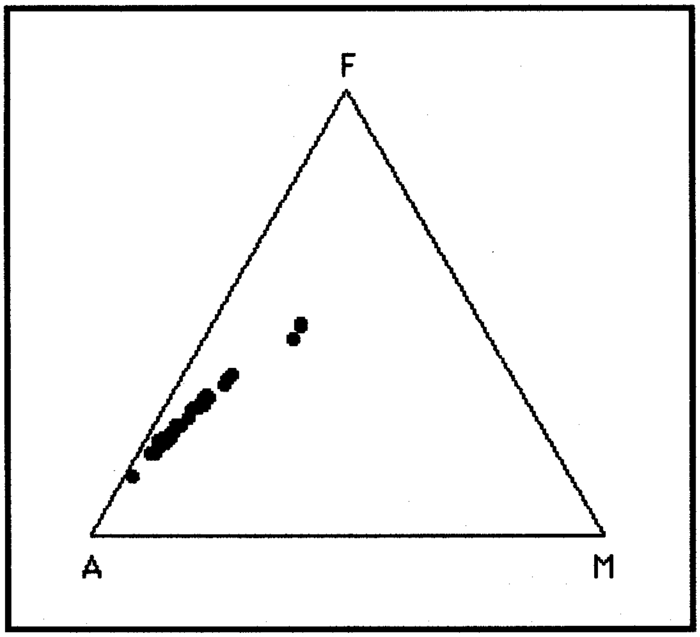


Figure 4.14 AFM diagram of Windy Creek tephra glass compositions. Plot vertices are FeO* (F), K_2O+Na_2O (A), and MgO (M).

geochemical analyses of other tephra layers throughout Alaska. These include: tephras from Hayes (Riehle, 1985; Begét et al, 1991; Campbell, unpub. data), Spurr (Riehle, 1985), Redoubt (Riehle, 1985), Iliamna (Riehle, 1985), and Augustine volcanoes (Riehle, 1985; Begét, unpub. data); Aniakchak tephra (Riehle et al, 1987); Jarvis Creek Ash (Begét et al, 1991); tephras in lake cores of Skilak Lake (Stihler, 1991); Old Crow Ash (Westgate et al, 1985; Begét, unpub. data); tephras on the Kenai Peninsula (Begét, unpub. data; Reger and Pinney, unpub. data); tephras in the Fairbanks area (Begét, unpub. data); pumice from Kaguyak caldera (Swanson, unpub. data); an ash from the Horn Mountains area in Bethel Quadrangle (Bundtzen, unpub. data); and andesitic, dacitic, and rhyolitic

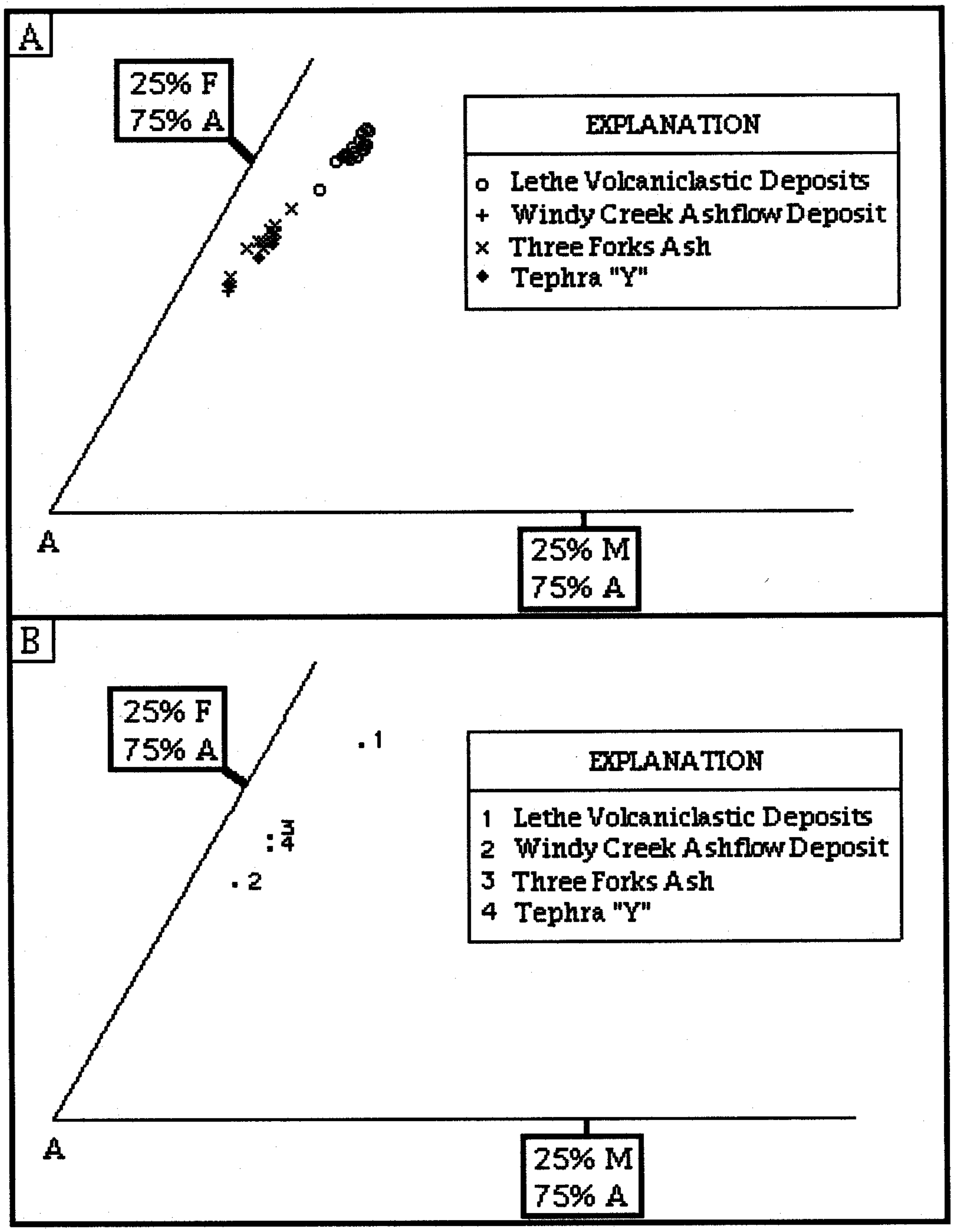


Figure 4.15 AFM diagrams of glass compositions of Windy Creek tephras present at two or more sites. A) Glass compositions of all members of each group. B) Mean glass compositions of each group. Plot vertices are FeO* (F), K_2O+Na_2O (A), and MgO (M).

components of the 1912 the Valley of Ten Thousand Smokes ashflow deposit (Avery, unpub. data). The resulting similarity coefficient matrix included 196 tephras and populations from all over the state of Alaska that range in age from more than one hundred thousand years (Old Crow Ash) to less than a century old (the 1912 Katmai ignimbrite). Tephras with intra-group similarity coefficients greater than 0.90 and that are stratigraphically and mineralogically (where data is available) compatible are shown in tables 4.8-4.11.

Lethe tephra correlatives are preserved over a large area of the western Kenai Peninsula and include thirteen tephras and populations in two multimodal tephras (Table 4.8). Four multimodal Windy Creek tephras included populations that yielded high similarity coefficients with the Kenai Peninsula Lethe correlatives, and comparison back to the Lethe tephra mean composition also shows this high degree of similarity. These populations are interpreted as contamination by Lethe ash, for all host tephra layers are stratigraphically considerably younger than the primary Lethe tephra deposits. Organic material below the Lethe tephra on the Kenai Peninsula gives a maximum age for the tephra of 16,480 ± 170 yr B.P. (Reger, written comm.). This date and the 12,640 ± 100 yr B.P. minimum date from the Windy Creek area show that the Lethe tephra was erupted between about 16,600 and 12,500 yr B.P.

A second group of tephras is the Augustine-like data set shown in Table 4.9. Similarity coefficients suggest correlation between ash "Y" and two Augustine ash layers (A88-11-5 and A88-7-5) that have themselves been correlated to one another and dated between 1,610 ± 70 and 1,830 ± 80 yr B.P. (Begét, oral comm.). This age is compatible with the stratigraphy at the Windy Creek sites. A third Augustine ash, sample 87A-91, also appears to be a member

Table 4.8 Regional Similarity Coefficient Matrix for the Lethe Tephra
"LETHE"=mean composition of Lethe tephra. Kenai data from Reger and Pinney (unpub. data).

Sample No.	LETHE	KL 11	KL 17	KL 18 P1	KL 22	KL 29	KL 33	KL 34	KL 50 P1
LETHE	1.00								
KL-11	0.96	1.00							
KL-17	0.98	0.96	1.00						
KL-18-P1	0.98	0.96	0.99	1.00					
KL-22	0.97	0.96	0.99	0.99	1.00				
KL-29	0.99	0.96	0.98	0.99	0.98	1.00			
KL-33	0.98	0.97	0.99	0.99	0.99	0.99	1.00		
KL-34	0.96	0.98	0.96	0.96	0.96	0.96	0.97	1.00	
KL-50-P1	0.96	0.94	0.96	0.96	0.96	0.96	0.96	0.93	1.00
KL-52	0.98	0.97	0.98	0.98	0.99	0.98	0.99	0.97	0.96
KL-63	0.97	0.98	0.97	0.97	0.97	0.97	0.98	0.98	0.94
KL-68	0.96	0.98	0.95	0.95	0.95	0.96	0.96	0.96	0.93
KL-72	0.97	0.97	0.97	0.97	0.96	0.97	0.97	0.96	0.94
KL-99	0.97	0.95	0.99	0.98	0.98	0.98	0.98	0.95	0.96
KL-100	0.98	0.96	0.98	0.98	0.99	0.98	0.98	0.96	0.96
H-88-2-4	0.98	0.97	0.98	0.98	0.98	0.99	0.99	0.96	0.96

Sample No.	KL 52	KL 63	KL 68	KL 72	KL 99	KL 100	H-88 2 4
KL-52	1.00						
KL-63	0.98	1.00					
KL-68	0.96	0.97	1.00				
KL-72	0.97	0.97	0.98	1.00			
KL-99	0.98	0.96	0.95	0.96	1.00		
KL-100	0.99	0.97	0.96	0.97	0.98	1.00	
H-88-2-4	0.98	0.98	0.96	0.98	0.98	0.98	1.00

of this set.

Regionally-applied similarity coefficients suggest that tephra WC4-90s may have been erupted during the caldera-forming explosion of Aniakchak (Table 4.10), which is believed to have occurred approximately 3,400 years ago (Riehle et al, 1987; Begét et al, 1991). The radiocarbon date of 3,320 ± 70 yr B.P. from directly beneath tephra WC4-90s is consistent with this proposed correlation. Of

Table 4.9 Regional Similarity Coefficient Matrix for Tephra "Y"
"Y MEAN"=mean composition of tephra "Y". Augustine data from Begét (unpub. data).

Sample No.	Y MEAN	A88 11 5	A88 7 5
Y MEAN	1.00		
A88-11-5	0.96	1.00	
A88-7-5	0.95	0.98	1.00

particular note in this instance is the fact that tephra WC4-90s is a bimodal tephra (mean SiO_2 contents 71.56 percent and 59.34 percent) and that both of these populations show high similarity with two distinct groups of deposits at Aniakchak (Table 4.10).

The final possible correlation was between the Windy Creek ashflow deposit and a newly-discovered ash layer in the Horn Mountains (Table 4.11), over 400 km from the study area. This ash has been dated relative to glacial deposits to be of probable early Wisconsin or pre-Wisconsin age (Bundtzen, oral comm.), making it older than the late Wisconsin age that is estimated for the proximal Windy Creek deposits (Chapter 2). Given the uncertainties of preservation in the geologic record and of counting drift units in fortuitous exposures, it is not impossible that the Windy Creek ashflow is older than first believed. If this is the case, then some of the glacial deposits in the Windy Creek area are also older than initially reported (Chapter 3). Improved stratigraphy and/or direct dating of these tephras are required to make this correlation, however, for chemistry alone is insufficient to justify it.

Table 4.10 Regional Similarity Coefficient Matrix for Tephra "WC4-90s"
Aniakchak data from Riehle and others (1987).

Population 1

Sample No.	WC4 90s P1	ANIAK 6 PUM	ANIAK 7B	ANIAK 8	ANIAK 4
WC4-90s-P1	1.00				
ANIAK-6 PUM	0.97	1.00			
ANIAK-7B	0.98	0.99	1.00		
ANIAK-8	0.97	0.98	0.99	1.00	
ANIAK-4	0.96	0.95	0.95	0.95	1.00

Population 2

Sample No.	WC4 90s P1	ANIAK 6 BGL
WC4-90s-P2	1.00	
ANIAK-6 BGL	0.98	1.00

Table 4.11 Regional Similarity Coefficient Matrix for the Windy Creek Ashflow Deposit
Horn Mountains ash data (91-BT) from Bundtzen (unpub. data).

Sample No.	WCA	91 BT
WCA	1.00	
91-BT	0.97	1.00

4.5 SUMMARY OF TEPHRA STUDY

Thirty-eight tephra samples were collected for analysis from nine measured sections and three surface collection sites near Windy Creek, and two measured sections near Brooks Lake. These samples ranged from proximal, meters-thick pyroclastic flows containing half-meter pumice blocks, to distal fallout ash barely thick enough to sample. Grain mount petrography of mafic mineral phenocrysts and glass shards yielded little data useful for tephra correlation, probably as a result of having too little data. Most samples were mineralogically inseparable, consisting of orthopyroxene, clinopyroxene and amphibole in decreasing order of abundance. Ternary diagrams with these minerals as vertices failed to show any obvious groupings of samples. No discernable trends in glass shard morphology were noted. Correlation among Windy Creek tephras was then attempted by combining stratigraphic information with geochemical data derived from electron microprobe analysis of individual glass shards. Compositional similarity coefficients were calculated between all pairs of samples to determine possible correlations. These efforts met with moderate success, allowing three tephras to be traced through multiple localities in the study area. Thirteen samples were identified as primary and five as wind-reworked Lethe tephra. Six samples were correlated and informally named Three Forks ash. One bimodal tephra was also tentatively identified: ash "Y", found in two locations. In addition to these, the three samples of the Windy Creek ashflow deposit correlated with one another as expected. Comparison of the data set with tephra chemistries collected from throughout the state allowed additional, regional, correlations to be made. Lethe tephra was recognized in fifteen sites on the Kenai Peninsula, and a radiocarbon date from the Peninsula gave a maximum age for the tephra of approximately 16,600 yr B.P. Ash "Y" was correlated with proximal deposits at Mt. St. Augustine, an ash found in only one Windy Creek site was correlated with Aniakchak proximal deposits, and distal ash of the Windy Creek ashflow deposit *may* be traceable to west-central Alaska. The majority of the samples proved unrelated to any other tephras, and some showed evidence suggesting mixing, reworking and/or contamination.

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The four-fold objective of the Windy Creek study was to map and describe the Quaternary deposits of the area, refine the late Quaternary glacial chronology of the northern Alaska Peninsula, carry out a tephrochronologic study of preserved ash layers, and ultimately develop a synthesized Quaternary geologic history of the Windy Creek area.

A geologic map of the approximately 40 km^2 study area was constructed using aerial photographs, with ground truth verified by foot traverse and field mapping on enlargements of topographic maps. Mapped deposits can be grouped into three main categories: pre-Quaternary "bedrock" consisting of Jurassic Naknek Formation sedimentary strata; late Quaternary and early Holocene glacial and volcanic deposits; and minor late Holocene-to-Recent surficial sediments. Several linear features observed on the photographs may be faults of unknown displacement.

Previous studies of Pleistocene glacial deposits on the Alaska Peninsula recognized four major drift units, including an unnamed pre-Wisconsin drift, pre-Wisconsin Johnston Hill drift, early Wisconsin Mak Hill drift, and late Wisconsin Brooks Lake drift. The Brooks Lake Glaciation has been subdivided into four stades: the Kvichak, Iliamna, Newhalen, and Iliuk. Probable Iliamna and Newhalen drift is exposed in Windy Creek valley, which was subsequently dammed by Iliuk ice to form a glacial lake. A soil layer overlying the resulting lacustrine deposits was dated at 8,410$\pm$140 yr B.P., providing an upper limiting age for the Iliuk advance 25 km from the type Iliuk moraine. Ukak glaciolacustrine deposits, representing a latest Pleistocene ice readvance, has been radiocarbon dated between *ca.* 10,000 and 12,000 yr B.P. This also provides an upper limiting date for the Brooks Lake Glaciation and its four stades. The early Holocene Katolinat drift, which forms morainal loops that partially obstructed flow of the 1912 ignimbrite, has been radiocarbon dated between *ca.* 8,500 and 10,000 yr B.P.

The ages of the Newhalen and Iliuk alpine valley glacier advances, like that of the major Iliamna advance, were poorly constrained by upper limiting dates of *ca.* 9,000 yr B.P. prior to the present study. These limits have now been pushed back some 4,000 years to greater than *ca.*13,000 yr B.P. Lethe volcaniclastic deposits, dated between *ca.* 16,000 and 12,500 yr B.P., overlie all these deposits and underlie all younger glacial deposits, forming an important marker horizon that is traceable at least as far as the Kenai Peninsula. The Ukak readvance of alpine glaciers near the Pleistocene-Holocene boundary *ca.* 11,000 yr B.P. extended about 25 km downvalley from modern glaciers, some 25 km behind the Iliuk ice margin. Early Holocene Katolinat moraines (*ca.* 9,000 yr B.P.) are preserved 1-5 km upvalley from Ukak deposits in the Windy Creek area. The *ca.* 4,000 yr B.P. rhyodacitic Three Forks tephra is a mid-Holocene marker horizon that may prove valuable in separating the older deposits from subsequent Neoglacial deposits.

Thirty-eight Windy Creek tephra samples were collected for tephrochronologic study. Grain mount petrography of mafic mineral phenocrysts and glass shards was of little help for tephra correlation; most samples were mineralogically inseparable, and no discernable trends in glass shard morphology were noted. Correlation among Windy Creek tephras was then attempted using stratigraphic information and geochemical data derived from electron microprobe analysis of glass shards. Similarity coefficients calculated between all pairs of samples allowed four tephras to be traced through multiple localities in the study area. Thirteen samples were identified as Lethe tephra, six were Three Forks ash, and two were bimodal tephra "Y". Three samples of the Windy Creek ashflow deposit correlated with one another.

Comparison of the data set with tephra chemistries collected from throughout the state allowed regional correlations to be made. Lethe tephra was recognized in fifteen sites on the Kenai Peninsula, ash "Y" was correlated with proximal deposits at Mt. St. Augustine, an unnamed ash found in only one Windy Creek site was correlated with Aniakchak proximal deposits, and distal ash of the Windy Creek ashflow deposit may be traceable to west-central Alaska. The majority of the samples were unrelated to any other documented tephras, and many showed evidence of mixing, reworking and/or contamination.

5.2 LATE QUATERNARY GEOLOGIC HISTORY AT WINDY CREEK

Table 5.1 summarizes the late Quaternary geologic history of the Windy Creek area, as determined in this study. The oldest Quaternary deposits recognized in the area are sediments believed to have been laid down during the late Wisconsin-age Iliamna glacial advance. An eruption at one of the many nearby volcanic centers buried Windy Creek valley in thick ashflow deposits, which were subsequently overridden by glacial ice of the Newhalen Stade and buried by drift. Another late Wisconsin ice advance, the Iliuk, blocked drainage from Windy Creek and dammed a lake in the valley, leaving thick glaciolacustrine

Table 5.1 Late Quaternary Geologic History of the Windy Creek Area

Age	Event	Deposit
Recent *(1912 A.D.)*	Volcanic eruption	Katmai ashflow deposit
Late Holocene *(ca. 1,700 yr B.P.)*	Volcanic eruption	Mt. St. Augustine ash *(Tephra "Y")*
Middle Holocene *(ca. 3,400 yr B.P.)*	Volcanic eruption	Aniakchak ash *(WC4-90s)*
Middle Holocene *(ca. 4,000 yr B.P.)*	Volcanic eruption	Three Forks ash
Early Holocene *(10,000-8,500 yr B.P.)*	Glacial advance	Katolinat drift
Latest Wisconsin *(12,000-10,000 yr B.P.)*	Glacial advance	Ukak drift
Late Wisconsin *(16,000-12,500 yr B.P.)*	Volcanic eruption	Lethe volcaniclastic deposits
Late Wisconsin *(> 13,000 yr B.P.)*	Glacial advance	Iliuk drift and glaciolacustrine deposits
Late Wisconsin (?)	Glacial advance	Newhalen drift (?)
Late Wisconsin (?)	Volcanic eruption	Windy Creek ashflow deposit
Late Wisconsin (?)	Glacial advance	Iliamna drift (?)

deposits in addition to well-preserved lateral moraines and drift sheets. Sometime between approximately 16,000 and 12,500 yr B.P., a major volcanic eruption that was probably centered at the head of present-day Valley of Ten Thousand Smokes deposited a wide variety of volcaniclastic deposits over much of the area. Lethe ash was carried across Cook Inlet to blanket large parts of the western Alaska Peninsula. Alpine glaciers advanced between 10,000 and 12,000 yr B.P. and deposited the Ukak drift, which may be equivalent to deposits of the

Allerød-Bølling cooling trend and Younger Dryas cold event of western Europe. A glacial readvance between 8,500 and 10,000 yr B.P. may have occurred in response to a brief period of climatic deterioration, depositing the early Holocene Katolinat drift. The remainder of the Holocene record is characterized by deposition of tephra-rich eolian silts and multiple discrete ash layers. The 4,000-year-old Three Forks Ash has been identified in many sections in the Windy Creek area, but has not yet been found elsewhere. Distal ash from the caldera-forming eruption of Aniakchak Crater (*ca.* 3,400 yr B.P.) was preserved in one Windy Creek sample site. Another tephra, ash "Y", was tentatively correlated to proximal deposits at Mt. St. Augustine that have been dated at approximately 1,700 yr B.P. The youngest major event of geologic note was the Katmai eruption of 1912, which created the Valley of Ten Thousand Smokes. Although it is this feature which continues to fascinate visitors to the Katmai area, it behooves the onlooker to ponder what lies overshadowed by this awesome spectacle, for it masks a richly detailed tapestry of interacting earth processes ranging from repeated cataclysmic volcanic devastation and immense masses of ice inexorably grinding rocks into powder to the slow infilling of a lake basin over countless years and the accumulation of layer upon layer of microscopic eolian dust.

REFERENCES CITED

Abrahamson, S.R., 1949; Geography of the Naknek region, Alaska; Ph.D. Dissertation, Clark Univ., Worcester, Mass., 148 pp.

Allen, E.T., and E.G. Zeis, 1923; A chemical study of the fumaroles of the Katmai Region; Natl. Geogr. Soc. Contrib. Tech. Papers, Katmai Series 2, p. 75-155.

Ashley, G.M., 1989; Classification of glaciolacustrine sediments; *in* R.P. Goldthwait and C.L. Matsch, Genetic Classification of Glacigenic Deposits, p. 243-260.

Atwood, W.W., 1911; Geology and mineral resources of parts of the Alaska Peninsula; U.S.G.S. Bull., 467, 137 pp.

Begét, J.E., and A.J. Limke, 1988; Two-dimensional kinematic and rheological modeling of the 1912 pyroclastic flow, Katmai, Alaska; Bull. Volcanol., 50, p. 148-160.

Begét, J.E., R.D. Reger, D. Pinney, T. Gillispie, and K. Campbell, 1991; Correlation of the Holocene Jarvis Creek, Tangle Lakes, Cantwell, and Hayes tephras in south-central and central Alaska; Quat. Res., 35, p. 174-189.

Booth, D.B., 1986; The formation of ice-marginal embankments into ice-dammed lakes in the eastern Puget Lowland, Washington, U.S.A., during the late Pleistocene; Boreas, 15, p. 247-263.

Borchardt, G.A., P.J. Aruscavage, and H.T. Millard, Jr., 1972; Correlation of the Bishop Ash, a Pleistocene marker bed, using instrumental neutron activation analysis; J. Sed. Pet., 42(2), p. 301-306.

Burk, C.A., 1965; Geology of the Alaska Peninsula-Island Arc and continental margin (Part 1); Geol. Soc. Am. Mem., 99 (Part 1), 250 pp.

Clark, G.H., 1977; Archaeology on the Alaska Peninsula; The coast of Shelikof Strait, 1963-1965; Univ. Oregon Anthropological Papers, 13, 247 pp.

Curtis, G.H., 1968; The stratigraphy of the ejecta from the 1912 eruption of Mount Katmai and Novarupta, Alaska; *in* R.R. Coats, R.L. Hay, and C.A. Anderson (eds.), Studies in Volcanology; Geol. Soc. Am. Mem., 116, p. 153-210.

Detterman, R.L., 1986; Glaciation of the Alaska Peninsula; *in* T.D. Hamilton, K.M. Reed, and R.M. Thorson (eds.), Glaciation in Alaska: The Geologic Record, Alaska Geol. Soc., p. 151-170.

Detterman, R.L., and B.L. Reed, 1973; Surficial deposits of the Iliamna quadrangle, Alaska; U.S.G.S. Bull., 1368-A, 64 pp.

Donnelly, R., and C. Harris, 1989; Sedimentology and origin of deposits from a small ice-dammed lake, Leirbree, Norway; Sedimentol., 36, p. 581-600.

Dumond, D.E., 1980; The archeology of Alaska and the peopling of America; Science, 209, p. 984-991.

———, 1981; Archaeology of the Alaska Peninsula: The Naknek Region, 1960-1975; Univ. Oregon Anthropological Papers, 21, 277 pp.

Eichelberger, J.C., S. Ballard, C.R. Carrigan, A. Goodliffe, W. Hildreth, E. Iwatsubo, P.W. Kasameyer, T.E.C. Keith, J. Kienle, J.J. Papike, D.D. Pollard, D.B. Stone, P.C. Wallman, P.L. Ward, M. Wilt, and M.E. Yount, 1990; Geophysical expedition to Novarupta Volcano, Katmai National Park, Alaska; EOS, Trans. Am. Geophys. Union, 71(22), p. 733-735.

Eichelberger, J.C., and W. Hildreth, 1986; Research drilling at Katmai, Alaska; EOS, Trans. Am. Geophys. Union, 67, p. 778-780.

Eichelberger, J.C., W. Hildreth, and J.J. Papike, 1991; The Katmai scientific drilling project, surface phase: Investigation of an exceptional igneous system; Geophys. Res. Let., 18(8), p. 1513-1516.

Eyles, C.H., and N. Eyles, 1983; Sedimentation in a large lake: A reinterpretation of the late Pleistocene stratigraphy at Scarborough Bluffs, Ontario, Canada; Geology, 11, p. 146-152.

Fenner, C.N., 1920; The Katmai region, Alaska, and the great eruption of 1912; J. Geol., 28(7), p. 569-606.

———, 1921; Evidences of assimilation during the Katmai eruption of 1912 [abs.]; Geol. Soc. Am. Bull., 33, p. 129.

———, 1925; Earth movements accompanying the Katmai eruption; J. Geol., 33(3), p. 116-139 and p. 193-223.

———, 1926; The Katmai magmatic province; J. Geol., 34(7), p. 673-772.

———, 1950; The chemical kinetics of the Katmai eruption; Am. J. Sci., 248, p. 593-627 and p. 697-725.

Fisher, R.U., and H.-U. Schmincke, 1984; Pyroclastic Rocks; Springer-Verlag, 472 pp.

Froggatt, P.C., 1981; Stratigraphy and nature of Taupo Pumice Formation; N. Zeal. J. Geol. Geophys., 24, p. 231-248.

Griggs, R.F., 1922; The Valley of Ten Thousand Smokes; Natl. Geogr. Soc., Washington, D.C., 340 pp.

Henn, W., 1978; Archaeology on the Alaska Peninsula: The Ugashik drainage, 1973-1975; Univ. Oregon Anthropological Papers, 14, 183 pp.

Heusser, C.J., 1963; Postglacial palynology and archaeology in the Naknek River drainage area, Alaska; Am. Antiquity, 29, p. 74-81.

Hildreth, W., 1983; The compositionally zoned eruption of 1912 in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska; J. Volcanol. Geotherm. Res., 18, p. 1-56.

———, 1987; New perspectives on the eruption of 1912 in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska; Bull. Volcanol., 49, p. 680-693.

———, 1991; The timing of caldera collapse at Mount Katmai in response to magma withdrawal toward Novarupta; Geophys. Res. Let., 18(8), p. 1541-1544.

Hildreth, W., J.E. Fierstein, A. Grunder, and L. Jager, 1984; The 1912 eruption in the Valley of Ten Thousand Smokes, Katmai National Park: A summary of the stratigraphy and petrology of the ejecta; U.S.G.S. Circ., 868, p. 37-39.

Keith, T.E.C., 1984; Preliminary observations on fumarole distribution and alteration, Valley of 10,000 Smokes, Alaska; U.S.G.S. Circ., 939, p. 82.

Keller, A.S., and H.N. Reiser, 1959; Geology of the Mount Katmai area, Alaska; U.S.G.S. Bull., 1058-G, p. 261-298.

Kienle, J., 1969; Gravity survey in the general area of the Katmai National Monument; Ph.D. Thesis, Univ. Alaska, Fairbanks, 151 pp.

———, 1970; Gravity traverses in the Valley of Ten Thousand Smokes, Katmai National Monument, Alaska; J. Geophys. Res., 75, p. 6641.

———, 1991; Depth of the ashflow deposit in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska; Geophys. Res. Let., 18(8), p. 1533-1536.

Kienle, J., and S.E. Swanson, 1983; Volcanism in the eastern Aleutian arc: Late Quaternary and Holocene centers, tectonic setting and petrology; J.

Volcanol. Geotherm. Res., 17, p. 393-432.

Kienle, J., S.E. Swanson, and H. Pulpan, 1981; Volcanic centers in the Katmai area, Alaska [abs.]; EOS, Trans. Am. Geophys. Union, 62, p. 430.

Kodosky, L.G., 1989; Surface Mercury geochemistry as a guide to volcanic vent structure and zones of high heat flow in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska; J. Volcanol. Geotherm. Res., 38, p. 227-242.

Kosco, D.G., 1981a; Characteristics of andesitic to dacitic volcanism at Katmai National Park, Alaska [abs.]; Geol. Soc. Am. Abst. with Progr., 13, p. 490.

Kosco, D.G., 1981b; Characteristics of andesitic to dacitic volcanism at Katmai National Park, Alaska; Ph.D. Thesis, Univ. California, Berkeley, 249 pp.

Kubota, S., and E. Berg, 1967; Evidence for magma in the Katmai volcanic range; Bull. Volcanol., 31, p. 175-214.

Lowe, D.R., 1975; Water escape structures in coarse-grained sediments; Sedimentol., 22, p. 157-204.

Martin, G.C., 1913; The recent eruption of Katmai Volcano in Alaska: An account of one of the most tremendous volcanic explosions known in history; Natl. Geogr. Mag., 24(2), p. 131-181.

Matumoto, T., 1971, Seismic body waves observed in the vicinity of Mount Katmai, Alaska, and evidence for the existence of molten chambers; Geol. Soc. Am. Bull., 82, p. 2905-2920.

May, R.W., 1977; Facies models for sedimentation in the glaciolacustrine environment; Boreas, 6, p. 175-180.

Muller, E.H., 1952; Glacial history of the Naknek District, Alaska Peninsula, Alaska [abs.]; Geol. Soc. Am. Bull., 63, p. 1284.

———, 1953; Northern Alaska Peninsula and eastern Kilbuck Mountains, Alaska; U.S.G.S. Circ., 289, p. 2-3.

Muller, E.H., W. Juhle, and H.W. Coulter, 1954; Current volcanic activity in Katmai National Monument; Science, 119, p. 319-321.

National Park Service, 1985; General management plan/Land protection plan/Wilderness suitability review: Katmai National Park and Preserve, Alaska; U.S. Dept. of the Interior, 147 pp.

Nowak, M., 1968; Archaeological dating by means of volcanic ash strata; Ph.D. Dissertation, Univ. Oregon, 210 pp.

Paterson, W.S.B., and C.U. Hammer, 1987; Ice core and other glaciological data; *in* W.F. Ruddiman and H.E. Wright, Jr. (eds.), North America and Adjacent Areas During the Last Deglaciation, The geology of North America, K-3, Geol. Soc. Am., Boulder, p. 91-109.

Péwé, T.L., 1975; Quaternary geology of Alaska; U.S.G.S. Prof. Paper, 835, 145 pp.

Pinney, D.S., 1991; Laboratory procedures for processing tephra samples; Ak. Div. Geol. Geophys. Surv. Public-data File, 91-30, 12 pp.

Pinney, D.S., and J.E. Begét, 1990; Quaternary tephrochronology near the Valley of Ten Thousand Smokes, Katmai National Park, Alaska [abs.]; EOS, Trans. Am. Geophys. Union, 71(43), p. 1721.

———, 1991; Deglaciation and latest Pleistocene and early Holocene glacier readvances on the Alaska Peninsula: Records of rapid climate change due to transient changes in solar intensity and atmospheric CO_2 content?; Proc. Internatl. Conf. on the Role of the Polar Regions in Global Change, p. 634-640.

———, 1992; Late Pleistocene volcanic deposits near the Valley of Ten Thousand Smokes, Katmai National Park, Alaska; Alaska Div. Geol. Geophys. Surv. Prof. Rept., 111, p. 45-53.

Riehle, J.R., 1985; A reconnaissance of the major Holocene tephra deposits in the upper Cook Inlet region, Alaska; J. Volcanol. Geotherm. Res., 26, p. 37-74.

Riehle, J.R., R.L. Detterman, M.E. Yount, and J.W. Miller, 1987; Preliminary geologic map of the Mount Katmai quadrangle and portions of the Afognak and Naknek quadrangles, Alaska; U.S.G.S. Open-file Rep., 87-593.

Riehle, J.R., C.E. Meyer, T.A. Ager, D.S. Kaufman, and R.E. Ackerman, 1987; The Aniakchak tephra deposit, a late Holocene marker horizon in western Alaska; U.S.G.S. Circ. 998, p. 19-22.

Scott, K.M., 1988; Origins, behavior, and sedimentology of lahars and lahar-runout flows in the Toutle-Cowlitz River system; U.S.G.S. Prof. Paper, 1447-A, 76 pp.

———, 1989; Magnitude and frequency of lahars and lahar-runout flows in the Toutle-Cowlitz River system; U.S.G.S. Prof. Paper, 1447-B, 33 pp.

Self, S., and R.S.J. Sparks (eds.), 1981; <u>Tephra Studies</u>; NATO Adv. Study Inst. Series, Series C, Math. and Phys. Sci., 75, 481 pp.

Smith, D.G.W., and J.A. Westgate, 1969; Electron microprobe technique for characterizing pyroclastic deposits; Earth Planet. Sci. Let., 5, p. 313-319.

Smith, N.D., and G. Ashley, 1985; Proglacial lacustrine environment; *in* G.M. Ashley, J. Shaw, and N.D. Smith (eds.), <u>Glacial Sedimentary Environments</u>, SEPM Short Course, 16, p. 135-215.

Smith, W.R., 1925; The Cold Bay-Katmai District; U.S.G.S. Bull., 773, p. 183-207.

Sparks, R.S.J., S. Self, and G.P.L. Walker, 1973; Products of ignimbrite eruptions; Geology, 1, p. 115-118.

Spurr, J.E., 1900; A reconnaissance in southwestern Alaska in 1898; 20th Ann. Rept. of the U.S.G.S., Part VII, p. 31-264.

Steen-MacIntyre, V., 1977; A Manual for Tephrochronology; Virginia Steen-MacIntyre, Idaho Springs, Colorado, 167 pp.

Stihler, S., 1991; Paleomagnetic investigation of seismic and volcanic activity recorded in the sediments of Skilak Lake, Alaska; M.Sc. Thesis, Univ. Alaska, Fairbanks, 197 pp.

Theakstone, W.H., 1976; Glacial lake sedimentation, Austerdalsisen, Norway; Sedimentol., 23, p. 671-688.

Valentine, G.A., and R.A. Fisher, 1986; Origin of layer 1 deposits in ignimbrites; Geology, 14, p. 146-148.

Walker, G.P.L., S. Self, and P.C. Froggatt, 1981; Low-aspect ratio ignimbrites; Nature, 283, p. 286-287.

Walker, G.P.L., and C.J.N. Wilson, 1983; Lateral variations in the Taupo ignimbrite; *in* S. Aramaki and I. Kushiro (eds.), Arc Volcanism; J. Volcanol. Geotherm. Res., 18, p. 117-133.

Westgate, J.A., and M.P. Gorton, 1981; Correlation techniques in tephra studies; *in* S. Self and R.S.J. Sparks (eds.), Tephra Studies; NATO Adv. Study Inst. Series, Series C, Math. and Phys. Sci., 75, p. 73-94.

Westgate, J.A., R.C. Walter, G.W. Pearce, and M.P. Gorton, 1985; Distribution and character of the late Pleistocene Old Crow tephra in Alaska and the Yukon; Can. J. Earth Sci., 22, p. 893-906.

Wilson, C.J.N., 1985; The Taupo eruption, New Zealand. II. The Taupo ignimbrite;

Phil. Trans. R. Soc. London A., 314, p. 229-310.

Wilson, C.J.N., and G.P.L. Walker, 1982; Ignimbrite depositional facies: The anatomy of a pyroclastic flow; J. Geol. Soc. London, 139, p. 581-592.

———, 1985; The Taupo eruption, New Zealand. I. General aspects; Phil. Trans. R. Soc. London. A., 314, p. 199-228.

Wright, J.V., Smith, A.L., and S. Self, 1980; A working terminology of pyroclastic deposits; J. Volcanol. Geotherm. Res., 8, p. 315-336.

Zies, E.G., 1929; The Valley of 10,000 Smokes, 1, The fumarolic incrustations and their bearing on ore deposition, 2, The acid gases contributed to the sea during volcanic activity; Natl. Geogr. Soc. Contrib. Tech. Papers, Katmai Series 4, p. 1-79.

APPENDIX I: TEPHRA ANALYTICAL PROCEDURES

Measurement of stratigraphic sections was the first step in unraveling the tephrochronology of the Windy Creek area. Exposures in stream cuts (in the case of the Brooks Lake sections, gravel pits) were cleared by shovel and cleaned with hand trowels before photographing and measurement. A 5-m tape measure marked in 1-cm increments was used to measure thicknesses. Tephras were carefully collected from the cleaned, measured sections using a hand trowel or pocketknife blade. Every effort was made to recover the tephra samples as pure as possible for subsequent analytical work.

The following preparation procedures are modified from Steen-MacIntyre (1977), and are presented in laboratory-manual fashion to provide a step-by-step guide to processing tephra samples for petrographic and geochemical analysis. An alternative procedure using nontoxic sodium polytungstate instead of bromoform for heavy liquid separations is described by Pinney (1991).

PART 1: PRELIMINARY PROCESSING

1) Allow samples to air dry, or dry in oven with very low heat
2) Transfer samples to large vials or jars labeled with sample number
3) Prepare temporary grain mounts of fine-grained samples and examine for glass using petrographic microscope:
    a) shake vial to homogenize tephra and use small spatula to transfer small amount of sample to slide

b) carefully place square 18x18 mm cover glass over sample on slide

c) place drops of refractive index oil or vegetable oil at margin of cover glass and allow capillary action to draw oil beneath cover glass

d) place finger on cover glass and move gently in circular fashion to disperse sample in oil

e) place slide on microscope stage and examine for glass; with polars crossed and gypsum plate in, glass will appear as red or magenta fragments the same color as the oil and will not change color as stage is rotated (isotropic)

f) determine if sample is tephra; heavily contaminated samples, particularly those recovered from eolian silt, may contain very few glass shards and operator judgement must be used to determine if sample warrants further treatment as a tephra

g) samples determined not to be tephras are labeled NAT (Not A Tephra); no further analysis

h) discard used cover glasses; wash slides for reuse

PART 2: INITIAL PREPARATIONS

1) Separate fraction to be analyzed:

a) coarse pumice: select at least five clasts; break into pieces using hammer or mortar and pestle; select pieces from clast interiors; crush (do not grind) to pass through 60-mesh screen (wet-sieve over sediment trap using 60- and 230-mesh screens); transfer the -60- to-+230-mesh fraction to beaker labeled with sample number

b) medium pumice (lapilli) : select at least ten lapilli; crush (do not grind) to pass through 60-mesh screen (wet-sieve as in "a"); transfer -60-to-+230-mesh fraction to beaker labeled with sample number

c) fine ash: shake sample vial well to homogenize sample and transfer approximately 10 mL (if possible)to beaker labeled with sample number; if initial petrographic examination showed little glass, commensurately more sample is necessary to recover sufficient glass for analysis

***) for all samples, try to retain at least one-half of total sample as bulk raw material to be archived for future reference, textural analysis, or in the event of loss or contamination of the initial analysis fraction (this may not be possible for some small-volume fine-grained samples, but always retain <u>some</u> material in raw form)

2) Sonically clean separates:

a) add water to samples until beakers are full

b) place beakers in sonic cleaner basin and fill basin with water to approximately same level as water in beakers; do not overfill

c) sonically clean samples 10 to 15 minutes, stirring occasionally; be sure to rinse stirring rod well between samples

d) remove sample beakers from basin and wet-sieve contents over sediment trap using 230-mesh screen; transfer +230-mesh fraction back to labeled beakers and decant excess water

***) always wear ear protection when sonic cleaner is in use, and keep lab door closed to protect others

PART 3: TREATMENT FOR CEMENTS AND CONTAMINANTS

1) If present, treat samples for organics (rootlets, disseminated organic

material, dark humic stains):

a) prepare boiling water bath in hood with fan on

b) add several times (4 to 6) the sample volume of household bleach to each sample and gently swirl to mix

c) using clothes-pins, affix beakers to inner sides of pan containing boiling water, keeping beakers suspended off pan bottom

d) keep sample beakers immersed in bath for 10 to 15 minutes

e) remove beakers and carefully fill with water to dilute bleach; allow to sit for several minutes, then decant liquid and suspended material into drain; repeat rinse

f) bleach treatment procedure may be repeated if necessary

g) if bleached organic fragments persist after second treatment, process as for iron cement even if no iron is present (see "2")

h) fill beakers with water and sonically clean 5 to 10 minutes

2) If present, treat for iron stains/cements (tephra has yellow-to-orange-to-red discoloration):

a) set hot plate on lowest setting in hood with fan on and water running in drain

b) add several times (3 to 5) the sample volume of 6N hydrochloric acid to each sample and gently swirl to mix

c) place sample beakers on hot plate to gently warm for about 2 to 4 minutes (no longer), swirling occasionally to mix

d) remove beakers from heat and carefully fill with water to dilute acid; allow to sit for several minutes, then carefully decant liquid and suspended material into drain in which water is running; repeat rinse twice more

e) fill beakers with water and sonically clean 5 to 10 minutes

***) keep water running in drain for at least 15 minutes after last acid is discarded into drain to dilute acid and thoroughly flush the drainage system

PART 4: SEPARATING COARSE AND FINE FRACTIONS

1) Wet-sieve samples over sediment trap using 60- and 230-mesh screens, rinsing well; transfer +60-mesh fraction to disposable evaporating dishes labeled with sample numbers and suffix "b", and -60-to-+230-mesh fraction to disposable evaporating dishes labeled with sample numbers and suffix "a"; decant excess water
2) Allow samples to air dry, or dry in oven with very low heat
3) Transfer coarse fraction "b" to vials labeled with sample number and suffix "b"and archive; no further analysis (remember that coarse- and medium-grained samples should not have "b"-vials as their analysis fractions were crushed to pass through 60-mesh screen)
4) Transfer fine fraction "a" to vials labeled with sample number and suffix "a"

PART 5: PETROGRAPHIC ANALYSIS

1) Prepare permanent grain mounts of tephras using cleaned "a" fractions:
   a) label clean 1"x3" slides with sample numbers and arrange on paper towels next to corresponding sample vials
   b) mix epoxy according to instructions; wear gloves and avoid inhaling

fumes

c) dispense sufficient epoxy on each slide such that, when cover glass is ultimately pressed down, epoxy will spread beneath entire area of cover glass without much excess squeezing out

d) shake sample vial to homogenize, then use spatula or flattened toothpick to sprinkle some sample over epoxy; wipe instrument carefully between samples to avoid contamination

e) using separate toothpick for each sample, carefully mix tephra into epoxy using circular and side-to-side motions; avoid introducing air bubbles into epoxy

f) place 24x60 mm rectangular cover glass over epoxy/tephra mixture and press gently to squeeze out excess; a toothpick or strip of stiff paper may be used to scoop excess epoxy from margins of slide

g) petrographic examination may be carried out after one hour if desired; allow at least one day for epoxy to cure completely before putting grain mounts in labeled slots in slide boxes

2) Characterize tephras petrographically:

a) coarse - and medium-grained tephras: note color of glass, presence of inclusions and vesicles; point count mafic minerals; note unusual minerals and mineral characteristics

b) fine-grained tephras: note color of glass, shard morphology, presence of inclusions and vesicles, relative abundance of glass shards; point count only mafic minerals with attached glass; note unusual minerals and mineral characteristics (only for minerals with attached glass)

PART 6: HEAVY-LIQUID SEPARATION OF GLASS SHARDS

*****WARNING: BROMOFORM IS EXTREMELY TOXIC; ALL WORK MUST BE CARRIED OUT IN A LABORATORY HOOD RATED AT 130 F/S OR BETTER, AND A RESPIRATOR AND GLOVES MUST BE WORN WHENEVER HANDLING BROMOFORM*****

1) Separations are performed on fine "a" fraction
2) Fold and label in pencil two filter paper circles for each sample, one for "glass" and one for "heavies" (minerals, etc.)
3) Place papers in funnels, and insert funnels into Ehrlenmeyer flasks
4) Label tubes for small centrifuge with sample numbers; the tubes required for this procedure must have a narrow "waist" at their midpoint that can be sealed using a rubber stopper attached to the end of a glass rod
5) In a laboratory hood, prepare a solution of bromoform and acetone with density 2.42
6) Shake sample vial to mix and add approximately one-quarter teaspoon of sample to the appropriately labeled centrifuge tube; be sure to retain some "a" fraction in vial for archiving; repeat with remaining samples
7) At the hood, add a small amount of bromoform solution to the centrifuge tube, close top and shake gently to mix; uncap tube and fill to within 1.5 cm of the top with bromoform solution, recap and set aside in rack; repeat with remaining samples
8) Put centrifuge in hood and load tubes, making certain that the load is balanced; centrifuge samples for at least 15 minutes
9) At the hood, uncap centrifuge tube; gently insert glass rod with rubber stopper affixed to its end into the tube to seal the bottom chamber, taking

care not to drag many floating particles down with the stopper

10) At the hood, with glass rod/stopper firmly in place, pour contents of top chamber into appropriate filter paper/funnel labeled "glass"; particles adhering to the tube or stopper may be rinsed into the funnel using acetone in a wash bottle; remove stopper and pour contents of bottom chamber into appropriate filter paper/funnel labeled "heavies" and flush adhering particles into funnel using wash bottle with acetone

11) Thoroughly rinse "heavies" and "glass" fractions many times with acetone from wash bottle, making certain to saturate filter paper each time; it is imperative that separates be absolutely rinsed clean of bromoform

12) Remove filter papers containing separates from funnels and allow to air dry, or dry in oven with very low heat

13) When dry, transfer samples to labeled vials; "heavies" fraction vials are labeled with sample numbers and suffix "h", "glass" fraction vials with sample numbers and suffix "g"

WINDY CREEK PETROGRAPHIC PROCEDURE

Two grain mount slides of the cleaned "a" fractions were prepared for most of the Windy Creek tephra samples and examined for petrographic characteristics. An attempt was made to count a minimum of fifty mineral grains in each sample, but this proved more difficult than anticipated due to the paucity of glass-mantled grains in many of the samples. In some cases it proved impossible to achieve this number even after scanning both slides in their entirety and, in the interests of timeliness, no further efforts were made to prepare and examine additional grain mounts. Glass shard morphology was also described for non-pumice samples as an additional characteristic that might prove helpful in making comparisons.

WINDY CREEK ELECTRON MICROPROBE PROCEDURES

Analyses were carried out on the glass-rich fraction resulting from heavy-liquid separation of the cleaned "a" fractions. The instrument used to analyze the samples was the Washington State University Cameca MBX microprobe. Analytical standards were CCNM-211 (obsidian), K-411 (NBS glass for Mg, Ca) and KCL (CMTB-2 for Cl). Analytical conditions were 15 kV, 13.5 nA, with an 8-μm beam and counting time of 10 sec. Total Fe, initially analysed and reported as Fe_2O_3, was converted into FeO* and then all major element oxide analyses were normalized to 100 percent (Appendix II).

APPENDIX II: GEOCHEMICAL DATA FOR WINDY CREEK TEPHRAS

The following data are the result of electron microprobe analysis of tephra glass separates, reported as normalized oxide weight percent of eight elements: Si, Al, Na, Fe, Ca, K, Mg, Ti, and Cl. Total Fe is expressed as FeO*. The analyses for each sample are grouped into analyses that comprise populations and analyses that were regarded as outliers and removed from further calculations. Each population consists of all the analyses that fall into the group, the average composition calculated from these analyses, and the standard deviation for each oxide. Analyses of outliers, when present, are listed at the bottom for each sample.

INDEX OF WINDY CREEK MICROPROBE RESULTS

WC50-X (n=16)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.40	13.49	4.02	2.87	2.28	2.48	0.56	0.58	0.32	100.00
	73.08	13.54	3.93	3.16	2.46	2.44	0.62	0.62	0.15	100.00
	72.99	13.83	3.75	3.32	2.38	2.42	0.63	0.57	0.10	100.00
	72.85	13.88	3.99	3.07	2.43	2.37	0.69	0.57	0.15	100.00
	72.79	13.84	4.16	3.09	2.38	2.43	0.64	0.58	0.10	100.00
	72.62	13.64	4.15	3.07	2.51	2.51	0.67	0.66	0.16	100.00
	72.53	14.10	3.55	3.29	2.56	2.35	0.78	0.71	0.11	100.00
	72.41	13.77	3.91	3.15	2.85	2.39	0.78	0.59	0.15	100.00
	72.36	14.14	3.65	3.28	2.82	2.37	0.72	0.68	0.00	100.00
	72.30	13.97	3.66	3.43	2.74	2.40	0.77	0.64	0.10	100.00
	72.19	13.93	4.31	3.20	2.59	2.42	0.66	0.57	0.13	100.00
	72.10	13.88	3.79	3.29	2.91	2.36	0.75	0.74	0.18	100.00
	72.05	13.83	4.16	3.39	2.80	2.24	0.72	0.66	0.15	100.00
	72.02	13.96	4.26	3.25	2.57	2.37	0.72	0.68	0.16	100.00
	71.71	13.92	4.26	3.59	2.66	2.42	0.71	0.62	0.13	100.00
	71.58	13.97	4.29	3.38	2.84	2.39	0.73	0.69	0.13	100.00
avg	72.44	13.85	3.99	3.24	2.61	2.40	0.70	0.64	0.14	100.00
std dev	0.50	0.18	0.25	0.17	0.20	0.06	0.06	0.06	0.06	0.00

PI-D2 (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.04	13.78	4.91	1.24	1.36	1.97	0.31	0.21	0.18	100.00
	76.01	13.59	4.89	1.16	1.47	2.10	0.36	0.30	0.13	100.00
	75.61	13.53	4.72	1.61	1.42	2.32	0.28	0.31	0.20	100.00
	75.57	13.60	4.88	1.58	1.46	2.13	0.33	0.31	0.14	100.00
	75.57	13.56	4.80	1.72	1.34	2.26	0.29	0.27	0.21	100.00
	75.46	13.66	4.90	1.62	1.39	2.29	0.34	0.19	0.16	100.00
	75.44	13.63	4.91	1.73	1.41	2.23	0.31	0.18	0.17	100.00
	75.38	13.65	4.99	1.83	1.32	2.21	0.31	0.09	0.22	100.00
	75.32	13.52	5.04	1.72	1.39	2.26	0.28	0.29	0.19	100.00
	75.31	13.75	4.88	1.66	1.55	2.13	0.31	0.24	0.18	100.00
	75.30	13.66	4.78	1.75	1.38	2.29	0.28	0.37	0.18	100.00
	75.31	13.72	4.98	1.73	1.48	2.08	0.30	0.32	0.07	100.00
	75.23	13.62	4.93	1.63	1.53	2.22	0.40	0.25	0.18	100.00
	75.13	13.69	4.95	1.71	1.46	2.38	0.30	0.22	0.15	100.00
	75.12	13.70	5.06	1.76	1.44	2.19	0.28	0.25	0.20	100.00
	75.11	13.59	4.88	1.94	1.37	2.33	0.31	0.25	0.22	100.00
	75.02	13.58	4.73	1.64	2.10	2.27	0.26	0.25	0.17	100.00
	74.93	13.71	5.08	2.06	1.32	2.28	0.28	0.20	0.15	100.00
avg	75.38	13.64	4.91	1.67	1.45	2.22	0.31	0.25	0.17	100.00
std dev	0.30	0.08	0.10	0.21	0.17	0.10	0.04	0.06	0.03	0.00

PI-C (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.32	13.09	4.84	1.67	1.36	2.22	0.29	0.00	0.21	100.00
	75.74	13.64	4.71	1.62	1.38	2.14	0.28	0.23	0.25	100.00
	75.53	13.76	4.63	1.67	1.39	2.12	0.31	0.26	0.33	100.00
	75.52	13.67	4.83	1.59	1.38	2.19	0.30	0.28	0.24	100.00
	75.50	13.65	4.89	1.62	1.44	2.15	0.32	0.24	0.19	100.00
	75.47	13.72	4.90	1.58	1.40	2.15	0.28	0.25	0.25	100.00
	75.44	13.82	4.81	1.64	1.36	2.15	0.29	0.26	0.23	100.00
	75.44	13.72	5.01	1.73	1.31	2.10	0.20	0.23	0.27	100.00
	75.43	13.72	4.98	1.70	1.25	2.10	0.30	0.29	0.23	100.00
	75.41	13.72	4.97	1.60	1.38	2.05	0.32	0.30	0.24	100.00
	75.40	13.76	4.97	1.60	1.42	2.07	0.30	0.26	0.21	100.00
	75.33	13.78	4.89	1.68	1.37	2.12	0.33	0.28	0.23	100.00
	75.31	13.60	5.05	1.64	1.40	2.21	0.30	0.27	0.21	100.00
	75.29	13.57	4.91	1.69	1.48	2.19	0.31	0.30	0.24	100.00
	75.28	13.62	4.98	1.76	1.46	2.09	0.30	0.27	0.24	100.00
	75.15	13.71	5.03	1.80	1.42	2.14	0.29	0.26	0.20	100.00
	75.14	13.86	5.01	1.73	1.35	2.16	0.27	0.21	0.27	100.00
	74.55	13.46	5.13	2.25	1.35	2.42	0.32	0.31	0.20	100.00
avg	75.40	13.66	4.92	1.70	1.38	2.15	0.29	0.25	0.23	100.00
std dev	0.33	0.17	0.12	0.15	0.05	0.08	0.03	0.07	0.03	0.00

WC11-D4 (n=27)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	75.84	13.53	4.76	1.73	1.42	2.09	0.29	0.21	0.13	100.00
	75.80	13.90	4.62	1.67	1.27	2.07	0.25	0.24	0.17	100.00
	75.79	13.84	4.69	1.61	1.27	2.08	0.27	0.31	0.13	100.00
	75.73	13.63	4.84	1.61	1.34	2.16	0.28	0.24	0.17	100.00
	75.71	13.69	4.77	1.70	1.38	2.02	0.32	0.24	0.16	100.00
	75.67	13.68	4.86	1.57	1.39	2.11	0.26	0.25	0.21	100.00
	75.63	13.48	4.93	1.74	1.41	2.08	0.28	0.28	0.17	100.00
	75.59	13.62	5.03	1.68	1.37	2.03	0.28	0.22	0.18	100.00
	75.56	13.83	4.80	1.51	1.41	2.11	0.26	0.37	0.14	100.00
	75.57	13.73	4.64	1.62	1.50	2.14	0.38	0.25	0.16	100.00
	75.52	13.63	4.85	1.59	1.49	2.16	0.33	0.27	0.16	100.00
	75.54	13.61	4.84	1.94	1.30	2.15	0.23	0.22	0.16	100.00
	75.48	13.57	5.09	1.57	1.46	1.99	0.31	0.30	0.22	100.00
	75.47	13.77	4.99	1.52	1.44	2.05	0.29	0.27	0.19	100.00
	75.49	13.78	4.88	1.82	1.29	2.08	0.29	0.22	0.14	100.00
	75.40	13.78	4.98	1.59	1.44	2.10	0.26	0.22	0.22	100.00
	75.43	13.66	5.02	1.77	1.48	2.02	0.26	0.20	0.15	100.00
	75.42	13.75	4.83	1.87	1.36	2.07	0.27	0.23	0.19	100.00
	75.35	13.75	4.77	1.81	1.37	2.20	0.29	0.25	0.20	100.00
	75.28	13.72	4.97	1.83	1.42	2.03	0.29	0.26	0.19	100.00
	75.24	13.55	4.99	1.93	1.41	2.10	0.27	0.34	0.16	100.00
	75.22	13.70	5.14	1.63	1.46	2.15	0.24	0.30	0.15	100.00
	75.17	13.66	4.89	1.98	1.32	2.06	0.27	0.22	0.42	100.00
	74.90	14.52	5.33	1.26	1.52	1.99	0.15	0.19	0.13	100.00
	74.80	13.91	4.89	1.97	1.43	2.16	0.33	0.34	0.16	100.00
	76.93	13.94	4.44	0.77	1.40	1.77	0.25	0.32	0.17	100.00
	73.27	14.71	5.01	2.23	1.99	1.85	0.43	0.31	0.18	100.00
avg	75.44	13.78	4.88	1.69	1.42	2.07	0.28	0.26	0.18	100.00
std dev	0.57	0.27	0.18	0.27	0.13	0.09	0.05	0.05	0.05	0.00

WC15-A (n=10)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.22	13.97	4.30	2.95	2.66	2.40	0.75	0.64	0.11	100.00
	72.16	14.03	4.03	3.17	2.78	2.29	0.79	0.60	0.14	100.00
	72.03	14.14	4.00	3.17	2.82	2.34	0.76	0.59	0.14	100.00
	71.97	13.86	4.49	3.13	2.73	2.31	0.77	0.61	0.14	100.00
	71.89	14.26	4.14	3.08	2.71	2.38	0.75	0.67	0.11	100.00
	71.88	14.10	4.28	3.22	2.78	2.28	0.63	0.70	0.13	100.00
	71.81	13.86	4.12	3.28	2.91	2.43	0.79	0.66	0.14	100.00
	71.77	14.23	4.28	3.13	2.63	2.49	0.73	0.61	0.12	100.00
	71.70	14.05	4.14	3.33	2.80	2.36	0.77	0.70	0.14	100.00
	71.48	14.46	4.28	3.24	2.64	2.34	0.82	0.60	0.13	100.00
avg	71.89	14.10	4.21	3.17	2.75	2.36	0.76	0.64	0.13	100.00
std dev	0.22	0.19	0.15	0.11	0.09	0.07	0.05	0.04	0.01	0.00

WC15-D (n=35)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	79.35	11.47	3.34	1.41	0.69	3.21	0.11	0.26	0.18	100.00
	79.34	11.23	3.31	1.48	0.79	3.22	0.20	0.23	0.20	100.00
	79.00	11.40	3.45	1.56	0.77	3.22	0.18	0.28	0.14	100.00
	78.91	11.45	3.65	1.39	0.58	3.34	0.18	0.31	0.20	100.00
	78.59	11.39	3.72	1.58	0.85	3.24	0.21	0.25	0.18	100.00
	78.57	11.58	3.59	1.56	0.78	3.28	0.19	0.32	0.13	100.00
	78.45	11.54	3.58	1.43	0.87	3.43	0.17	0.32	0.20	100.00
	78.43	11.72	3.78	1.54	0.82	3.23	0.11	0.27	0.09	100.00
	78.43	11.41	3.75	1.65	0.88	3.20	0.20	0.33	0.15	100.00
	78.38	11.52	3.92	1.56	0.80	3.21	0.15	0.29	0.17	100.00
	78.32	11.47	3.81	1.66	0.84	3.23	0.18	0.31	0.17	100.00
	78.25	11.48	3.67	1.82	0.91	3.34	0.17	0.30	0.06	100.00
	78.19	11.72	3.33	1.43	0.99	3.71	0.21	0.28	0.14	100.00
	78.02	11.47	3.88	1.43	0.82	3.55	0.15	0.50	0.18	100.00
	77.96	11.79	3.75	1.86	0.87	3.17	0.18	0.34	0.08	100.00
	77.74	11.43	3.95	1.87	0.85	3.50	0.18	0.32	0.15	100.00
	77.70	12.02	3.07	1.81	1.24	3.33	0.26	0.39	0.18	100.00
	77.67	11.55	4.04	1.80	1.02	3.29	0.20	0.00	0.43	100.00
	77.48	11.78	3.76	1.94	1.18	3.25	0.28	0.30	0.04	100.00
	76.90	12.05	3.26	2.04	1.22	3.73	0.29	0.38	0.12	100.00
	76.57	12.49	3.52	2.03	1.56	3.13	0.29	0.31	0.09	100.00
	76.43	12.38	3.57	2.19	1.44	3.09	0.36	0.39	0.14	100.00
	76.10	13.37	3.75	1.17	1.46	2.98	0.25	0.63	0.29	100.00
	75.88	12.51	3.72	2.24	1.64	3.13	0.38	0.37	0.12	100.00
	75.83	12.56	3.61	2.18	1.59	3.30	0.40	0.40	0.11	100.00
	75.83	12.50	3.83	2.35	1.41	3.17	0.29	0.48	0.13	100.00
	75.73	12.55	3.50	2.17	1.60	3.55	0.40	0.39	0.12	100.00
	75.59	12.81	3.60	2.24	1.87	2.92	0.38	0.48	0.10	100.00
	75.29	12.77	3.74	2.34	1.78	3.10	0.36	0.45	0.16	100.00
	75.27	13.04	3.47	2.36	1.79	3.12	0.41	0.44	0.10	100.00
	75.17	12.95	3.91	2.31	1.84	2.87	0.41	0.44	0.08	100.00
	74.97	13.01	4.00	2.56	1.92	2.43	0.47	0.57	0.06	100.00
	74.55	13.23	3.81	2.41	1.90	3.06	0.48	0.47	0.09	100.00
	74.10	13.11	3.90	2.94	2.11	2.61	0.52	0.60	0.11	100.00
	73.46	13.58	3.82	2.95	2.36	2.50	0.59	0.61	0.14	100.00
avg	77.04	12.12	3.67	1.92	1.26	3.19	0.28	0.37	0.14	100.00
std dev	1.62	0.70	0.23	0.45	0.48	0.28	0.13	0.13	0.07	0.00

WC15-E (n=13)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.11	13.59	4.08	2.76	2.40	2.63	0.66	0.60	0.16	100.00
	72.82	13.96	3.77	2.65	2.85	2.32	0.82	0.72	0.09	100.00
	72.70	13.83	4.01	3.15	2.46	2.43	0.69	0.60	0.13	100.00
	72.68	13.73	4.80	3.01	2.15	2.36	0.52	0.61	0.15	100.00
	72.30	14.05	4.07	2.88	2.69	2.44	0.75	0.69	0.13	100.00
	72.16	14.01	4.12	3.01	2.74	2.42	0.74	0.67	0.13	100.00
	72.10	14.05	4.17	2.72	2.98	2.46	0.73	0.61	0.18	100.00
	72.10	13.97	4.13	3.22	2.63	2.41	0.76	0.64	0.14	100.00
	72.01	14.04	4.33	2.98	2.73	2.43	0.76	0.60	0.12	100.00
	72.02	14.11	3.91	3.21	2.88	2.38	0.70	0.65	0.14	100.00
	71.89	14.16	4.25	3.22	2.64	2.26	0.76	0.70	0.13	100.00
	71.70	14.33	4.16	3.18	2.82	2.34	0.78	0.55	0.13	100.00
	71.50	13.82	4.42	3.42	2.62	2.44	0.79	0.81	0.17	100.00
avg	72.24	13.97	4.17	3.03	2.66	2.41	0.73	0.65	0.14	100.00
std dev	0.47	0.19	0.25	0.23	0.22	0.09	0.08	0.07	0.02	0.00

WC15-HD (n=11)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.52	13.94	4.43	2.86	2.43	2.46	0.71	0.55	0.09	100.00
	72.07	14.17	4.28	3.01	2.53	2.43	0.82	0.56	0.13	100.00
	72.05	13.99	4.26	3.13	2.67	2.53	0.68	0.55	0.15	100.00
	72.03	14.13	4.20	3.16	2.56	2.38	0.80	0.64	0.09	100.00
	71.98	13.96	4.25	3.03	2.88	2.38	0.78	0.60	0.13	100.00
	71.94	14.04	4.09	3.24	2.75	2.34	0.82	0.64	0.14	100.00
	71.91	13.90	4.32	3.17	2.63	2.48	0.77	0.68	0.14	100.00
	71.81	13.99	4.27	3.32	2.67	2.34	0.80	0.67	0.13	100.00
	71.62	13.93	4.34	3.53	2.70	2.38	0.69	0.62	0.18	100.00
	71.63	14.19	4.30	3.42	2.63	2.33	0.80	0.59	0.11	100.00
	71.35	14.22	4.45	3.15	2.86	2.41	0.79	0.65	0.12	100.00
avg	71.90	14.04	4.29	3.18	2.66	2.40	0.77	0.62	0.13	100.00
std dev	0.30	0.11	0.10	0.19	0.13	0.06	0.05	0.05	0.03	0.00

WC15-HL (n=10)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.55	13.92	4.21	2.92	2.58	2.36	0.73	0.64	0.09	100.00
	72.27	13.96	4.18	3.21	2.48	2.41	0.76	0.61	0.12	100.00
	72.20	13.87	4.30	3.22	2.50	2.45	0.75	0.59	0.13	100.00
	72.10	13.90	4.23	3.17	2.65	2.44	0.75	0.70	0.06	100.00
	72.05	13.92	4.29	3.23	2.53	2.46	0.76	0.62	0.13	100.00
	72.03	14.22	4.08	3.15	2.49	2.38	0.67	0.85	0.12	100.00
	71.98	14.04	4.18	3.29	2.56	2.43	0.73	0.67	0.12	100.00
	71.85	14.02	4.35	3.16	2.59	2.49	0.75	0.65	0.14	100.00
	71.83	13.95	4.16	3.30	2.89	2.29	0.80	0.67	0.10	100.00
	71.75	14.17	4.35	3.36	2.54	2.27	0.75	0.68	0.13	100.00
avg	72.06	14.00	4.23	3.20	2.58	2.40	0.75	0.67	0.11	100.00
std dev	0.24	0.12	0.09	0.12	0.12	0.07	0.03	0.07	0.02	0.00

WC15-I (n=21)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	75.47	12.67	4.08	2.42	1.57	2.69	0.38	0.54	0.17	100.00
	75.26	12.83	3.99	2.43	1.78	2.66	0.47	0.44	0.14	100.00
	75.19	12.68	4.06	2.64	1.58	2.86	0.36	0.53	0.09	100.00
	74.03	13.59	4.53	2.19	1.34	3.55	0.25	0.24	0.28	100.00
	73.85	13.30	4.19	2.65	2.16	2.55	0.53	0.60	0.16	100.00
	73.45	13.17	4.22	3.26	1.95	2.70	0.54	0.56	0.15	100.00
	73.03	13.65	4.17	2.96	2.38	2.39	0.68	0.57	0.17	100.00
	72.85	13.62	4.24	3.06	2.38	2.47	0.65	0.58	0.13	100.00
	72.74	13.79	4.02	3.21	2.38	2.44	0.68	0.59	0.15	100.00
	72.37	14.03	4.27	3.35	2.42	2.29	0.48	0.69	0.10	100.00
	72.36	13.76	4.07	3.17	2.68	2.32	0.72	0.76	0.17	100.00
	72.18	13.92	4.25	3.25	2.62	2.37	0.76	0.48	0.15	100.00
	72.10	13.76	4.42	3.25	2.58	2.31	0.80	0.64	0.14	100.00
	72.07	13.96	4.41	3.15	2.57	2.32	0.73	0.63	0.15	100.00
	72.04	14.05	4.25	3.28	2.71	2.20	0.74	0.59	0.13	100.00
	71.94	13.94	4.26	3.40	2.63	2.32	0.77	0.62	0.13	100.00
	71.82	13.93	4.34	3.47	2.71	2.29	0.72	0.70	0.00	100.00
	71.80	13.81	4.30	3.48	2.68	2.43	0.86	0.57	0.07	100.00
	71.80	13.95	4.15	3.45	2.81	2.28	0.77	0.67	0.11	100.00
	71.72	13.74	4.66	3.29	2.59	2.37	0.78	0.70	0.16	100.00
	71.58	13.80	4.51	3.55	2.62	2.50	0.69	0.61	0.13	100.00
avg	72.84	13.62	4.26	3.09	2.34	2.49	0.64	0.59	0.14	100.00
std dev	1.24	0.43	0.17	0.39	0.44	0.30	0.17	0.11	0.05	0.00

WC15-I Discarded Analyses (n=3)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.68	11.39	3.70	1.57	0.69	3.66	0.21	0.00	0.09	100.00
78.16	11.80	4.14	1.33	0.61	3.51	0.09	0.20	0.16	100.00
77.12	13.14	2.99	1.14	1.89	2.68	0.44	0.44	0.17	100.00

WC15-I2-P1 (n=10)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.35	11.93	3.94	1.38	0.54	3.46	0.10	0.12	0.19	100.00
	78.11	11.85	4.36	1.33	0.78	3.07	0.17	0.16	0.17	100.00
	77.38	12.20	3.82	1.80	1.19	2.76	0.28	0.41	0.15	100.00
	76.47	12.54	3.39	1.99	1.45	3.25	0.36	0.49	0.06	100.00
	76.25	12.82	3.90	1.80	1.12	3.26	0.17	0.58	0.11	100.00
	76.24	12.62	3.55	2.09	1.45	3.33	0.26	0.36	0.10	100.00
	76.15	13.04	3.65	1.63	1.47	3.30	0.35	0.41	0.00	100.00
	76.11	12.69	3.45	2.17	1.41	3.29	0.30	0.47	0.11	100.00
	76.00	12.76	3.71	2.10	0.99	3.84	0.16	0.35	0.09	100.00
	75.79	12.57	3.82	2.36	1.31	3.11	0.35	0.57	0.11	100.00
avg	76.68	12.50	3.76	1.87	1.17	3.26	0.25	0.39	0.11	100.00
std dev	0.92	0.39	0.28	0.34	0.32	0.28	0.09	0.15	0.05	0.00

WC15-I2-P2 (n=16)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	74.31	13.21	3.98	2.60	1.84	3.00	0.39	0.52	0.15	100.00
	74.13	13.49	3.99	2.64	2.05	2.51	0.54	0.51	0.15	100.00
	73.94	14.12	3.49	3.10	1.40	2.50	0.65	0.62	0.17	100.00
	73.34	13.88	3.63	2.93	2.38	2.47	0.67	0.56	0.14	100.00
	73.30	13.57	4.11	2.87	2.22	2.52	0.62	0.65	0.14	100.00
	73.02	14.40	2.43	3.50	2.63	2.50	0.72	0.67	0.13	100.00
	72.79	13.76	4.10	3.06	2.44	2.45	0.68	0.59	0.13	100.00
	72.69	13.91	3.89	3.09	2.61	2.32	0.70	0.66	0.13	100.00
	72.61	13.94	4.07	3.07	2.46	2.41	0.70	0.61	0.12	100.00
	72.54	13.78	4.08	3.32	2.57	2.33	0.68	0.51	0.19	100.00
	72.39	13.91	3.90	3.32	2.63	2.35	0.72	0.62	0.15	100.00
	72.30	13.87	4.15	3.29	2.45	2.51	0.70	0.63	0.10	100.00
	72.24	13.93	4.13	3.15	2.60	2.38	0.68	0.71	0.17	100.00
	72.20	13.90	4.20	3.28	2.63	2.31	0.69	0.66	0.13	100.00
	72.13	14.28	3.91	3.28	2.49	2.34	0.75	0.62	0.19	100.00
	71.86	14.20	4.30	3.11	2.69	2.33	0.68	0.66	0.17	100.00
avg	72.86	13.88	3.90	3.10	2.38	2.45	0.66	0.61	0.15	100.00
std dev	0.75	0.30	0.44	0.25	0.35	0.17	0.09	0.06	0.03	0.00

WC15-I3-P1 (n=14)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.31	11.90	3.79	1.20	0.65	3.59	0.09	0.22	0.26	100.00
	77.85	11.72	3.97	1.76	0.64	3.56	0.17	0.17	0.16	100.00
	76.78	12.54	3.90	2.02	0.25	3.65	0.32	0.41	0.13	100.00
	76.45	12.53	3.49	1.89	1.49	3.28	0.33	0.42	0.12	100.00
	76.38	12.45	3.89	2.15	1.34	2.79	0.33	0.59	0.08	100.00
	76.33	12.58	3.43	2.07	1.63	3.03	0.35	0.44	0.14	100.00
	76.15	12.65	3.57	1.93	1.62	3.11	0.38	0.45	0.14	100.00
	75.87	12.61	3.48	2.38	1.51	3.21	0.42	0.45	0.06	100.00
	75.66	12.57	3.59	2.39	1.67	3.16	0.39	0.49	0.07	100.00
	75.57	12.94	3.98	2.23	1.66	2.58	0.39	0.50	0.14	100.00
	75.49	12.98	3.83	1.98	1.73	3.04	0.35	0.50	0.11	100.00
	75.28	12.89	3.67	2.27	1.74	3.11	0.40	0.47	0.16	100.00
	75.24	13.80	4.45	1.89	1.57	2.25	0.32	0.33	0.15	100.00
	74.85	13.58	3.50	2.62	1.83	2.71	0.40	0.45	0.07	100.00
avg	76.16	12.70	3.75	2.06	1.38	3.07	0.33	0.42	0.13	100.00
std dev	0.98	0.55	0.28	0.34	0.49	0.40	0.09	0.11	0.05	0.00

WC15-I3-P2 (n=15)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	74.00	14.04	3.79	2.55	2.16	2.42	0.35	0.61	0.08	100.00
	73.86	13.29	3.41	2.83	2.87	2.62	0.46	0.54	0.12	100.00
	73.78	15.03	4.45	0.96	2.88	2.56	0.16	0.15	0.02	100.00
	73.65	13.51	3.87	3.01	2.18	2.38	0.61	0.66	0.13	100.00
	73.39	13.68	3.80	2.94	2.22	2.63	0.61	0.59	0.14	100.00
	73.00	13.79	4.04	2.86	2.45	2.40	0.65	0.64	0.16	100.00
	72.99	13.50	4.35	2.97	2.38	2.34	0.66	0.63	0.17	100.00
	72.92	13.79	4.04	3.09	2.20	2.56	0.61	0.65	0.14	100.00
	72.67	13.84	4.14	3.13	2.55	2.31	0.64	0.58	0.14	100.00
	72.42	13.87	3.87	3.17	2.52	2.60	0.71	0.67	0.16	100.00
	72.29	14.04	4.16	3.16	2.56	2.33	0.71	0.61	0.13	100.00
	72.22	14.08	3.86	3.17	2.70	2.39	0.81	0.62	0.14	100.00
	72.19	14.14	4.02	3.22	2.57	2.40	0.68	0.63	0.14	100.00
	71.93	14.02	4.15	3.15	2.57	2.58	0.74	0.70	0.15	100.00
	71.79	14.13	3.94	3.39	2.92	2.39	0.77	0.67	0.00	100.00
avg	72.87	13.92	4.00	2.91	2.51	2.46	0.61	0.60	0.12	100.00
std dev	0.73	0.40	0.25	0.57	0.26	0.12	0.17	0.13	0.05	0.00

WC15-J1-P1 (n=10)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.48	10.89	3.45	1.61	0.71	3.87	0.39	0.37	0.23	100.00
	77.81	12.58	3.77	1.29	1.96	1.75	0.33	0.33	0.18	100.00
	77.60	12.57	3.69	1.66	1.90	1.81	0.34	0.25	0.17	100.00
	77.56	12.57	3.75	1.53	1.91	1.83	0.31	0.32	0.21	100.00
	77.55	12.74	3.85	1.62	1.88	1.80	0.33	0.00	0.22	100.00
	77.40	12.65	3.69	1.66	1.90	1.81	0.34	0.36	0.18	100.00
	77.37	12.89	3.59	1.67	1.99	1.80	0.37	0.31	0.00	100.00
	77.21	12.50	4.02	1.92	2.00	1.86	0.03	0.26	0.19	100.00
	77.21	12.60	4.01	1.51	2.01	1.79	0.37	0.30	0.19	100.00
	77.08	12.71	3.85	1.73	1.89	1.89	0.34	0.27	0.23	100.00
avg	77.53	12.47	3.76	1.62	1.82	2.02	0.32	0.28	0.18	100.00
std dev	0.40	0.57	0.18	0.16	0.39	0.65	0.10	0.11	0.07	0.00

WC15-J1-P2 (n=8)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.00	12.93	3.33	1.91	1.83	2.99	0.41	0.46	0.14	100.00
	75.77	12.92	3.19	2.30	1.63	3.28	0.38	0.39	0.14	100.00
	75.69	12.92	3.70	2.11	1.58	3.06	0.33	0.46	0.14	100.00
	75.68	12.98	3.91	2.00	1.33	3.12	0.39	0.47	0.12	100.00
	75.51	13.75	4.75	1.60	1.35	2.20	0.29	0.34	0.20	100.00
	75.45	13.07	3.33	2.21	1.59	3.34	0.42	0.49	0.09	100.00
	75.40	13.06	3.53	2.21	1.85	2.97	0.40	0.44	0.13	100.00
	75.40	12.98	4.12	2.18	2.28	1.86	0.44	0.53	0.20	100.00
avg	75.61	13.08	3.73	2.07	1.68	2.85	0.38	0.45	0.15	100.00
std dev	0.21	0.28	0.52	0.23	0.31	0.53	0.05	0.06	0.04	0.00

WC15-J1-P3 (n=9)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.20	13.73	3.87	3.00	2.30	2.51	0.65	0.60	0.14	100.00
	72.86	13.86	4.03	3.09	2.42	2.49	0.64	0.47	0.14	100.00
	72.66	14.71	4.60	2.09	1.31	3.74	0.36	0.36	0.16	100.00
	72.59	14.20	3.68	3.06	2.58	2.36	0.72	0.65	0.16	100.00
	72.38	14.03	4.12	2.94	2.63	2.42	0.71	0.60	0.17	100.00
	71.54	14.90	4.35	2.96	1.79	3.31	0.51	0.50	0.13	100.00
	70.90	14.95	4.49	3.34	2.03	3.01	0.59	0.56	0.13	100.00
	70.72	15.05	4.23	3.48	2.01	3.16	0.61	0.60	0.14	100.00
	70.23	14.80	4.93	3.54	2.03	3.11	0.58	0.59	0.18	100.00
avg	71.90	14.47	4.26	3.06	2.12	2.90	0.60	0.55	0.15	100.00
std dev	1.07	0.51	0.38	0.43	0.42	0.48	0.11	0.09	0.02	0.00

WC15-J1 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
67.54	15.50	4.83	5.48	2.79	2.15	0.90	0.68	0.13	100.00

WC15-J2 (n=27)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	77.62	11.73	3.61	1.26	0.95	3.54	0.13	0.89	0.27	100.00
	76.47	12.33	3.51	2.22	1.37	3.21	0.29	0.48	0.12	100.00
	76.20	12.56	3.79	1.91	1.47	3.06	0.31	0.38	0.32	100.00
	76.02	12.69	3.51	2.14	1.57	3.10	0.37	0.47	0.13	100.00
	75.85	12.73	3.82	2.16	1.45	3.14	0.36	0.39	0.10	100.00
	75.50	13.67	5.01	1.67	1.36	2.18	0.30	0.10	0.21	100.00
	75.48	13.01	3.64	2.20	1.71	2.93	0.42	0.49	0.11	100.00
	75.47	12.88	3.74	2.16	1.76	2.91	0.45	0.50	0.13	100.00
	75.42	12.89	3.76	2.20	1.79	2.96	0.41	0.44	0.13	100.00
	75.32	12.96	3.80	2.43	1.61	2.94	0.37	0.45	0.11	100.00
	75.32	13.02	3.77	2.23	1.62	2.99	0.33	0.59	0.13	100.00
	75.17	13.34	5.04	1.87	0.56	3.35	0.13	0.24	0.31	100.00
	75.10	13.06	3.71	2.46	1.78	2.85	0.39	0.55	0.10	100.00
	75.07	12.85	3.71	2.32	1.75	3.29	0.41	0.46	0.13	100.00
	74.93	12.99	4.25	2.36	1.77	2.59	0.40	0.53	0.17	100.00
	74.89	13.09	3.90	2.46	1.75	2.88	0.41	0.45	0.16	100.00
	74.58	13.17	3.90	2.30	2.00	2.94	0.46	0.53	0.12	100.00
	74.58	13.06	3.42	2.83	1.81	3.17	0.47	0.53	0.13	100.00
	74.51	13.67	3.83	1.88	2.15	3.21	0.31	0.38	0.06	100.00
	73.36	13.40	4.17	2.75	1.95	2.49	0.56	0.57	0.74	100.00
	72.87	13.55	4.36	2.95	2.43	2.40	0.67	0.60	0.16	100.00
	72.51	13.77	4.11	3.34	2.39	2.41	0.66	0.65	0.15	100.00
	72.29	13.85	4.10	3.32	2.48	2.33	0.67	0.79	0.16	100.00
	72.13	13.92	4.04	3.00	2.91	2.43	0.73	0.67	0.16	100.00
	71.59	14.56	4.86	3.29	1.45	3.29	0.40	0.46	0.10	100.00
	71.54	13.92	4.70	3.32	2.58	2.31	0.71	0.72	0.19	100.00
	71.45	13.88	4.46	3.36	2.49	2.77	0.68	0.75	0.15	100.00
avg	74.49	13.21	4.02	2.46	1.81	2.88	0.44	0.52	0.18	100.00
std dev	1.67	0.59	0.46	0.56	0.51	0.37	0.16	0.16	0.13	0.00

WC15-J2 Discarded Analyses (n=2)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
67.24	15.56	5.15	5.60	2.70	2.16	0.82	0.65	0.13	100.00
64.54	14.63	4.88	7.26	3.62	2.29	1.45	1.20	0.14	100.00

WC16-X (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.85	13.21	4.20	2.76	2.05	2.62	0.56	0.58	0.16	100.00
	73.56	13.22	4.33	3.03	2.17	2.44	0.56	0.53	0.16	100.00
	73.29	13.56	4.25	2.80	2.37	2.36	0.66	0.55	0.16	100.00
	73.09	13.72	4.14	2.92	2.32	2.50	0.61	0.65	0.05	100.00
	72.90	13.77	4.32	3.03	2.34	2.26	0.59	0.61	0.17	100.00
	72.64	13.51	4.36	3.23	2.34	2.50	0.63	0.61	0.18	100.00
	72.64	13.67	4.09	3.27	2.45	2.47	0.66	0.60	0.15	100.00
	72.44	13.75	4.29	3.15	2.49	2.36	0.67	0.69	0.15	100.00
	72.29	13.71	4.41	3.27	2.40	2.34	0.69	0.60	0.29	100.00
	72.28	13.90	4.23	3.23	2.63	2.46	0.72	0.55	0.00	100.00
	72.24	13.83	4.49	3.03	2.51	2.51	0.67	0.55	0.17	100.00
	72.02	14.00	4.32	3.24	2.57	2.39	0.73	0.58	0.15	100.00
	71.99	13.77	4.27	3.40	2.73	2.32	0.67	0.67	0.18	100.00
	71.97	14.00	4.47	3.23	2.51	2.39	0.72	0.58	0.13	100.00
	71.96	13.95	4.41	3.37	2.59	2.23	0.72	0.57	0.20	100.00
	71.86	13.99	4.38	3.27	2.66	2.28	0.74	0.70	0.12	100.00
	71.82	13.89	4.48	3.46	2.56	2.17	0.75	0.73	0.13	100.00
	71.51	13.90	4.78	3.32	2.75	2.29	0.68	0.64	0.13	100.00
avg	72.46	13.74	4.35	3.17	2.47	2.38	0.67	0.61	0.15	100.00
std dev	0.65	0.24	0.15	0.20	0.19	0.12	0.06	0.06	0.06	0.00

WC16-X Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.03	11.60	3.76	1.76	0.87	3.32	0.17	0.35	0.14	100.00

WC3-26-P1 (n=6)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.86	11.88	3.96	1.16	0.74	3.06	0.08	0.03	0.21	100.00
	78.47	12.01	4.16	1.14	0.68	3.07	0.10	0.13	0.22	100.00
	78.42	11.96	4.31	1.14	0.73	3.16	0.09	0.13	0.06	100.00
	78.32	11.93	4.39	1.04	0.71	3.07	0.13	0.17	0.24	100.00
	78.31	12.05	4.16	1.10	0.74	3.14	0.13	0.12	0.24	100.00
	78.08	12.10	4.16	1.23	0.81	3.15	0.10	0.11	0.26	100.00
avg	78.41	11.99	4.19	1.14	0.74	3.11	0.11	0.12	0.21	100.00
std dev	0.26	0.08	0.14	0.07	0.04	0.05	0.02	0.05	0.07	0.00

WC3-26-P2 (n=12)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.39	12.20	3.98	2.01	1.54	3.08	0.21	0.43	0.16	100.00
	75.63	12.79	3.86	2.12	1.78	2.94	0.37	0.39	0.12	100.00
	75.22	13.41	4.88	1.42	1.77	2.54	0.23	0.46	0.07	100.00
	75.03	12.95	3.73	2.41	1.99	2.87	0.42	0.49	0.11	100.00
	74.29	13.45	3.48	2.52	2.25	2.76	0.55	0.59	0.12	100.00
	73.65	13.45	4.44	2.55	2.13	2.41	0.62	0.62	0.13	100.00
	73.17	13.72	4.35	2.64	2.32	2.40	0.65	0.58	0.17	100.00
	72.86	14.05	4.20	2.74	2.35	2.36	0.61	0.69	0.14	100.00
	72.81	14.53	4.69	2.13	1.39	3.51	0.39	0.43	0.11	100.00
	72.45	13.78	4.07	3.09	2.69	2.47	0.72	0.60	0.13	100.00
	72.10	14.06	4.38	3.03	2.58	2.40	0.69	0.61	0.15	100.00
	71.89	13.91	4.23	3.13	2.86	2.41	0.78	0.63	0.15	100.00
avg	73.79	13.52	4.19	2.48	2.14	2.68	0.52	0.54	0.13	100.00
std dev	1.49	0.64	0.40	0.51	0.46	0.36	0.19	0.10	0.03	0.00

WC3-26 Discarded Analyses (n=4)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
66.50	15.68	4.90	4.64	3.43	2.57	1.26	0.88	0.13	100.00
65.03	15.42	4.69	5.30	4.38	2.28	1.70	1.09	0.12	100.00
64.41	15.77	4.71	5.72	4.47	2.13	1.75	0.92	0.12	100.00
58.88	16.28	4.36	8.17	6.36	1.65	2.94	1.26	0.10	100.00

WC3-55/62 (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	77.02	12.32	3.78	1.64	1.43	3.05	0.27	0.38	0.12	100.00
	76.74	12.70	3.67	1.73	1.39	3.03	0.35	0.36	0.03	100.00
	76.52	12.55	3.91	1.63	1.42	3.28	0.24	0.30	0.15	100.00
	76.20	12.60	3.83	1.93	1.59	2.91	0.33	0.46	0.13	100.00
	76.14	12.61	3.71	2.18	1.56	2.92	0.34	0.41	0.12	100.00
	76.10	12.78	3.65	2.15	1.60	2.93	0.33	0.45	0.00	100.00
	76.05	12.50	4.01	2.06	1.52	2.88	0.34	0.44	0.20	100.00
	75.83	12.65	3.86	2.19	1.61	2.96	0.37	0.39	0.13	100.00
	75.83	12.77	3.69	2.24	1.69	2.83	0.37	0.42	0.14	100.00
	75.76	12.94	3.80	2.14	1.55	2.94	0.34	0.46	0.07	100.00
	75.75	12.67	3.85	2.14	1.56	2.95	0.40	0.54	0.13	100.00
	75.68	12.79	3.69	2.05	1.75	3.07	0.39	0.40	0.16	100.00
	75.50	12.88	3.79	2.11	1.60	3.07	0.45	0.46	0.13	100.00
	75.42	12.88	3.56	2.12	1.65	3.44	0.31	0.47	0.14	100.00
	75.36	13.04	3.69	2.20	1.72	2.92	0.41	0.52	0.13	100.00
	75.33	13.04	3.70	2.16	1.78	3.00	0.39	0.49	0.12	100.00
	75.28	13.01	3.89	2.11	1.87	2.81	0.39	0.45	0.18	100.00
	75.02	12.95	3.80	2.30	1.87	2.86	0.45	0.51	0.24	100.00
avg	75.86	12.76	3.77	2.06	1.62	2.99	0.36	0.44	0.13	100.00
std dev	0.53	0.20	0.11	0.20	0.14	0.16	0.06	0.06	0.06	0.00

WC3-91-P1 (n=20)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	70.05	15.00	4.55	3.37	2.57	2.77	0.81	0.73	0.14	100.00
	69.33	14.56	4.38	4.13	2.46	3.17	0.88	0.94	0.14	100.00
	69.26	14.75	4.60	4.00	2.42	3.03	0.88	0.90	0.15	100.00
	69.22	14.77	4.98	3.79	2.79	2.62	0.93	0.73	0.16	100.00
	68.82	14.78	4.75	3.84	2.61	3.11	0.84	0.95	0.28	100.00
	68.61	14.62	4.62	4.42	2.51	2.96	0.95	0.90	0.39	100.00
	68.42	14.83	4.39	4.49	2.87	2.93	1.08	0.86	0.12	100.00
	68.11	14.82	4.73	4.49	2.93	2.71	1.03	1.04	0.13	100.00
	67.90	15.01	4.76	4.56	2.87	2.85	1.06	0.98	0.00	100.00
	67.81	14.65	4.57	5.03	2.98	2.78	1.01	1.02	0.17	100.00
	67.55	14.95	4.60	4.59	2.84	3.00	1.00	1.30	0.16	100.00
	67.21	15.62	4.78	4.55	3.14	2.58	1.16	0.77	0.19	100.00
	67.19	14.77	4.74	4.94	2.98	3.10	1.06	1.05	0.18	100.00
	67.01	15.69	4.47	4.62	3.41	2.57	1.24	0.84	0.14	100.00
	66.08	14.85	4.81	5.65	3.45	2.51	1.44	1.01	0.20	100.00
	65.96	15.48	4.62	5.21	3.81	2.33	1.59	0.85	0.14	100.00
	65.60	15.66	4.96	5.09	3.79	2.41	1.40	0.96	0.14	100.00
	65.33	15.50	4.66	5.52	3.92	2.23	1.52	0.93	0.38	100.00
	64.86	15.61	4.54	5.53	4.49	2.13	1.83	0.91	0.11	100.00
	63.88	15.66	4.87	5.85	4.45	2.19	1.88	1.04	0.17	100.00
avg	67.41	15.08	4.67	4.68	3.17	2.70	1.18	0.94	0.18	100.00
std dev	1.68	0.41	0.17	0.67	0.63	0.32	0.32	0.13	0.09	0.00

WC3-91-P2 (n=11)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	59.98	15.28	4.43	8.61	5.61	1.99	2.52	1.19	0.37	100.00
	59.74	15.98	4.49	7.76	6.06	1.91	2.76	1.10	0.20	100.00
	59.61	16.69	4.72	7.68	6.23	1.78	2.01	1.23	0.05	100.00
	59.22	16.07	4.22	8.03	6.48	1.64	3.00	1.24	0.11	100.00
	59.08	15.94	4.43	8.33	6.34	1.69	2.95	1.11	0.14	100.00
	58.86	16.36	4.33	7.93	6.60	1.60	3.07	1.16	0.09	100.00
	58.85	16.36	4.16	8.25	6.55	1.60	2.94	1.21	0.08	100.00
	58.80	16.25	4.19	8.39	6.52	1.58	3.03	1.16	0.08	100.00
	58.45	16.19	3.81	8.55	6.93	1.46	3.16	1.34	0.11	100.00
	58.28	16.24	4.07	8.51	6.72	1.65	3.30	1.15	0.08	100.00
	58.22	16.02	4.22	8.63	6.93	1.46	3.22	1.18	0.11	100.00
avg	59.01	16.13	4.28	8.24	6.45	1.67	2.90	1.19	0.13	100.00
std dev	0.59	0.35	0.24	0.34	0.39	0.16	0.37	0.07	0.09	0.00

WC3-91 Discarded Analyses (n=3)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.33	11.95	4.19	1.23	0.79	3.09	0.11	0.14	0.18	100.00
75.90	12.66	3.72	2.12	1.71	2.98	0.40	0.40	0.11	100.00
72.77	14.60	4.95	1.98	1.48	3.24	0.35	0.41	0.21	100.00

WC34-X (n=21)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	74.18	13.62	3.91	2.34	2.17	2.51	0.55	0.60	0.13	100.00
	73.62	13.62	3.88	2.64	2.30	2.58	0.60	0.59	0.17	100.00
	73.34	13.64	4.05	2.57	2.47	2.51	0.64	0.64	0.14	100.00
	73.27	13.69	4.12	2.73	2.28	2.52	0.67	0.58	0.14	100.00
	73.27	13.70	4.02	2.94	2.27	2.57	0.58	0.64	0.00	100.00
	73.25	13.71	3.87	2.85	2.45	2.48	0.66	0.59	0.13	100.00
	73.12	13.84	4.14	2.65	2.31	2.57	0.60	0.65	0.12	100.00
	73.12	13.65	4.33	2.78	2.37	2.52	0.64	0.59	0.00	100.00
	72.90	13.94	3.90	2.81	2.52	2.47	0.70	0.65	0.10	100.00
	72.70	13.80	4.23	3.03	2.53	2.30	0.68	0.60	0.13	100.00
	72.69	13.86	3.94	3.02	2.61	2.37	0.72	0.66	0.13	100.00
	72.67	14.04	3.76	3.19	2.42	2.40	0.74	0.64	0.14	100.00
	72.61	13.72	4.33	2.98	2.41	2.50	0.66	0.64	0.14	100.00
	72.62	14.01	3.94	3.13	2.55	2.43	0.79	0.39	0.14	100.00
	72.47	14.02	4.06	2.92	2.58	2.48	0.75	0.60	0.12	100.00
	72.39	13.78	3.82	3.32	2.63	2.49	0.79	0.66	0.12	100.00
	72.16	14.03	4.18	3.12	2.69	2.39	0.70	0.61	0.12	100.00
	72.16	14.07	4.03	3.22	2.61	2.42	0.71	0.63	0.15	100.00
	72.10	14.04	4.22	3.12	2.58	2.47	0.67	0.62	0.18	100.00
	72.09	14.23	4.20	2.97	2.71	2.35	0.72	0.62	0.11	100.00
	71.45	14.21	4.19	3.40	2.70	2.50	0.75	0.66	0.14	100.00
avg	72.77	13.87	4.06	2.94	2.48	2.47	0.68	0.61	0.12	100.00
std dev	0.62	0.20	0.17	0.26	0.16	0.07	0.07	0.06	0.04	0.00

WC34-Z2 (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	75.80	12.83	3.65	2.27	1.63	2.92	0.31	0.48	0.11	100.00
	75.49	13.75	4.76	1.69	1.39	2.17	0.27	0.29	0.19	100.00
	75.49	13.09	4.31	1.88	1.48	2.82	0.34	0.38	0.21	100.00
	75.42	13.68	4.85	1.64	1.43	2.28	0.28	0.24	0.17	100.00
	75.29	12.99	3.81	2.34	1.79	2.77	0.41	0.51	0.08	100.00
	75.25	13.68	5.14	1.62	1.39	2.07	0.32	0.33	0.19	100.00
	75.05	13.00	3.86	2.68	1.61	2.96	0.31	0.46	0.06	100.00
	75.04	13.21	3.37	2.53	1.91	2.84	0.47	0.53	0.11	100.00
	75.02	13.00	3.88	2.21	1.83	2.91	0.46	0.57	0.12	100.00
	74.96	13.22	3.39	2.67	1.96	2.86	0.45	0.49	0.00	100.00
	74.88	13.15	3.88	2.37	1.93	2.90	0.45	0.44	0.00	100.00
	74.77	13.24	3.88	2.29	2.02	2.88	0.38	0.42	0.12	100.00
	74.72	12.42	3.86	2.71	1.26	3.89	0.45	0.53	0.15	100.00
	74.64	13.29	3.80	2.51	2.02	2.75	0.36	0.53	0.10	100.00
	74.63	13.31	3.66	2.49	1.97	2.92	0.47	0.45	0.11	100.00
	74.40	12.99	3.83	2.74	1.90	2.98	0.39	0.56	0.20	100.00
	73.56	13.54	4.34	2.70	2.15	2.46	0.57	0.57	0.11	100.00
	72.24	13.74	4.41	3.22	2.55	2.34	0.74	0.60	0.16	100.00
avg	74.81	13.23	4.04	2.37	1.79	2.76	0.41	0.47	0.12	100.00
std dev	0.81	0.35	0.49	0.43	0.32	0.41	0.11	0.10	0.06	0.00

WC34-Z2 Discarded Analyses (n=2)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.50	11.72	4.17	1.29	0.62	3.41	0.11	0.00	0.19	100.00
67.38	15.37	4.99	5.21	2.82	2.41	0.86	0.67	0.28	100.00

WC34-Z5-P1 (n=35)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.88	11.73	1.86	1.79	0.26	4.97	0.10	0.38	0.02	100.00
	78.67	11.67	3.64	1.50	0.83	3.11	0.15	0.23	0.20	100.00
	78.48	11.87	4.09	1.07	0.62	3.41	0.08	0.16	0.20	100.00
	78.35	11.51	3.94	1.47	0.79	3.21	0.15	0.39	0.20	100.00
	78.34	11.50	3.93	1.55	0.81	3.38	0.14	0.30	0.06	100.00
	78.22	11.58	3.72	1.59	0.80	3.40	0.20	0.31	0.19	100.00
	77.95	11.84	4.09	1.56	0.95	3.05	0.16	0.24	0.16	100.00
	77.92	11.65	3.91	1.58	0.80	3.27	0.15	0.53	0.20	100.00
	77.83	12.01	3.90	1.62	0.96	3.18	0.20	0.17	0.13	100.00
	77.54	12.97	3.86	1.25	1.87	1.78	0.29	0.20	0.24	100.00
	77.40	11.52	3.70	2.03	0.79	3.91	0.20	0.39	0.06	100.00
	77.05	11.44	2.84	1.82	0.37	5.60	0.07	0.51	0.30	100.00
	77.00	13.10	3.89	1.59	2.07	1.41	0.46	0.22	0.26	100.00
	76.99	12.14	3.52	1.37	1.09	4.36	0.23	0.31	0.00	100.00
	76.27	12.45	3.64	1.98	1.32	3.48	0.32	0.36	0.18	100.00
	76.23	12.54	3.49	1.98	1.61	3.25	0.40	0.41	0.09	100.00
	76.12	12.67	3.80	1.89	1.55	3.17	0.30	0.38	0.12	100.00
	76.03	12.62	3.99	1.99	1.46	3.11	0.32	0.41	0.07	100.00
	75.90	12.72	3.95	1.52	1.09	4.10	0.10	0.32	0.30	100.00
	75.85	12.68	3.91	1.98	1.60	3.05	0.42	0.41	0.10	100.00
	75.69	13.04	3.53	2.17	1.60	3.04	0.41	0.44	0.08	100.00
	75.69	13.30	4.49	1.99	1.61	2.28	0.22	0.34	0.08	100.00
	75.65	13.01	3.89	2.08	1.53	2.97	0.30	0.42	0.15	100.00
	75.60	12.78	3.91	2.09	1.56	3.20	0.37	0.43	0.06	100.00
	75.57	13.61	4.79	1.69	1.39	2.24	0.33	0.22	0.16	100.00
	75.57	13.08	3.72	2.01	1.66	3.07	0.38	0.38	0.13	100.00
	75.56	13.04	3.93	1.99	1.69	2.89	0.31	0.38	0.21	100.00
	75.45	12.97	3.66	2.23	1.79	2.96	0.40	0.45	0.09	100.00
	75.33	13.06	3.88	2.28	1.75	2.89	0.36	0.44	0.00	100.00
	75.24	12.92	3.80	2.35	1.75	2.95	0.39	0.46	0.14	100.00
	75.13	12.82	3.57	2.49	1.71	3.10	0.43	0.58	0.16	100.00
	75.08	13.58	4.99	1.71	1.43	2.41	0.27	0.33	0.19	100.00
	74.94	13.62	5.12	1.75	1.45	2.29	0.25	0.42	0.16	100.00
	74.53	13.45	4.67	2.12	1.86	2.42	0.20	0.61	0.14	100.00
	74.13	13.15	4.05	2.88	1.72	3.11	0.35	0.49	0.12	100.00
avg	76.46	12.56	3.87	1.86	1.32	3.14	0.27	0.37	0.14	100.00
std dev	1.32	0.69	0.56	0.37	0.47	0.79	0.11	0.11	0.08	0.00

WC34-Z5-P2 (n=6)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.51	13.81	4.08	3.15	2.36	2.40	0.66	0.60	0.42	100.00
	72.12	12.80	4.05	4.14	2.41	2.62	0.68	0.77	0.40	100.00
	71.73	13.97	4.34	3.37	2.75	2.38	0.71	0.64	0.11	100.00
	71.63	13.96	4.43	3.45	2.64	2.38	0.74	0.63	0.13	100.00
	71.52	15.01	5.09	2.54	1.42	3.39	0.31	0.55	0.16	100.00
	71.24	14.76	4.57	2.58	1.82	3.74	0.64	0.59	0.05	100.00
avg	71.79	14.05	4.43	3.21	2.23	2.82	0.63	0.63	0.21	100.00
std dev	0.45	0.78	0.38	0.60	0.51	0.60	0.16	0.08	0.16	0.00

WC34-Z5-P3 (n=4)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	66.80	15.31	5.01	4.76	3.20	2.55	1.26	1.01	0.11	100.00
	66.32	15.27	5.16	4.98	3.28	2.60	1.25	0.98	0.17	100.00
	66.27	15.44	4.89	5.01	3.38	2.47	1.36	1.05	0.15	100.00
	65.89	15.29	4.87	5.26	3.38	2.72	1.23	1.24	0.14	100.00
avg	66.32	15.33	4.98	5.00	3.31	2.59	1.27	1.07	0.14	100.00
std dev	0.37	0.07	0.13	0.20	0.09	0.10	0.06	0.12	0.03	0.00

WC34-Z5 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
56.24	26.42	5.87	0.84	9.89	0.34	0.11	0.11	0.19	100.00

WC34-Z6 (n=24)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.20	11.62	3.78	1.55	0.78	3.44	0.15	0.36	0.13	100.00
	77.90	12.51	3.80	1.45	1.94	1.59	0.35	0.28	0.18	100.00
	77.46	12.39	4.08	1.61	1.81	1.76	0.37	0.25	0.26	100.00
	77.43	12.46	4.01	1.70	1.87	1.71	0.30	0.30	0.22	100.00
	77.35	11.80	2.93	1.28	0.25	5.83	0.11	0.30	0.15	100.00
	77.28	12.47	3.95	1.66	1.82	1.94	0.39	0.25	0.23	100.00
	77.26	12.68	4.02	1.51	1.93	1.79	0.32	0.33	0.16	100.00
	77.24	12.49	4.00	1.80	1.86	1.83	0.31	0.26	0.20	100.00
	77.23	12.56	4.05	1.69	1.87	1.82	0.34	0.43	0.00	100.00
	77.15	12.52	4.00	1.61	2.00	1.81	0.35	0.38	0.17	100.00
	77.12	12.64	4.03	1.64	1.86	1.77	0.36	0.34	0.23	100.00
	76.95	12.54	3.90	1.66	1.87	1.85	0.40	0.59	0.24	100.00
	76.93	12.59	4.11	1.58	2.08	1.84	0.40	0.27	0.19	100.00
	76.89	12.53	3.98	1.90	2.02	1.76	0.35	0.33	0.23	100.00
	76.79	12.62	3.98	1.98	1.93	1.73	0.43	0.29	0.25	100.00
	76.58	12.62	4.14	1.72	1.86	1.81	0.37	0.27	0.62	100.00
	75.89	12.94	3.73	1.96	1.59	2.96	0.35	0.48	0.10	100.00
	75.79	13.03	4.01	2.12	2.26	1.84	0.46	0.30	0.18	100.00
	75.51	12.76	3.95	2.36	1.50	3.09	0.35	0.38	0.09	100.00
	75.46	12.91	3.74	2.28	1.60	2.89	0.39	0.59	0.13	100.00
	75.42	13.64	4.98	1.56	1.37	2.24	0.29	0.28	0.21	100.00
	75.38	12.75	3.90	2.26	1.65	3.16	0.39	0.36	0.14	100.00
	75.19	12.95	3.96	2.16	1.64	3.00	0.33	0.42	0.35	100.00
	74.41	13.17	3.51	1.79	1.33	4.73	0.23	0.58	0.26	100.00
avg	76.62	12.63	3.94	1.78	1.70	2.43	0.34	0.36	0.21	100.00
std dev	0.98	0.40	0.33	0.29	0.43	1.06	0.08	0.11	0.11	0.00

WC34-Z6 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
79.98	11.68	3.29	1.14	0.92	2.50	0.11	0.25	0.12	100.00

WC34-Z8 (n=16)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.26	12.44	3.88	2.05	1.36	3.16	0.27	0.42	0.15	100.00
	76.11	12.62	3.87	2.07	1.41	3.08	0.31	0.37	0.15	100.00
	75.83	12.73	3.70	2.17	1.70	2.94	0.37	0.41	0.14	100.00
	75.73	12.70	3.82	2.16	1.56	3.03	0.41	0.45	0.14	100.00
	75.59	12.98	3.69	2.08	1.71	2.97	0.41	0.44	0.12	100.00
	75.58	12.72	3.84	2.26	1.78	2.92	0.38	0.50	0.03	100.00
	75.57	12.85	3.80	2.25	1.77	2.88	0.36	0.42	0.11	100.00
	75.56	12.65	3.86	2.14	1.85	2.89	0.49	0.41	0.13	100.00
	75.51	12.91	3.84	2.29	1.62	2.95	0.35	0.39	0.13	100.00
	75.41	12.89	3.77	2.34	1.70	2.92	0.36	0.43	0.16	100.00
	75.41	12.78	3.52	2.44	1.70	2.93	0.41	0.46	0.35	100.00
	75.27	13.00	3.81	2.21	1.66	2.91	0.40	0.48	0.25	100.00
	75.24	12.77	4.09	2.20	1.75	3.00	0.39	0.42	0.15	100.00
	75.20	12.87	3.92	2.28	1.69	2.98	0.42	0.43	0.19	100.00
	75.14	12.89	3.74	2.34	1.85	3.00	0.41	0.46	0.15	100.00
	75.09	13.07	3.83	2.26	1.79	2.97	0.35	0.46	0.17	100.00
avg	75.53	12.80	3.81	2.22	1.68	2.97	0.38	0.44	0.16	100.00
std dev	0.33	0.16	0.12	0.11	0.14	0.07	0.05	0.03	0.07	0.00

WC34-Z9-P1 (n=28)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.80	11.41	3.74	1.35	0.79	3.22	0.16	0.35	0.18	100.00
	78.35	11.52	3.74	1.54	0.87	3.27	0.18	0.28	0.26	100.00
	78.33	12.10	3.75	0.71	0.99	3.76	0.19	0.12	0.05	100.00
	78.29	11.60	2.48	1.65	0.34	5.22	0.07	0.34	0.00	100.00
	78.22	11.51	3.80	1.76	0.81	3.34	0.16	0.23	0.18	100.00
	77.91	11.54	3.83	1.65	0.75	3.39	0.16	0.57	0.20	100.00
	77.77	12.51	4.32	1.05	0.98	2.82	0.20	0.22	0.13	100.00
	77.32	12.21	3.69	1.79	1.20	3.10	0.28	0.40	0.01	100.00
	76.95	11.66	2.79	1.72	0.48	5.83	0.07	0.36	0.14	100.00
	76.84	12.96	4.26	1.73	1.33	2.11	0.32	0.27	0.18	100.00
	76.42	12.38	3.82	1.70	1.39	3.21	0.31	0.38	0.39	100.00
	76.39	12.46	4.05	1.30	0.76	4.44	0.13	0.34	0.13	100.00
	75.58	13.72	4.69	1.70	1.32	2.16	0.33	0.29	0.21	100.00
	75.57	13.60	5.01	1.58	1.36	2.16	0.31	0.25	0.17	100.00
	75.44	12.88	3.73	2.11	1.79	2.96	0.42	0.55	0.12	100.00
	75.42	13.67	5.02	1.54	1.44	2.19	0.31	0.26	0.16	100.00
	75.39	13.67	4.86	1.79	1.39	2.18	0.32	0.26	0.13	100.00
	75.34	13.71	4.89	1.75	1.37	2.19	0.31	0.28	0.17	100.00
	75.31	12.83	3.98	2.09	1.67	2.93	0.39	0.64	0.15	100.00
	75.22	13.61	4.74	1.73	1.37	2.57	0.27	0.27	0.22	100.00
	75.17	13.87	5.05	1.67	1.35	2.17	0.28	0.28	0.17	100.00
	75.14	12.94	3.90	2.22	1.75	2.91	0.37	0.43	0.34	100.00
	75.06	13.78	5.09	1.69	1.40	2.23	0.32	0.29	0.15	100.00
	74.39	13.62	4.16	2.20	2.07	2.71	0.23	0.49	0.12	100.00
	74.37	13.35	4.21	1.77	0.78	5.08	0.07	0.05	0.32	100.00
	73.55	13.88	4.16	2.49	2.20	2.73	0.46	0.52	0.00	100.00
	72.56	13.97	4.16	3.01	2.53	2.36	0.63	0.61	0.18	100.00
	72.16	13.60	4.60	3.20	2.49	2.47	0.66	0.66	0.15	100.00
avg	75.97	12.88	4.16	1.80	1.32	3.06	0.28	0.36	0.16	100.00
std dev	1.75	0.89	0.64	0.51	0.55	1.00	0.15	0.15	0.09	0.00

WC34-Z9-P2 (n=3)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	67.72	15.90	4.56	4.19	3.17	2.51	1.13	0.66	0.16	100.00
	67.65	15.67	4.56	4.34	3.06	2.59	1.10	0.89	0.14	100.00
	67.21	15.77	4.80	4.30	3.34	2.47	1.11	0.86	0.14	100.00
avg	67.53	15.78	4.64	4.28	3.19	2.52	1.12	0.80	0.15	100.00
std dev	0.28	0.12	0.14	0.08	0.14	0.06	0.02	0.12	0.01	0.00

WC36-SI (n=35)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.20	13.75	4.30	2.56	2.34	2.41	0.67	0.67	0.10	100.00
	73.06	13.71	4.24	2.99	2.43	2.32	0.62	0.56	0.09	100.00
	72.89	13.69	4.37	2.84	2.40	2.37	0.65	0.71	0.08	100.00
	72.85	13.77	4.26	3.15	2.46	2.28	0.71	0.40	0.10	100.00
	72.84	13.86	4.11	2.97	2.43	2.34	0.75	0.64	0.06	100.00
	72.75	13.71	4.30	2.91	2.34	2.62	0.67	0.59	0.10	100.00
	72.72	13.88	4.22	2.88	2.50	2.28	0.74	0.70	0.07	100.00
	72.70	13.84	4.38	2.93	2.39	2.40	0.70	0.57	0.09	100.00
	72.67	13.92	4.31	2.94	2.39	2.32	0.68	0.62	0.14	100.00
	72.63	13.95	4.32	2.98	2.45	2.38	0.68	0.52	0.09	100.00
	72.54	13.83	4.38	2.95	2.52	2.37	0.68	0.56	0.17	100.00
	72.50	14.02	4.39	2.97	2.38	2.38	0.58	0.65	0.12	100.00
	72.48	13.88	4.19	3.08	2.61	2.40	0.73	0.55	0.08	100.00
	72.46	13.75	4.26	3.11	2.56	2.33	0.72	0.66	0.15	100.00
	72.41	13.84	4.50	2.91	2.56	2.32	0.78	0.61	0.07	100.00
	72.41	13.85	4.39	3.08	2.63	2.38	0.71	0.41	0.14	100.00
	72.41	14.05	4.12	3.08	2.61	2.28	0.77	0.60	0.08	100.00
	72.41	13.99	4.31	3.06	2.55	2.26	0.65	0.70	0.06	100.00
	72.28	13.98	4.36	2.90	2.46	2.47	0.68	0.67	0.19	100.00
	72.29	13.99	4.40	3.09	2.62	2.24	0.67	0.69	0.00	100.00
	72.26	13.77	4.33	3.23	2.62	2.34	0.70	0.59	0.16	100.00
	72.26	13.79	4.35	3.38	2.49	2.39	0.72	0.62	0.00	100.00
	72.22	13.86	4.42	3.15	2.54	2.34	0.72	0.68	0.07	100.00
	72.18	13.94	4.35	3.30	2.47	2.32	0.66	0.63	0.15	100.00
	72.07	14.05	4.43	3.10	2.59	2.24	0.74	0.66	0.12	100.00
	72.10	13.93	4.27	3.35	2.59	2.35	0.69	0.63	0.09	100.00
	72.07	13.95	4.37	3.21	2.53	2.34	0.75	0.67	0.11	100.00
	72.05	14.01	4.28	3.29	2.64	2.32	0.72	0.65	0.04	100.00
	72.02	13.97	4.40	2.85	2.42	2.36	0.67	0.68	0.62	100.00
	72.05	13.51	4.47	3.28	2.70	2.43	0.71	0.69	0.16	100.00
	71.91	13.99	4.35	3.41	2.41	2.40	0.72	0.68	0.14	100.00
	71.84	14.10	4.24	3.57	2.60	2.23	0.68	0.60	0.14	100.00
	71.80	14.02	4.27	3.40	2.68	2.27	0.82	0.65	0.09	100.00
	71.51	13.92	4.53	3.63	2.53	2.34	0.75	0.66	0.12	100.00
	71.19	13.66	4.43	3.99	2.59	2.65	0.73	0.65	0.11	100.00
avg	72.34	13.88	4.33	3.13	2.51	2.36	0.71	0.62	0.12	100.00
std dev	0.42	0.13	0.09	0.27	0.10	0.09	0.05	0.07	0.10	0.00

WC4-50 (n=23)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	77.39	12.26	3.73	1.61	1.07	3.34	0.18	0.26	0.16	100.00
	77.10	12.42	3.61	1.59	1.33	3.23	0.26	0.35	0.11	100.00
	76.92	12.41	3.75	1.59	1.31	3.26	0.26	0.34	0.17	100.00
	76.29	12.82	3.82	1.71	1.44	3.07	0.37	0.34	0.14	100.00
	76.13	12.79	3.80	1.90	1.52	2.93	0.34	0.44	0.15	100.00
	76.03	12.82	3.72	2.04	1.59	3.00	0.38	0.41	0.01	100.00
	75.98	12.60	3.94	2.04	1.57	3.06	0.37	0.32	0.12	100.00
	75.97	12.79	3.89	1.94	1.52	2.93	0.33	0.48	0.15	100.00
	75.93	12.78	3.90	2.00	1.60	2.97	0.31	0.37	0.14	100.00
	75.92	12.79	3.58	2.16	1.58	3.04	0.38	0.44	0.11	100.00
	75.86	12.81	3.79	1.95	1.65	3.00	0.38	0.40	0.16	100.00
	75.81	12.84	3.75	1.91	1.62	3.06	0.37	0.44	0.20	100.00
	75.70	12.90	4.00	2.01	1.64	2.90	0.34	0.40	0.11	100.00
	75.64	12.80	3.87	2.17	1.58	3.02	0.34	0.46	0.11	100.00
	75.56	12.78	3.89	2.19	1.67	2.94	0.41	0.45	0.11	100.00
	75.53	12.98	3.86	2.24	1.68	2.94	0.35	0.39	0.03	100.00
	75.46	12.81	3.80	2.17	1.69	3.13	0.39	0.41	0.13	100.00
	75.43	12.89	3.63	2.37	1.83	2.80	0.39	0.48	0.17	100.00
	75.26	12.78	4.08	2.20	1.70	2.89	0.36	0.44	0.29	100.00
	75.07	12.84	3.89	2.42	1.74	2.92	0.45	0.50	0.16	100.00
	75.03	12.87	3.67	2.53	1.76	2.95	0.41	0.48	0.29	100.00
	74.86	13.02	3.71	2.23	1.84	3.17	0.43	0.59	0.14	100.00
	74.69	12.95	3.85	2.43	1.90	3.10	0.44	0.50	0.13	100.00
avg	75.81	12.77	3.80	2.06	1.60	3.03	0.36	0.42	0.14	100.00
std dev	0.67	0.18	0.12	0.27	0.19	0.13	0.06	0.07	0.06	0.00

WC4-50 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
55.61	27.45	5.74	0.40	10.54	0.21	0.04	0.00	0.00	100.00

WC4-90s-P1 (n=17)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.75	14.24	5.00	2.28	1.40	3.38	0.34	0.43	0.17	100.00
	72.33	14.45	4.90	2.30	1.35	3.68	0.35	0.47	0.16	100.00
	71.88	15.04	4.97	2.45	1.71	2.93	0.46	0.40	0.15	100.00
	71.84	14.90	5.29	2.29	1.61	3.07	0.45	0.43	0.12	100.00
	71.75	14.96	5.24	2.28	1.60	2.99	0.44	0.54	0.19	100.00
	71.70	15.26	5.21	1.92	1.88	2.98	0.48	0.41	0.16	100.00
	71.64	14.97	5.44	2.21	1.60	2.98	0.48	0.52	0.16	100.00
	71.63	15.08	5.21	2.30	1.70	2.88	0.52	0.45	0.22	100.00
	71.47	15.08	5.20	2.28	1.72	2.91	0.56	0.54	0.22	100.00
	71.42	15.29	5.07	2.40	1.64	3.00	0.55	0.49	0.13	100.00
	71.40	15.21	5.53	2.26	1.80	2.81	0.34	0.47	0.18	100.00
	71.27	14.98	4.67	2.66	1.53	3.67	0.54	0.56	0.10	100.00
	71.23	15.11	5.34	2.52	1.91	2.80	0.53	0.46	0.10	100.00
	71.18	14.59	4.98	2.99	1.76	3.32	0.48	0.57	0.13	100.00
	71.08	15.18	5.30	2.48	1.88	2.94	0.49	0.47	0.18	100.00
	71.05	15.06	5.51	2.50	1.72	3.01	0.47	0.46	0.21	100.00
	70.97	15.19	5.12	2.64	1.89	2.93	0.61	0.51	0.13	100.00
avg	71.56	14.98	5.18	2.40	1.69	3.07	0.48	0.48	0.16	100.00
std dev	0.47	0.29	0.23	0.23	0.16	0.27	0.08	0.05	0.04	0.00

WC4-90s-P2 (n=6)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	60.45	16.55	4.92	6.46	5.94	1.67	2.47	1.36	0.18	100.00
	60.05	16.34	4.77	7.11	5.87	1.64	2.67	1.39	0.16	100.00
	59.26	16.42	4.63	7.41	6.45	1.58	2.86	1.28	0.10	100.00
	58.97	16.42	4.70	7.76	6.32	1.40	2.85	1.42	0.15	100.00
	58.86	16.55	4.48	7.43	6.64	1.57	3.10	1.23	0.14	100.00
	58.48	16.49	4.84	7.71	6.60	1.47	2.94	1.35	0.12	100.00
avg	59.34	16.46	4.72	7.31	6.30	1.56	2.81	1.34	0.14	100.00
std dev	0.76	0.08	0.16	0.48	0.33	0.10	0.22	0.07	0.03	0.00

WC4-90s Discarded Analyses (n=2)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
76.33	12.59	3.96	1.71	1.46	3.09	0.31	0.44	0.10	100.00
66.04	15.11	4.84	5.09	3.58	2.75	1.37	1.11	0.12	100.00

WC7-40-P1 (n=18)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	77.80	12.52	3.89	1.34	1.82	1.79	0.36	0.30	0.17	100.00
	77.69	12.43	3.78	1.60	1.98	1.87	0.36	0.28	0.01	100.00
	77.68	12.38	3.77	1.67	1.91	1.74	0.37	0.28	0.19	100.00
	77.36	12.43	4.09	1.62	1.93	1.74	0.33	0.45	0.04	100.00
	77.34	12.48	3.87	1.74	1.90	1.79	0.35	0.32	0.20	100.00
	77.32	12.57	4.08	1.61	1.90	1.78	0.30	0.28	0.15	100.00
	77.28	12.38	4.00	1.61	1.93	1.71	0.38	0.29	0.41	100.00
	77.23	12.46	4.02	1.73	1.99	1.77	0.35	0.27	0.17	100.00
	77.18	12.52	4.14	1.80	1.90	1.67	0.34	0.29	0.15	100.00
	77.04	12.52	3.90	1.86	2.04	1.84	0.38	0.25	0.16	100.00
	77.03	12.65	4.10	1.74	1.98	1.83	0.38	0.12	0.16	100.00
	76.92	12.55	4.06	1.83	1.99	1.83	0.39	0.26	0.16	100.00
	76.87	12.41	3.79	1.94	2.07	1.92	0.36	0.30	0.34	100.00
	76.62	12.35	3.99	1.90	1.43	2.84	0.33	0.37	0.17	100.00
	76.62	12.64	4.18	1.93	2.04	1.77	0.40	0.33	0.09	100.00
	76.61	12.77	4.07	1.76	2.01	1.85	0.44	0.29	0.19	100.00
	76.55	12.56	4.15	2.03	2.02	1.86	0.39	0.25	0.18	100.00
	75.87	12.65	3.72	2.11	1.85	2.68	0.44	0.51	0.16	100.00
avg	77.06	12.52	3.98	1.77	1.93	1.91	0.37	0.30	0.17	100.00
std dev	0.48	0.11	0.15	0.18	0.14	0.32	0.04	0.08	0.09	0.00

WC7-40-P2 (n=10)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	74.45	13.06	4.31	2.57	2.03	2.40	0.46	0.56	0.16	100.00
	73.26	13.47	4.13	2.88	2.42	2.49	0.61	0.59	0.15	100.00
	73.01	13.36	4.43	3.11	2.36	2.33	0.57	0.72	0.12	100.00
	72.97	13.51	4.22	3.03	2.42	2.40	0.68	0.61	0.15	100.00
	72.89	13.77	4.23	2.77	2.53	2.36	0.68	0.59	0.17	100.00
	72.76	13.71	4.36	2.92	2.51	2.38	0.66	0.60	0.10	100.00
	72.72	13.75	4.35	3.22	2.39	2.28	0.68	0.60	0.02	100.00
	72.21	14.19	4.30	2.75	2.73	2.37	0.65	0.65	0.14	100.00
	72.14	13.64	4.27	3.40	2.73	2.22	0.79	0.67	0.14	100.00
	72.13	13.73	4.30	3.39	2.74	2.31	0.72	0.54	0.14	100.00
avg	72.85	13.62	4.29	3.00	2.48	2.35	0.65	0.62	0.13	100.00
std dev	0.68	0.30	0.08	0.28	0.22	0.07	0.09	0.05	0.04	0.00

WC7-40 Discarded Analyses (n=8)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
93.77	3.78	1.78	0.10	0.27	0.05	0.00	0.25	0.00	100.00
79.55	10.98	3.74	1.27	0.43	3.54	0.06	0.41	0.02	100.00
79.45	11.49	3.92	1.18	1.24	2.15	0.20	0.29	0.08	100.00
70.58	15.58	4.99	2.40	3.45	2.07	0.42	0.41	0.10	100.00
70.44	14.48	4.98	3.61	1.97	2.99	0.59	0.81	0.13	100.00
67.24	15.30	4.77	4.56	3.13	2.59	1.25	0.99	0.18	100.00
66.91	15.07	4.71	5.07	3.30	2.58	1.21	1.03	0.12	100.00
64.50	15.60	4.58	5.91	4.18	2.27	1.68	1.17	0.11	100.00

WC7-55 (n=24)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	77.27	12.22	3.63	1.64	1.30	3.22	0.27	0.33	0.12	100.00
	77.20	12.26	3.76	1.73	1.30	3.15	0.29	0.31	0.00	100.00
	76.85	12.32	3.72	1.76	1.36	3.11	0.31	0.38	0.19	100.00
	76.79	12.26	3.87	1.82	1.33	3.13	0.30	0.38	0.12	100.00
	76.74	12.42	3.84	1.79	1.37	3.02	0.31	0.36	0.14	100.00
	76.35	12.47	3.71	1.84	1.55	3.11	0.40	0.51	0.06	100.00
	76.31	12.66	3.68	2.11	1.49	2.84	0.36	0.38	0.17	100.00
	76.19	12.53	4.00	1.99	1.44	2.94	0.33	0.45	0.13	100.00
	76.14	12.67	3.71	2.06	1.54	3.02	0.34	0.42	0.10	100.00
	75.94	12.98	3.38	2.46	1.65	2.61	0.34	0.47	0.17	100.00
	75.93	12.78	3.76	2.02	1.72	2.96	0.38	0.45	0.00	100.00
	75.86	12.54	3.86	2.09	1.67	2.92	0.32	0.55	0.19	100.00
	75.82	12.54	4.07	2.17	1.57	2.89	0.36	0.41	0.16	100.00
	75.76	12.76	4.03	1.89	1.84	2.77	0.40	0.34	0.20	100.00
	75.62	12.76	3.63	2.19	1.89	2.95	0.40	0.44	0.11	100.00
	75.49	12.85	3.74	2.25	1.89	2.77	0.43	0.45	0.13	100.00
	75.45	12.85	3.73	2.26	1.78	2.92	0.40	0.49	0.12	100.00
	75.38	12.71	3.96	2.07	1.80	2.88	0.39	0.63	0.18	100.00
	75.16	12.65	3.89	2.27	1.84	3.11	0.40	0.44	0.23	100.00
	75.06	12.96	3.97	2.36	1.75	2.82	0.45	0.47	0.15	100.00
	74.95	13.09	3.89	2.17	1.97	2.98	0.37	0.43	0.14	100.00
	74.81	12.84	3.83	2.46	1.98	2.85	0.61	0.44	0.18	100.00
	73.75	13.37	4.11	2.71	2.24	2.52	0.56	0.61	0.13	100.00
	72.23	13.67	4.42	3.31	2.63	2.32	0.73	0.55	0.15	100.00
avg	75.71	12.72	3.84	2.14	1.71	2.91	0.39	0.45	0.14	100.00
std dev	1.10	0.34	0.21	0.36	0.32	0.21	0.11	0.08	0.06	0.00

WC7-55 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
67.47	18.79	4.86	1.37	5.45	1.65	0.31	0.01	0.09	100.00

WC8-0 (n=16)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.66	12.30	3.89	1.80	1.48	3.09	0.27	0.34	0.17	100.00
	76.02	12.68	3.84	1.98	1.49	3.10	0.34	0.39	0.17	100.00
	75.83	12.69	3.84	2.00	1.59	3.21	0.32	0.36	0.16	100.00
	75.75	12.76	3.76	2.13	1.55	2.92	0.29	0.66	0.18	100.00
	75.67	12.66	3.90	2.24	1.53	2.99	0.39	0.47	0.15	100.00
	75.65	12.71	3.96	2.13	1.56	3.04	0.30	0.44	0.21	100.00
	75.53	12.78	3.77	2.24	1.70	2.97	0.39	0.52	0.09	100.00
	75.48	12.89	3.80	2.23	1.66	2.96	0.37	0.45	0.15	100.00
	75.45	12.53	3.92	2.16	1.78	3.13	0.40	0.45	0.18	100.00
	75.41	12.76	3.74	2.30	1.74	3.10	0.36	0.41	0.17	100.00
	75.40	12.95	4.03	2.03	1.60	3.03	0.42	0.39	0.15	100.00
	75.27	12.93	3.72	2.35	1.72	2.92	0.43	0.52	0.14	100.00
	75.22	12.90	3.88	2.24	1.71	3.00	0.39	0.50	0.15	100.00
	75.24	12.88	3.74	2.41	1.69	2.99	0.42	0.43	0.20	100.00
	75.20	12.76	3.96	2.45	1.63	3.03	0.37	0.47	0.12	100.00
	74.75	13.14	3.72	2.32	1.98	2.89	0.43	0.51	0.27	100.00
avg	75.53	12.77	3.84	2.19	1.65	3.02	0.37	0.46	0.17	100.00
std dev	0.42	0.19	0.10	0.17	0.13	0.09	0.05	0.08	0.04	0.00

WC8-0 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
55.62	27.50	5.73	0.53	10.33	0.20	0.03	0.04	0.01	100.00

WC8-19-P1 (n=24)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.85	11.48	2.50	1.62	0.18	4.95	0.05	0.36	0.00	100.00
	78.57	11.65	3.36	1.56	0.84	3.37	0.18	0.30	0.18	100.00
	78.36	11.56	3.53	1.69	0.76	3.41	0.16	0.34	0.20	100.00
	78.34	11.47	3.82	1.52	0.82	3.42	0.13	0.25	0.23	100.00
	78.33	11.53	3.68	1.64	0.73	3.39	0.19	0.30	0.21	100.00
	78.25	11.87	3.12	1.94	0.92	3.28	0.18	0.34	0.10	100.00
	78.18	11.66	3.84	1.55	0.81	3.33	0.15	0.27	0.21	100.00
	78.16	11.65	3.78	1.52	0.85	3.42	0.17	0.30	0.15	100.00
	78.13	11.60	3.73	1.62	0.84	3.40	0.21	0.28	0.19	100.00
	78.09	11.67	3.87	1.62	0.75	3.43	0.15	0.29	0.13	100.00
	78.01	11.82	3.77	1.62	0.88	3.25	0.13	0.39	0.13	100.00
	77.89	11.61	3.92	1.81	0.85	3.24	0.20	0.32	0.16	100.00
	77.31	12.66	3.85	1.56	1.30	2.61	0.28	0.32	0.11	100.00
	77.25	11.80	3.77	2.12	1.19	3.14	0.20	0.43	0.10	100.00
	76.85	12.25	4.17	1.42	0.71	4.21	0.08	0.29	0.03	100.00
	76.70	11.25	3.41	2.93	1.20	3.52	0.29	0.56	0.14	100.00
	76.07	12.84	3.45	2.21	1.47	3.07	0.34	0.42	0.13	100.00
	76.02	12.81	3.60	2.22	1.03	3.41	0.20	0.53	0.18	100.00
	75.83	11.60	3.01	2.59	0.47	6.07	0.13	0.27	0.03	100.00
	75.81	12.54	3.65	2.22	1.60	3.11	0.38	0.39	0.30	100.00
	75.62	12.76	3.78	2.34	1.47	3.31	0.19	0.42	0.11	100.00
	75.20	12.85	3.82	2.58	1.97	2.55	0.44	0.50	0.09	100.00
	75.10	12.05	3.85	3.13	1.63	3.07	0.39	0.62	0.16	100.00
	74.71	13.03	3.67	2.54	1.89	3.11	0.50	0.50	0.06	100.00
avg	77.15	12.00	3.62	1.98	1.05	3.46	0.22	0.38	0.14	100.00
std dev	1.29	0.55	0.35	0.49	0.44	0.72	0.11	0.10	0.07	0.00

WC8-19-P2 (n=4)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.92	13.75	4.04	3.04	2.37	2.50	0.60	0.67	0.10	100.00
	72.40	13.84	4.15	3.28	2.41	2.47	0.66	0.66	0.13	100.00
	71.67	14.01	4.37	3.47	2.63	2.38	0.71	0.62	0.14	100.00
	71.45	15.16	5.06	2.54	1.71	2.97	0.48	0.47	0.15	100.00
avg	72.11	14.19	4.40	3.08	2.28	2.58	0.61	0.61	0.13	100.00
std dev	0.67	0.65	0.46	0.40	0.39	0.26	0.10	0.09	0.02	0.00

WC8-30-P1 (n=20)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	78.74	12.37	3.63	1.08	0.99	2.77	0.18	0.10	0.13	100.00
	78.32	11.35	3.94	1.52	0.78	3.39	0.16	0.41	0.13	100.00
	78.29	11.53	3.79	1.79	0.84	3.21	0.11	0.27	0.17	100.00
	78.11	11.62	3.56	1.64	0.88	3.49	0.19	0.42	0.09	100.00
	78.08	11.83	3.85	1.53	0.79	3.34	0.11	0.35	0.12	100.00
	77.86	12.49	3.89	1.21	0.90	3.03	0.17	0.16	0.29	100.00
	77.81	11.56	3.25	1.61	0.72	4.53	0.14	0.27	0.12	100.00
	77.77	12.10	3.75	1.68	0.96	3.21	0.18	0.25	0.11	100.00
	77.36	13.75	3.55	1.14	1.25	2.45	0.23	0.13	0.14	100.00
	76.21	12.54	3.71	2.19	1.28	3.24	0.29	0.42	0.12	100.00
	75.72	12.85	3.33	2.46	1.52	3.11	0.33	0.39	0.28	100.00
	75.44	13.05	3.54	2.40	1.59	3.05	0.45	0.45	0.02	100.00
	75.34	12.91	3.51	2.45	1.65	3.05	0.45	0.49	0.15	100.00
	75.20	13.10	3.66	2.28	1.75	3.10	0.33	0.40	0.17	100.00
	74.97	12.42	4.00	3.06	1.41	3.32	0.25	0.42	0.13	100.00
	74.97	12.66	3.70	2.76	1.62	3.32	0.37	0.45	0.14	100.00
	74.84	13.09	4.50	2.46	1.78	2.26	0.50	0.47	0.09	100.00
	74.71	13.27	3.65	2.65	1.94	2.75	0.48	0.46	0.10	100.00
	74.63	12.87	3.83	2.80	1.79	3.00	0.40	0.56	0.12	100.00
	74.10	13.76	4.08	2.27	1.32	3.63	0.26	0.30	0.27	100.00
avg	76.42	12.56	3.74	2.05	1.29	3.16	0.28	0.36	0.14	100.00
std dev	1.58	0.71	0.28	0.60	0.40	0.46	0.13	0.13	0.07	0.00

WC8-30-P2 (n=7)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.67	13.65	4.20	3.41	2.37	2.28	0.68	0.59	0.15	100.00
	72.52	13.83	3.97	3.38	2.44	2.41	0.69	0.64	0.12	100.00
	72.28	13.78	4.40	3.29	2.38	2.45	0.64	0.61	0.17	100.00
	71.90	14.18	4.11	3.33	2.56	2.37	0.73	0.68	0.13	100.00
	71.86	14.01	4.31	3.22	2.71	2.42	0.67	0.66	0.13	100.00
	71.84	13.81	4.47	3.39	2.56	2.42	0.72	0.64	0.15	100.00
	71.81	13.91	4.19	3.55	2.62	2.40	0.74	0.67	0.11	100.00
avg	72.13	13.88	4.23	3.37	2.52	2.39	0.70	0.64	0.14	100.00
std dev	0.36	0.17	0.17	0.10	0.13	0.06	0.04	0.03	0.02	0.00

WC8-30 Discarded Analyses (n=3)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
96.88	1.88	0.03	0.17	0.07	0.06	0.00	0.05	0.86	100.00
64.18	16.02	4.79	5.95	3.98	2.13	1.61	1.09	0.25	100.00
54.34	28.30	5.32	0.71	11.11	0.14	0.05	0.02	0.01	100.00

WC8-60 (n=38)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	79.23	11.23	2.33	1.98	0.97	3.47	0.11	0.65	0.03	100.00
	78.89	13.23	2.47	0.83	1.31	2.81	0.24	0.10	0.13	100.00
	78.85	11.30	3.71	1.46	0.81	3.21	0.19	0.30	0.17	100.00
	78.75	11.65	3.47	1.40	0.80	3.27	0.17	0.27	0.21	100.00
	78.70	11.40	3.68	1.49	0.84	3.28	0.17	0.29	0.14	100.00
	78.58	11.61	3.62	1.49	0.94	3.13	0.14	0.30	0.20	100.00
	78.57	11.56	3.61	1.53	0.85	3.25	0.15	0.37	0.11	100.00
	78.51	11.51	3.80	1.44	0.83	3.34	0.16	0.26	0.16	100.00
	78.46	11.74	3.62	1.44	0.92	3.25	0.21	0.35	0.00	100.00
	78.44	11.49	3.44	1.64	0.93	3.33	0.20	0.27	0.25	100.00
	78.42	11.62	3.72	1.60	0.88	3.22	0.17	0.24	0.12	100.00
	78.36	11.43	3.84	1.54	0.77	3.25	0.18	0.31	0.32	100.00
	78.29	11.91	3.70	1.42	0.84	3.20	0.13	0.33	0.17	100.00
	78.23	11.76	3.81	1.54	0.92	3.19	0.18	0.26	0.11	100.00
	78.18	11.55	3.57	1.70	0.88	3.45	0.14	0.31	0.21	100.00
	78.11	11.62	3.67	1.78	1.03	3.11	0.24	0.31	0.11	100.00
	78.04	11.52	2.44	1.41	0.65	5.43	0.13	0.30	0.08	100.00
	77.98	11.44	3.90	1.80	0.81	3.47	0.19	0.29	0.13	100.00
	77.83	11.53	3.60	1.80	0.85	3.51	0.20	0.54	0.15	100.00
	77.78	11.90	3.80	1.62	0.98	3.09	0.20	0.53	0.10	100.00
	77.74	12.24	3.65	1.16	1.41	3.03	0.30	0.31	0.15	100.00
	77.65	11.43	3.23	1.48	0.25	5.47	0.11	0.25	0.12	100.00
	76.91	12.52	3.38	1.96	1.35	3.32	0.12	0.33	0.11	100.00
	76.41	12.40	3.75	1.96	1.48	3.16	0.31	0.43	0.09	100.00
	76.40	12.49	3.50	2.04	1.60	3.16	0.34	0.45	0.00	100.00
	76.35	12.54	3.71	1.90	1.54	3.07	0.31	0.41	0.17	100.00
	76.28	12.47	3.66	2.00	1.25	3.49	0.32	0.36	0.16	100.00
	76.06	12.38	3.55	2.14	1.61	3.28	0.33	0.43	0.22	100.00
	76.02	12.63	3.62	1.99	1.59	3.20	0.32	0.53	0.09	100.00
	75.97	12.97	3.85	1.80	1.62	3.26	0.14	0.38	0.00	100.00
	75.93	12.69	3.69	1.98	1.38	3.52	0.13	0.58	0.09	100.00
	75.89	13.03	3.51	2.34	1.19	3.07	0.39	0.48	0.10	100.00
	75.77	13.78	4.64	1.57	1.39	2.09	0.29	0.30	0.18	100.00
	75.47	12.80	3.56	2.34	1.80	3.00	0.36	0.53	0.14	100.00
	75.44	12.72	3.92	2.19	1.69	3.09	0.35	0.47	0.14	100.00
	74.39	13.52	4.21	2.10	1.21	3.69	0.25	0.31	0.33	100.00
	73.60	13.49	4.06	2.80	2.24	2.57	0.57	0.51	0.15	100.00
	73.02	13.82	3.67	3.11	2.53	2.42	0.69	0.64	0.11	100.00
avg	77.20	12.18	3.60	1.78	1.18	3.29	0.24	0.38	0.14	100.00
std dev	1.55	0.76	0.43	0.43	0.45	0.60	0.12	0.12	0.07	0.00

WC8-60 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
81.86	13.56	0.59	0.87	0.40	1.51	0.09	1.03	0.09	100.00

WC8-70-P1 (n=8)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	70.27	15.13	4.27	3.31	2.56	2.70	0.86	0.73	0.17	100.00
	70.13	15.11	4.28	3.42	2.50	2.91	0.82	0.73	0.10	100.00
	69.85	14.96	4.50	3.50	2.52	3.00	0.85	0.72	0.10	100.00
	69.67	14.83	5.16	3.56	2.54	2.60	0.77	0.72	0.15	100.00
	69.64	15.19	4.76	3.47	2.50	2.73	0.83	0.74	0.13	100.00
	69.58	15.24	4.45	3.69	2.59	2.69	0.84	0.71	0.20	100.00
	68.06	14.71	4.80	4.69	2.87	2.75	1.00	0.96	0.15	100.00
	67.86	14.96	4.90	4.50	2.85	2.97	1.00	0.96	0.00	100.00
avg	69.38	15.02	4.64	3.77	2.62	2.79	0.87	0.79	0.13	100.00
std dev	0.91	0.18	0.32	0.52	0.16	0.15	0.08	0.11	0.06	0.00

WC8-70-P2 (n=14)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	60.25	16.06	4.44	7.52	6.22	1.74	2.53	1.13	0.10	100.00
	60.05	16.24	4.32	7.43	6.24	1.72	2.77	1.13	0.09	100.00
	59.92	16.23	4.52	7.50	6.09	1.78	2.68	1.16	0.12	100.00
	59.45	16.33	4.41	7.75	6.33	1.70	2.77	1.14	0.11	100.00
	59.23	16.24	4.33	7.90	6.39	1.58	2.94	1.19	0.20	100.00
	59.23	16.26	4.59	7.83	6.30	1.64	2.83	1.23	0.08	100.00
	58.79	16.46	4.55	7.74	6.49	1.71	2.76	1.24	0.25	100.00
	58.44	16.48	4.27	8.24	6.79	1.58	2.97	1.12	0.11	100.00
	58.36	16.33	4.34	8.31	6.76	1.50	3.06	1.25	0.08	100.00
	58.29	15.98	4.48	8.40	6.95	1.58	3.09	1.12	0.09	100.00
	58.27	16.30	4.39	8.21	6.97	1.56	2.97	1.23	0.10	100.00
	58.26	16.19	5.30	7.99	6.61	1.49	2.90	1.18	0.08	100.00
	58.02	16.44	4.12	8.48	6.89	1.68	3.16	1.12	0.09	100.00
	57.55	16.23	4.02	8.92	7.14	1.52	3.23	1.26	0.13	100.00
avg	58.86	16.27	4.43	8.02	6.58	1.63	2.90	1.18	0.12	100.00
std dev	0.83	0.14	0.29	0.43	0.33	0.09	0.19	0.05	0.05	0.00

WC8-70 Discarded Analyses (n=6)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.14	11.45	3.62	1.53	0.70	4.04	0.17	0.26	0.09	100.00
78.12	11.96	3.90	1.40	0.87	3.17	0.15	0.32	0.11	100.00
65.96	15.49	4.86	5.03	3.75	2.36	1.46	0.92	0.17	100.00
64.81	15.94	4.30	5.33	4.51	2.26	1.84	0.91	0.10	100.00
63.21	15.88	4.17	6.23	5.17	2.03	2.09	1.10	0.12	100.00
52.62	28.99	4.55	0.89	12.47	0.24	0.15	0.08	0.00	100.00

WC9-X (n=19)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.93	13.04	4.12	3.04	1.99	2.51	0.58	0.58	0.21	100.00
	73.27	13.39	4.35	2.93	2.17	2.49	0.58	0.60	0.21	100.00
	73.01	13.75	3.87	3.13	2.43	2.39	0.60	0.64	0.18	100.00
	72.76	13.66	4.28	2.91	2.60	2.38	0.59	0.62	0.19	100.00
	72.75	13.76	4.15	3.21	2.35	2.43	0.65	0.61	0.09	100.00
	72.71	13.78	3.93	3.42	2.43	2.34	0.63	0.62	0.13	100.00
	72.65	13.79	4.13	3.02	2.55	2.49	0.63	0.58	0.16	100.00
	72.58	13.92	3.76	3.37	2.48	2.38	0.67	0.65	0.18	100.00
	72.51	13.66	4.14	3.31	2.51	2.54	0.61	0.60	0.13	100.00
	72.48	13.66	4.35	3.29	2.44	2.47	0.60	0.61	0.11	100.00
	72.40	13.79	3.96	3.36	2.64	2.40	0.74	0.58	0.13	100.00
	72.40	13.79	4.12	3.32	2.68	2.34	0.71	0.58	0.06	100.00
	72.37	13.91	3.96	3.50	2.45	2.42	0.67	0.58	0.14	100.00
	72.36	13.60	4.46	3.32	2.38	2.50	0.68	0.60	0.11	100.00
	72.20	13.69	4.01	3.30	2.56	2.49	0.69	0.64	0.42	100.00
	72.04	13.74	4.20	3.52	2.63	2.43	0.72	0.56	0.16	100.00
	71.86	13.94	4.18	3.38	2.78	2.28	0.73	0.62	0.23	100.00
	71.42	14.15	4.08	3.58	2.77	2.34	0.83	0.68	0.15	100.00
	71.20	14.45	4.44	3.20	2.73	2.49	0.75	0.62	0.12	100.00
avg	72.47	13.76	4.13	3.27	2.50	2.43	0.67	0.61	0.16	100.00
std dev	0.61	0.28	0.19	0.19	0.20	0.07	0.07	0.03	0.08	0.00

WC9-X Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
78.03	11.90	3.91	1.57	1.21	2.72	0.24	0.30	0.12	100.00

BP-1 (n=24)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	75.53	12.62	4.10	2.22	1.66	2.81	0.38	0.51	0.17	100.00
	74.75	13.26	4.17	1.53	0.72	5.18	0.06	0.01	0.32	100.00
	74.68	13.21	4.21	1.59	0.83	5.06	0.02	0.06	0.34	100.00
	74.63	13.32	4.08	2.44	2.01	2.45	0.49	0.47	0.12	100.00
	74.51	13.30	4.31	1.60	0.69	5.12	0.06	0.06	0.35	100.00
	73.84	13.42	3.93	2.82	2.21	2.53	0.54	0.56	0.15	100.00
	73.33	13.61	4.24	2.87	2.31	2.32	0.60	0.55	0.16	100.00
	73.26	13.60	4.17	2.70	2.40	2.47	0.62	0.64	0.14	100.00
	72.86	13.87	4.17	2.78	2.49	2.41	0.67	0.59	0.15	100.00
	72.74	14.49	4.32	2.45	2.59	2.35	0.53	0.45	0.08	100.00
	72.74	13.88	3.95	3.12	2.49	2.33	0.73	0.63	0.13	100.00
	72.69	14.07	3.95	2.99	2.62	2.20	0.75	0.60	0.13	100.00
	72.69	13.96	4.11	3.01	2.42	2.41	0.63	0.63	0.14	100.00
	72.54	13.99	4.13	2.90	2.61	2.37	0.73	0.59	0.13	100.00
	72.48	13.71	4.40	2.98	2.59	2.36	0.67	0.66	0.15	100.00
	72.35	15.16	4.66	1.79	2.84	2.30	0.34	0.41	0.15	100.00
	72.31	13.93	4.21	3.10	2.76	2.29	0.72	0.59	0.09	100.00
	72.27	14.07	4.05	3.03	2.70	2.29	0.76	0.70	0.12	100.00
	72.23	14.05	4.21	3.22	2.51	2.33	0.73	0.58	0.14	100.00
	72.06	14.14	4.19	2.98	2.83	2.30	0.76	0.62	0.11	100.00
	72.05	13.98	4.14	3.13	2.85	2.36	0.68	0.64	0.17	100.00
	72.04	14.00	4.25	3.08	2.69	2.34	0.81	0.62	0.17	100.00
	71.99	14.08	4.01	3.13	2.88	2.37	0.72	0.63	0.18	100.00
	71.77	13.95	4.29	3.15	2.90	2.37	0.78	0.65	0.13	100.00
avg	73.01	13.82	4.18	2.69	2.32	2.72	0.58	0.52	0.16	100.00
std dev	1.07	0.49	0.16	0.55	0.67	0.93	0.24	0.20	0.07	0.00

BP-1 Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
54.23	0.07	0.07	14.75	15.95	0.01	14.89	0.01	0.02	100.00

BP-2 (n=17)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	72.46	13.82	4.12	3.05	2.71	2.36	0.70	0.61	0.16	100.00
	72.39	14.03	4.16	2.96	2.60	2.37	0.76	0.60	0.12	100.00
	72.31	14.08	4.08	2.99	2.62	2.42	0.71	0.62	0.17	100.00
	72.21	13.84	4.32	3.10	2.68	2.37	0.68	0.71	0.09	100.00
	72.23	13.61	4.62	3.23	2.37	2.28	0.75	0.69	0.22	100.00
	72.17	13.85	4.31	3.11	2.79	2.23	0.72	0.67	0.15	100.00
	72.16	14.00	4.24	3.15	2.56	2.33	0.76	0.65	0.14	100.00
	72.03	13.93	4.37	3.02	2.77	2.41	0.69	0.62	0.16	100.00
	72.05	14.05	4.15	3.07	2.89	2.33	0.75	0.59	0.11	100.00
	72.03	13.98	4.20	3.14	2.70	2.35	0.75	0.69	0.15	100.00
	72.01	14.11	4.19	3.15	2.66	2.32	0.79	0.65	0.11	100.00
	71.98	14.09	4.17	3.03	2.83	2.30	0.74	0.71	0.15	100.00
	71.97	14.23	4.11	3.06	2.76	2.40	0.79	0.57	0.10	100.00
	71.89	13.95	4.36	3.12	2.87	2.37	0.69	0.62	0.13	100.00
	71.87	14.20	4.17	3.06	2.77	2.32	0.74	0.72	0.14	100.00
	71.86	13.98	4.28	3.39	2.61	2.36	0.71	0.70	0.11	100.00
	71.81	14.14	4.16	3.23	2.71	2.37	0.73	0.69	0.15	100.00
avg	72.08	13.99	4.24	3.11	2.70	2.34	0.74	0.66	0.14	100.00
std dev	0.19	0.15	0.13	0.10	0.13	0.05	0.03	0.05	0.03	0.00

WC46-X (n=22)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	76.34	12.39	3.99	1.79	1.44	3.15	0.30	0.41	0.20	100.00
	76.12	12.61	3.82	1.89	1.62	2.96	0.35	0.46	0.16	100.00
	76.02	12.61	3.96	1.90	1.63	2.97	0.35	0.39	0.17	100.00
	75.95	12.53	3.95	1.92	1.49	3.19	0.36	0.40	0.21	100.00
	75.91	12.69	4.04	1.86	1.49	3.12	0.29	0.42	0.19	100.00
	75.91	12.71	4.03	1.85	1.56	2.95	0.35	0.46	0.19	100.00
	75.89	12.72	3.97	1.94	1.60	2.95	0.32	0.40	0.21	100.00
	75.84	12.74	3.83	2.06	1.72	2.89	0.34	0.38	0.20	100.00
	75.70	12.90	3.95	1.96	1.65	2.91	0.36	0.41	0.16	100.00
	75.64	12.82	3.80	2.18	1.64	2.93	0.34	0.44	0.20	100.00
	75.54	12.81	4.02	2.04	1.66	2.97	0.35	0.41	0.20	100.00
	75.51	12.77	3.76	2.13	1.78	2.94	0.42	0.45	0.24	100.00
	75.45	12.86	4.06	2.05	1.73	2.87	0.34	0.43	0.21	100.00
	75.41	13.02	3.96	1.98	1.67	2.93	0.40	0.46	0.17	100.00
	75.40	12.96	4.06	2.03	1.65	2.85	0.42	0.48	0.15	100.00
	75.35	12.85	3.90	2.22	1.73	2.91	0.39	0.43	0.21	100.00
	75.34	12.90	3.96	2.14	1.66	2.88	0.44	0.49	0.19	100.00
	75.29	12.88	3.87	2.18	1.81	2.94	0.40	0.47	0.15	100.00
	75.27	12.88	3.84	2.06	1.81	3.01	0.41	0.50	0.22	100.00
	75.12	13.00	3.87	2.07	1.79	2.94	0.44	0.57	0.20	100.00
	75.01	13.03	4.01	2.12	1.83	2.89	0.46	0.46	0.19	100.00
	74.76	13.05	3.97	2.26	1.91	2.91	0.40	0.51	0.23	100.00
avg	75.58	12.81	3.94	2.03	1.68	2.95	0.37	0.45	0.19	100.00
std dev	0.39	0.17	0.09	0.13	0.12	0.09	0.05	0.05	0.02	0.00

WC46-X Discarded Analyses (n=2)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
72.02	13.93	4.50	2.99	2.71	2.37	0.73	0.60	0.14	100.00
70.72	16.63	4.75	1.27	3.59	2.41	0.20	0.25	0.18	100.00

WC51-X (n=20)

	SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
	73.32	13.76	4.16	2.71	2.32	2.46	0.60	0.57	0.10	100.00
	72.77	13.90	4.12	2.82	2.65	2.28	0.73	0.59	0.14	100.00
	72.67	13.63	4.23	3.12	2.50	2.43	0.66	0.63	0.12	100.00
	72.62	13.62	4.39	2.98	2.54	2.38	0.75	0.58	0.13	100.00
	72.61	13.93	4.16	2.96	2.49	2.41	0.72	0.61	0.10	100.00
	72.59	13.91	4.24	2.94	2.57	2.24	0.78	0.66	0.06	100.00
	72.47	13.84	4.08	3.05	2.65	2.38	0.76	0.66	0.10	100.00
	72.44	13.91	4.26	2.97	2.69	2.42	0.70	0.46	0.14	100.00
	72.43	13.95	4.14	2.96	2.62	2.30	0.77	0.71	0.12	100.00
	72.38	13.79	4.26	3.08	2.66	2.35	0.75	0.60	0.13	100.00
	72.38	13.80	4.34	3.11	2.57	2.35	0.70	0.69	0.06	100.00
	72.29	14.08	4.25	2.81	2.70	2.30	0.76	0.65	0.15	100.00
	72.28	13.84	4.17	3.12	2.79	2.28	0.72	0.69	0.11	100.00
	72.24	13.94	4.21	3.05	2.56	2.39	0.77	0.65	0.18	100.00
	72.23	13.97	4.16	3.19	2.67	2.29	0.74	0.65	0.10	100.00
	72.16	14.08	4.29	2.94	2.70	2.31	0.72	0.68	0.12	100.00
	72.15	14.04	4.26	3.15	2.52	2.41	0.72	0.66	0.08	100.00
	71.99	13.88	4.18	3.44	2.63	2.27	0.78	0.69	0.14	100.00
	71.94	13.91	4.39	3.06	2.60	2.33	0.74	0.71	0.32	100.00
	71.87	13.97	4.53	3.13	2.67	2.31	0.74	0.66	0.12	100.00
avg	72.39	13.89	4.24	3.03	2.60	2.34	0.73	0.64	0.13	100.00
std dev	0.33	0.13	0.11	0.16	0.10	0.06	0.04	0.06	0.05	0.00

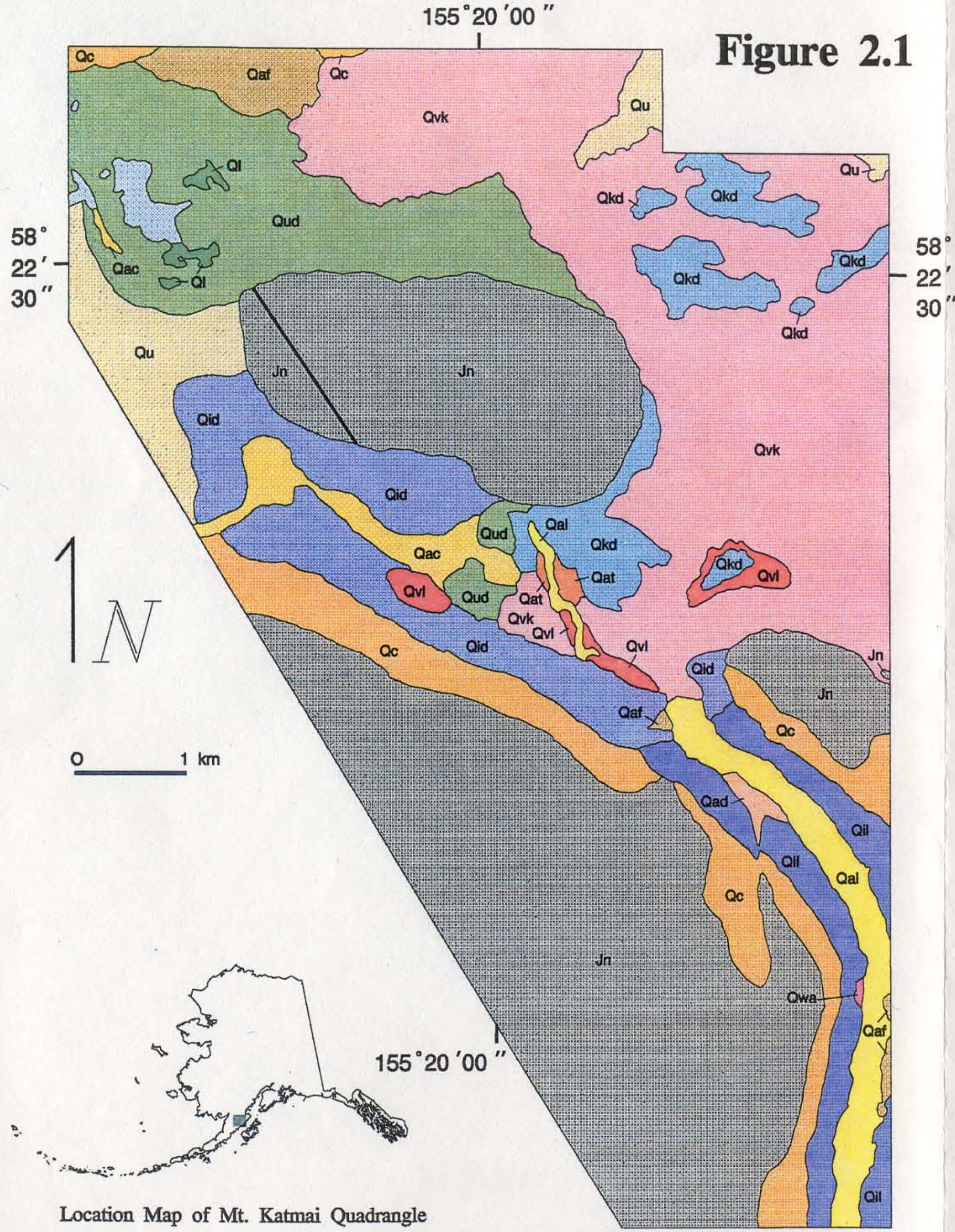
WC51-X Discarded Analyses (n=1)

SiO2	Al2O3	Na2O	FeO*	CaO	K2O	MgO	TiO2	Cl	Total
75.30	12.79	4.32	2.17	1.78	2.60	0.43	0.45	0.15	100.00

Figure 2.1 Surficial Geology Near Lower Windy Creek, Katmai National Park, Alaska

1993

D.S. Pinney



EXPLANATION

- Qal : Alluvium in modern floodplains
- Qat : Alluvial terraces flanking lower Windy Creek
- Qaf : Alluvial fans
- Qc : Colluvium
- Qad : 1912 delta deposits in Windy Creek valley
- Qvk : 1912 ashflow deposit
- Qkd : Katolinat drift
- Qac : Abandoned channel deposits of Ukak and/or Katolinat age
- Ql : Lake deposits in Ukak-age kettles
- Qud : Ukak drift
- Qvl : Lethe volcaniclastic deposits
- Qil : Iliuk glaciolacustrine deposits flanking Windy Creek valley
- Qid : Iliuk drift
- Qu : Undifferentiated drift; may include Iliuk drift
- Qwa : Windy Creek ashflow deposit
- Jn : Jurassic Naknek Formation
- Lake
- N Joint or fault of unknown displacement