# X-RAY FLUORESCENCE CHARACTERIZATION OF THE OBSIDIAN FLOWS FROM THE MOUNT EDZIZA VOLCANIC COMPLEX OF BRITISH COLUMBIA, CANADA

by

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# ABSTRACT

The purpose of this work was to determine how many chemically distinct obsidian flows exist in the Mount Edziza Volcanic Complex; to characterize these obsidian flows chemically; and to apply this information towards the understanding of prehistoric obsidian exploitation within the Complex. The Complex, located in northwestern British Columbia, constitutes the largest obsidian source area in Canada; by virtue of its size, accessibility, and location, it is also the most significant prehistorically exploited obsidian quarry in the Northwest. This is attested to by the wide distribution of artifacts made from Mount Edziza obsidian, extending hundreds of kilometres away from the Complex. This thesis reports the results of x-ray fluorescence analyses of both native obsidian rocks and of artifacts collected within the study area.

A set of 174 obsidian rocks from outcrop and gravel deposits was analyzed semi-quantitatively by energy-dispersive x-ray fluorescence, and the relative concentrations of a number of elements were determined. On the basis of these relative elemental concentrations, ten chemically distinct types of obsidian were identified. Each chemical type of obsidian was then correlated to a unique obsidian flow within the Complex.

The absolute concentrations of 28 major and minor elements in each of the ten obsidian flows were determined using wavelength-dispersive x-ray fluorescence. On the basis of these quantitative data, eight of the Edziza obsidians were found to have a peralkaline chemical composition; five of these fall within the class of rocks known as pantellerites, while three were classified as comendites. The other two flows were interpreted as sub-alkaline.

The semi-quantitative energy-dispersive x-ray fluorescence method was also applied to determine the sources of 169 obsidian artifacts from three archaeological sites situated within the Mount Edziza Volcanic Complex. The results indicate preferred exploitation of the high-elevation obsidian sources from one central location. The results also suggest that the people who exploited the Complex ignored all the poorer-quality low-elevation obsidian scatters, and that they may not have exploited the high plateau region north of Raspberry Pass. This raises the possibility that the obsidian sources north of Raspberry Pass were not accessible at that time, perhaps due to harsher environmental conditions than at present.

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# INTRODUCTION

It is known that many natural substances which were used by prehistoric peoples for the manufacture of goods, can be treated as tracers of long-distance contact. This idea has been applied successfully in the investigations of trade and exchange of materials such as obsidian and flint, the gem-quality stones carnelian and jade, the marine shells conch and dentalium, metal ores, and several types of rock used in ancient architecture (Jones 1983; Washington 1921; Pires-Ferreira 1976; Shotton and Hendry 1979). Some of these studies are summarized by Kempe and Harvey (1983).

Obsidian, a natural volcanic glass, was used throughout man's prehistory to make tools, ceremonial objects and ornaments. It continues to have certain minor uses even today. Because it is a glass, it forms an extremely sharp edge when freshly broken. It is amorphous and isotropic, and is relatively easy to work, either through flaking or cutting and polishing. It occurs naturally only in areas which have experienced some volcanic activity in the recent (late Tertiary or later) geologic past (Jack 1976). These areas may be young mountain ranges such as the Cordillèra of North and South America, or volcanic islands formed at sub-oceanic hot spots and the junctions of converging or diverging tectonic plates.

Obsidian devitrifies relatively quickly, and so it no longer exists in the very old mountain ranges of the world. For this reason, obsidian sources throughout the world are few and highly localized compared to other raw materials used to manufacture prehistoric goods, such as flint or clay deposits. The success of the methods which correlate obsidian artifacts with geological sources is due to the fact that a particular flow of obsidian is a geologically instantaneous event, and a high degree of chemical homogeneity is frozen into its composition. Obsidian artifacts are therefore chemically identical to the parent flow from which the raw material was collected. Since the formation of obsidian is a relatively rare geologic occurrence, and is confined to localized areas (either as flows or as clasts in nearby secondary deposits), correlation of the chemical type of obsidian in artifacts with a single geological source provides a good base for the study of human travel, material exchange and cultural contact in prehistory.

# RESEARCH GOALS

The principles outlined above form the basis of the study undertaken here, which was to identify and chemically characterize obsidian from the Mount Edziza Volcanic Complex in northwestern British Columbia, and to apply these results to an archaeological problem. This volcanic complex is known to contain the largest source of obsidian in Canada. It is also known to have been heavily exploited in prehistoric times, and the obsidian quarried there was widely traded to the north, east, and south (E. Nelson, pers. comm.).

This project was designed in three parts, each of which addressed a different goal. These are presented and discussed in three separate sections below.

Section 1.

The primary purpose of this research was to establish:

a. the number of chemically distinct obsidian flows within the Mount Edziza Volcanic Complex.

b. the geographic distributions of primary outcrops and reworked erosional deposits of each flow.

c. which outcrops and reworked deposits possess obsidian of the quantity and high quality suitable for artifact manufacture.

d. which deposits were most likely to have been easily accessible and most extensively exploited by prehistoric people.

The technique chosen to distinguish the obsidian sources was energy-dispersive x-ray fluorescence (ED-XRF). This method was used non-destructively, and it yielded semi-quantitative results. The results obtained here and the ED-XRF method were also used in Section 3 (see below) in the correlation of obsidian artifacts to specific sources.

## Section 2.

This section was designed to provide a quantitative determination of the chemical composition of each obsidian flow identified. These obsidian data would then serve as a reference library for other researchers using other analytical methods, and would form part of the worldwide database of obsidian chemical compositions. Wavelength-dispersive x-ray fluorescence (WD-XRF) was employed here to determine the absolute major, minor, trace, and some rare earth element concentrations of each obsidian flow.

## Section 3.

The purpose of the final part of this work was to apply the semi-quantitative ED-XRF technique to a study of prehistoric obsidian exploitation patterns within the Mount Edziza Volcanic Complex. A large number of obsidian artifacts from three archaeological sites within the Complex was examined to determine how the diversity of chemical types in the artifacts correlates with the natural distributions of the chemical types of obsidian nearest to the locations of the sites. A total of five distinct lithic assemblages was analysed in this manner. One of the sites was a single-component, multi-function campsite. The other two sites were made up of two components: a primary reduction lithic workshop component, and a multi-function campsite component.

The ED-XRF analyses of Sections 1 and 3 were carried out in the Chemistry Department at Simon Fraser University. The WD-XRF analysis used in Section 2 was carried out in the Oceanography Department at the University of British Columbia.

# STUDY AREA

The Mount Edziza Volcanic Complex, also known as the Mt. Edziza - Spectrum Plateau Complex, is located in northwestern British Columbia (Fig. 1). It covers an area of approximately 1,000 square kilometres in a Provincial Park and is situated within the Stikine river drainage, near the Iskut and the Klastline Rivers. It forms a rolling upland plateau, bounded by high, steep escarpments and is cross-cut by deep glacially eroded valleys. Its topography reflects a complex history of recent volcanic and glacial events.

## a. Archaeological significance

The Edziza Complex is significant in Northwest prehistory as the largest obsidian source in Canada. This obsidian was readily available in the form of clasts both on top of the plateau and on valley floors for sustained aboriginal lithic procurement purposes (Fladmark 1984). It was thus heavily exploited in prehistoric times and widely traded east, north, and south. Artifacts made from this obsidian have a distribution wider than artifacts made from any other western Canadian obsidian types. To the north, artifacts made from Mt. Edziza obsidian overlap in archaeological occurrence with obsidian artifacts that correspond to the Alaskan and Yukon obsidian sources. They also occur in archaeological sites located further south than the Anahim-Ilgachuz-Mackenzie sources of central British Columbia, and overlap with obsidian artifacts from sources located in southern Oregon (ibid.).

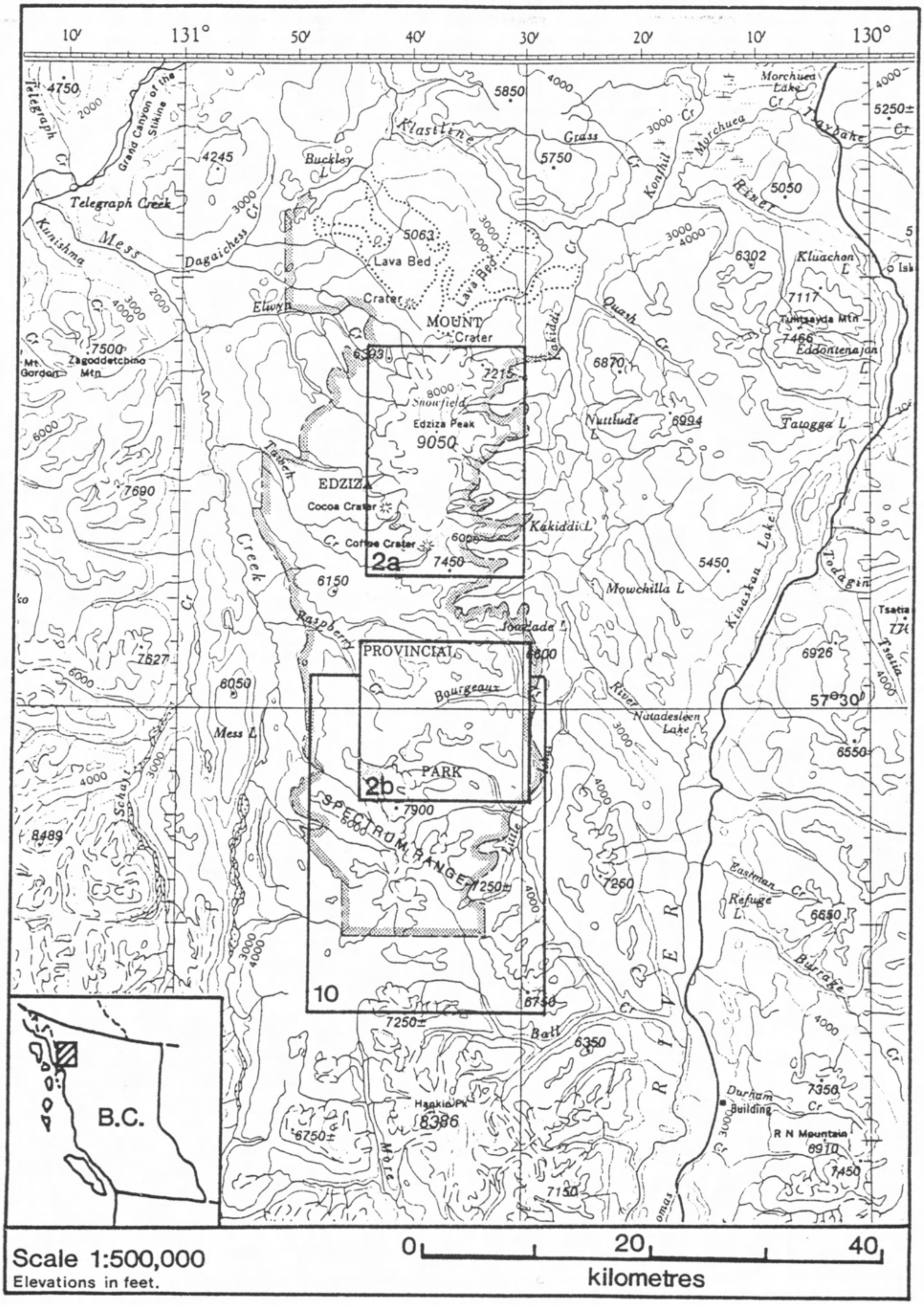


Figure 1: The Mount Edziza Study Area

Even in very early times, certainly by 6000-7000 BP if not earlier, Edziza obsidian occurs in archaeological contexts remote from the source. Its presence has been confirmed in the Yukon at the Moosehide Site (LaVk-2) by 6500 BP (J. Hunston, pers. comm.), and in British Columbia at Charlie Lake Cave (HbRf-39) by 7000-6000 BP. So far, it has also been found in two sites on the Peace and Athabasca Rivers in Alberta (Carlson 1984). By late prehistoric times its southern distribution in archaeological contexts has extended to Alexis Creek, near the confluence of the Chilcotin and Fraser rivers (Godfrey-Smith and D'Auria 1984).

The Edziza Complex is also significant for the important overland route which leads through it. This trail runs north to Atlin and southeast across Raspberry Pass to Terrace and further south. It provides a relatively easy and low-elevation route through the Edziza-Spectrum Ranges, and also gives the easiest land access into these mountains. In historic times the Telegraph Trail was erected along this trail in order to link Dawson with the world to the south. The Stikine River, whose tributaries Iskut and Mess Creek drain the Edziza Plateau, used to be a major route of travel to and from the Pacific coast. Thanks to this, and to the easy access offered by other major rivers which drain northward into different seas, the Edziza Complex lies at a convenient communications cross-road of the Northwest. Its strategic natural location was a significant factor in the widespread popularity it enjoyed in the past as a source of good quality raw obsidian (Fladmark 1982).

In modern times, areas of the Complex other than the Raspberry and Bourgeaux Creek valleys have remained largely undisturbed. A 1981 archaeological survey of the Spectrum Plateau, the main Edziza plateau, and the Raspberry and Bourgeaux valleys established that people have been using these valleys intensively for at least the last 5000 years (Fladmark 1982).

## b. Geology

The Complex is near the centre of the Stikine Volcanic Belt, about 300 km east of the transcurrent boundary between the North American and Pacific tectonic plates. It is associated with northerly trending Cenozoic normal faults, indicative of an extensional tectonic environment (Souther and Hickson 1984). Dating of the Edziza Complex (Souther, Armstrong and Harakal 1984) indicates that it is a set of late Cenozoic to Quaternary composite volcanoes that erupted in several cycles between 10 million and 2 thousand years ago. On the basis of an alternating stratigraphy of salic (high-silica), intermediate, and basic (low-silica) rock units, the Complex is interpreted as the product of five major magmatic cycles. It is further subdivided into 15 formations, each of which originated from a different centre or group of centres. The plateau is made up of large volumes of alkali olivine basalt interbedded with the salic rocks trachyte and comendite. Thin beds of unaltered obsidian are present as a quenched basal layer under these trachyte and comendite flows (Souther and Hickson 1984).

# PREVIOUS RESEARCH IN OBSIDIAN CHARACTERIZATION

Because obsidian sources are so highly localized and the material was traded over large distances, it is obvious that a means of distinguishing the obsidian which comes from different sources can be of great value to archaeologists. Early attempts to do so concentrated on physical properties such as colour, density, or refractive index, and on the concentrations of the major elements in the glass (Reeves and Ward 1976). However, since obsidian can form only from specific types of magma which vary little in chemical composition, most of the above criteria exhibit a narrow range of variation, and are not adequate for the purposes of reliable source characterization. The problem was first solved by Cann and Renfrew (1964) who used the variation of the concentrations in trace elements, principally Ba and Zr, to distinguish obsidians from several sources in the Near East. They then applied these methods to the study of obsidian sources and artifact distributions in the central Mediterranean and Aegean regions (Dixon, Cann and Renfrew 1968), and in the Near East (Renfrew, Dixon and Cann 1968).

At about the same time and following the success of Cann and Renfrew, researchers around the world began to apply a variety of methods of trace element analysis to obsidian sourcing. In North America these early investigations were concentrated at Berkeley (Weaver and Stross 1965; Heizer, Williams and Graham 1965) and at the University of Michigan (Griffin 1965; Griffin and Gordus 1966). Early and active interest in reliable obsidian sourcing was also pursued in New Zealand (Green 1962; Green, Brooks and Reeves 1967); it continues today. A good historical summary of obsidian studies in New Zealand is provided by Reeves and Ward (1976).

Obsidian sourcing in Canada was initiated by Roscoe Wilmeth (Evans and Wilmeth 1971; Wilmeth 1973). It was carried out with the use of neutron activation analysis. An energy-dispersive x-ray fluorescence technique was successfully developed and applied by Nelson, D'Auria and Bennett (1975).

The past 20 years have seen a massive accumulation of research data on the subject of obsidian source characterization. Regional summaries on sourcing and its archaeological applications in California, Mesoamerica, New Zealand, and the Mediterranean and Near East are presented in Part II of the Advances in Obsidian Glass Studies (Taylor 1976:183-333). Hester (1979) has compiled a detailed summary on the Mesoamerican work. Leach and Davidson (1981) have done so for the southern Pacific regions, and Thorpe et al (1984) for central and eastern Europe. Cann (1983) also provides an updated world overview of the subject.

## Review of Obsidian-Sourcing Methods

To date, a great variety of analytical methods has been applied to obsidian studies (Table 1). As mentioned above, the early attempts at obsidian characterization, based on petrographic thin section, refractive index, and density, met with very limited success.

Characterization on the basis of bulk element composition through wet chemical methods, major element x-ray fluorescence, and electron microprobe, have been partially successful (Michels 1982, Merrick and Brown 1984), but they are limited by the small range of major element variations in obsidian-forming magmas. The electron microprobe is the most efficient of the major element characterization methods. It has similar desirable characteristics for quantitative and qualitative work as the trace element methods discussed below, but it is insensitive to trace elements (Smith 1975:21D; Bizouard 1982; Appendix B, this work).

## TABLE 1

Chemical and physical methods
used in obsidian source studies

| METHOD | REFERENCE |
|---|---|
| Physical Characteristics: | |
| Refractive Index | Green 1962 |
| Density | Marshall 1936 |
| Thin-section Petrography | Shotton & Hendry 1979 |
| Transmitted Light | Schirmeisen 1936 |
| Major Element Composition: | |
| Electron Microprobe Analysis | Bizouard 1982 |
| ESCA - XPS | Michels 1982 |
| Trace Element Composition (Non-destructive): | |
| Instrumental Neutron Activation Analysis | Evans & Wilmeth 1971 |
| Wavelength-Dispersive X-Ray Fluorescence | Stevenson et al 1971 |
| Energy-Dispersive X-Ray Fluorescence | Nelson et al 1975 |
| PIGME, Proton-Induced Gamma Ray Emission | Coote et al 1972 |
| PIXE, Proton-Induced X-Ray Emission | Coote et al 1972,<br>Nielson et al 1976 |
| Trace Element Composition (Destructive): | |
| Optical Emission Spectography | Cann & Renfrew 1964 |
| Atomic Absorption Spectrophotometry | Wheeler & Clark 1977 |
| Atomic Absorption & Flame Emission | Armitage et al 1972 |
| Radiochemical NAA | Bird, Duerden & Wilson 1981 |
| Other Methods (not in common use): | |
| U - Th Natural Beta Emmission | Leach et al 1978 |
| Mossbauer Spectroscopy | Chavez-Rivas et al 1980 |
| Magnetic Properties | McDougall et al 1983 |
| Thermoluminescence | Huntley & Bailey 1978 |
| Strontium Isotope Analysis | Gale 1981 |
| Fission Track Age Analysis | Durrani et al 1971,<br>Miller & Wagner 1981 |

Characterization by minor and trace element concentrations is now accepted as the most powerful technique available. Fully quantitative neutron activation, x-ray fluorescence, and the new ion beam techniques (proton-induced x-ray emission PIXE, and proton-induced gamma-ray emission PIGME) all require that the samples be uniform, ie. ground or dissolved, but do not destroy them during analysis, so that a repetition of any analysis is theoretically possible. The ion beam techniques PIXE and PIGME offer the added advantage of increased sensitivity and thus smaller sample sizes, but require an accelerator. NAA, widely used, necessitates access to a source of neutrons, and it leaves the samples moderately radioactive for several years. All four of these techniques also permit semi-quantitative analysis which can be carried out on archaeological material without altering its physical shape (see Bird, Duerden and Wilson 1983:440-451; Shotton and Hendry 1979:77-82), although the necessity for complex instrumentation and the problems associated with NAA-induced residual radioactivity of the artifacts remain.

The use of some trace-element detection methods for archaeological obsidian characterization is no longer` justifiable because they are completely destructive. For example, optical emission spectrography and atomic absorption spectrometry consume the sample during analysis, and any repetitions require further destruction of the artifact.

The feasibility of distinguishing obsidian sources on the basis of Mossbauer spectroscopy (Chavez-Rivas, Regnard and Chappert 1980, T.Tominaga and Y.Minai 1984), thermoluminescence (Huntley and Bailey 1978), and magnetic properties (McDougall, Tarling and Warren 1983), among others, has been demonstrated. These seldom-used methods indicate that if necessary, obsidian may be source-typed with a measure of success even in the absence of multi-trace-element detecting instruments, but they are not likely to replace the more powerful techniques.

In view of the above, certain criteria had to be met when choosing the technique to be used in this study. The criterion of non-destructiveness was judged most important. Since the analysis of artifacts was to be included, a method permitting completely non-destructive analysis, yielding semi-quantitative results, was judged preferable. Secondary criteria of cost-effectiveness, minimum of pre-treatment, speed and simplicity of analysis, and availability of the analytical equipment, were also considered. Among the non-destructive methods of trace element analysis in Table 1, energy-dispersive x-ray fluorescence is by far the cheapest, simplest, and fastest in use.

Such an energy-dispersive x-ray fluorescence spectrometer is readily available at Simon Fraser University. This spectrometer uses a high-energy x-ray tube plus a secondary target as its excitation source. At present, a choice of six secondary targets (S, Ti, Zn, Mo, Ag, and Sm) is available, making it possible to detect with a high degree of efficiency the K emission lines of elements in the range of the periodic table from Al to I, as well as the L emission lines of the heavier elements. This system offers far more flexibility and is potentially more powerful than energy-dispersive x-ray fluorescence instruments that use radioactive isotopes (for example, Am-241) as their excitation sources. Thus the spectrometer most easily available is not only based on the optimum method for non-destructive artifact analysis, but also offers the potential for efficient detection of a very wide range of elements. It was therefore chosen for this work.

# SECTION 1

# OBSIDIAN CHEMICAL CHARACTERIZATION AND GEOLOGICAL FLOW IDENTIFICATION

## Sample Selection

The key objectives of this section were to identify how many chemically distinct types of obsidian are present in the Mount Edziza Volcanic Complex, and to determine the geographic distributions of each of these chemical types. Where possible, the attempt was also made to correlate each chemical type with a specific geological obsidian flow, several of which are found within certain geological formations of the Complex.

The material for the sourcing study consisted of 174 obsidian rock samples. Over half of the rocks were unworked naturally-occurring obsidian pebbles collected from erosional contexts such as talus slopes, river gravels, or high altitude surface scatters that had eroded out of the underlying obsidian bedrock. These were collected by Fladmark and Nelson in 1977, and by Fladmark in 1982 as part of archaeological surveys in the area (Fladmark and Nelson 1977, Fladmark 1982). The number of samples collected at each locality varied between 3 and 24. Also included in the data base were obsidian rocks collected over a span of several field seasons between 1965 and 1981 by J.G. Souther of the Geological Survey of Canada and loaned by him for this study. These pieces were collected from distinct bedrock outcrops during well-documented geological survey transects, and are associated with specific geological formations within the Edziza Volcanic Complex (for example, the Spectrum Formation, and the Armadillo Formation). These bedrock samples are extremely valuable in a sourcing study, since they can be used to pinpoint the geological origins of obsidian samples from erosional contexts. Sample locations for all the pieces used in this study are shown in Figure 2, and their provenience is detailed in Appendix A.

FIGURE 2a: Obsidian sample locations: samples collected north of Raspberry Pass.

LEGEND:

| | |
|---|---|
| ◆ | Outcrop samples |
| ◐ | Gravel samples |
| ----- | Limits of existing glaciers |
| —— | Elevations in feet<br>Contour interval 500' |

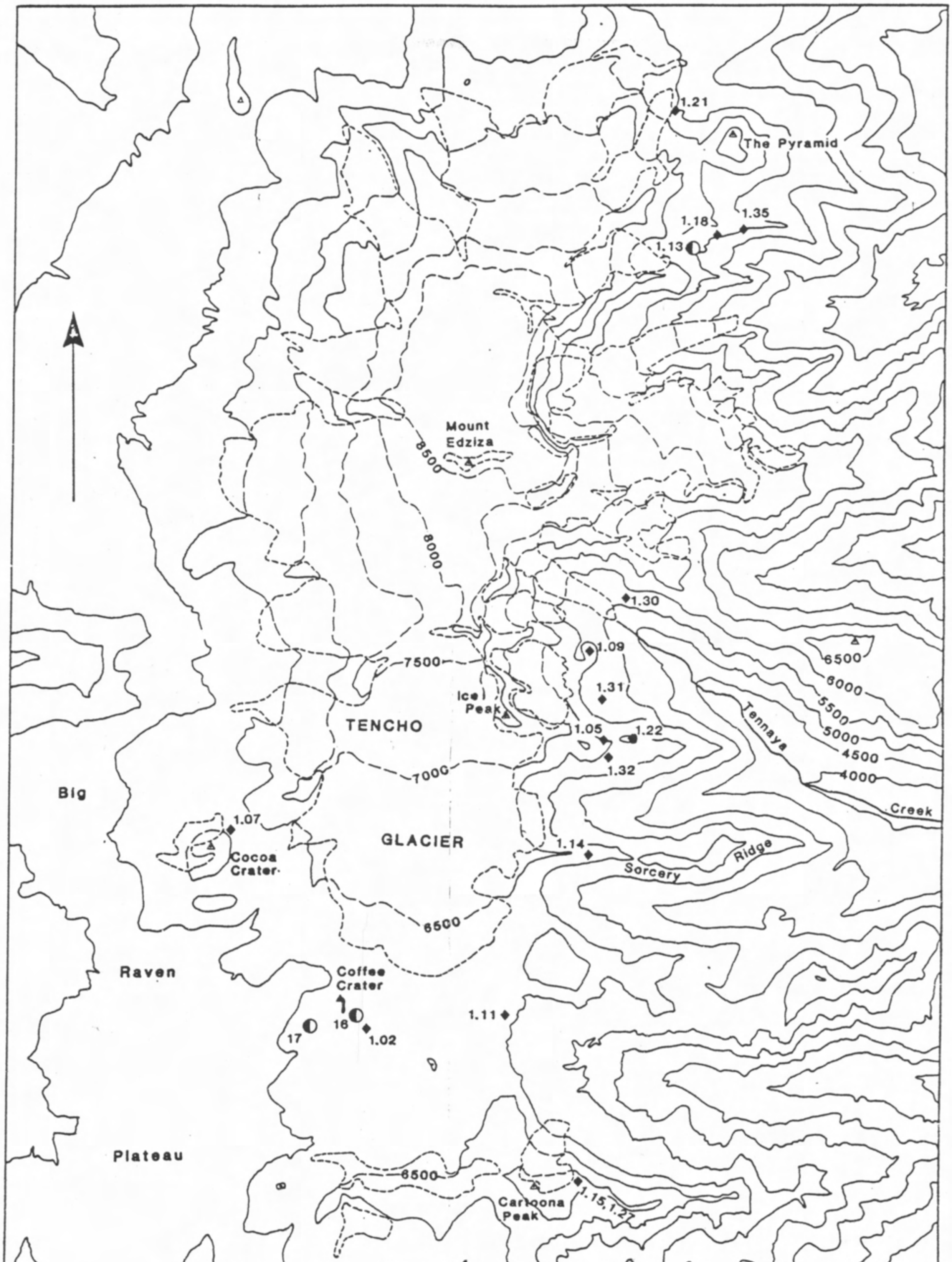

1.21
The Pyramid
1.18
1.35
1.13
Mount Edziza
8500
8000
1.30
1.09
6500
6000
5500
5000
4500
4000
Tennaya
Creek
7500
1.31
Ice Peak
TENCHO
1.05
1.22
1.32
7000
Big
1.07
Cocoa Crater
GLACIER
1.14
Sorcery
Ridge
6500
Raven
Coffee Crater
17
16
1.02
1.11
Plateau
6500
Cartoona Peak
1.15, 1.27
6000
5500
SCALE
0
1
2
3
4
5
KILOMETRES

FIGURE 2b: Obsidian sample locations: samples collected south of Raspberry Pass.

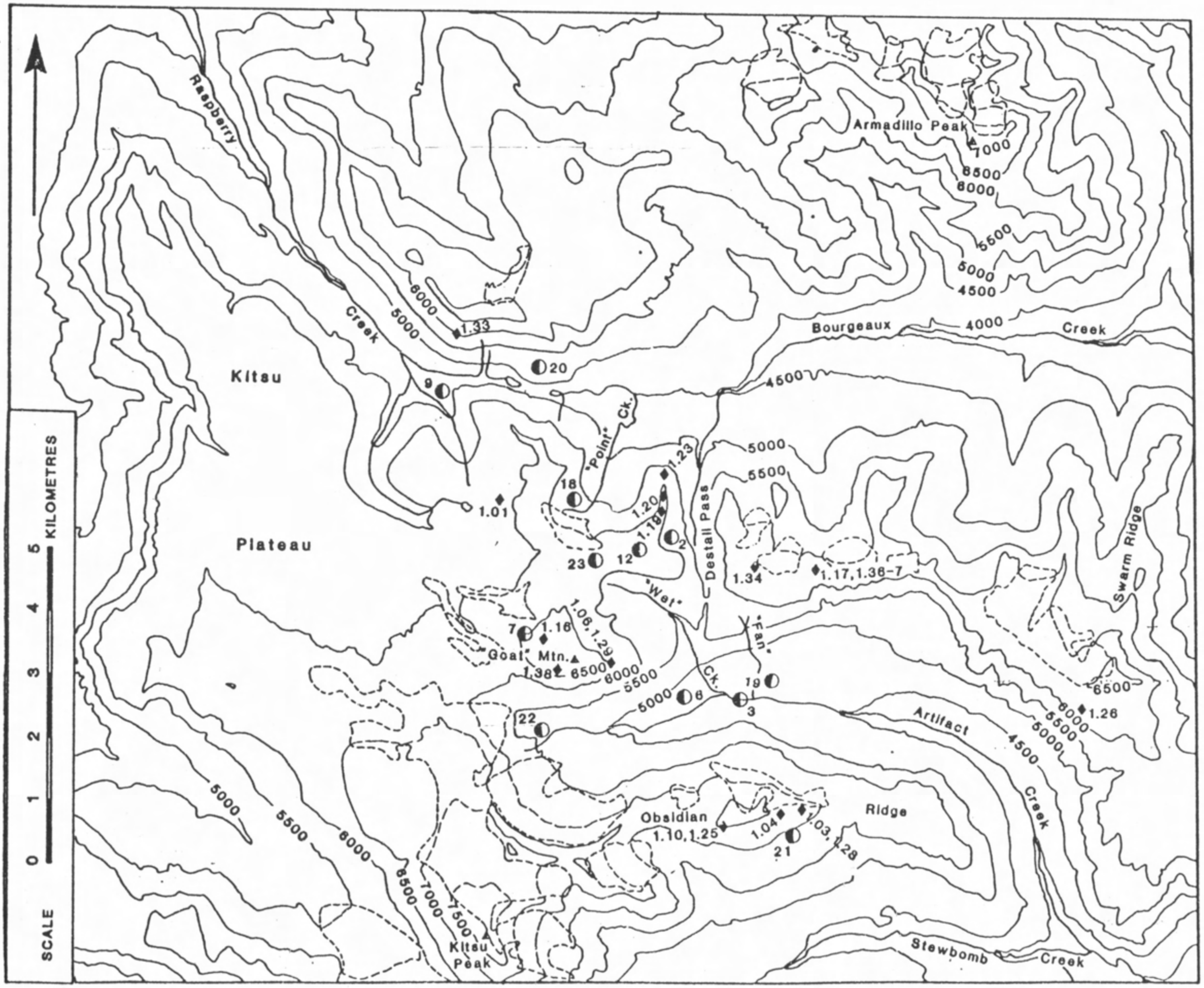
LEGEND:

◆ Outcrop samples

◐ Gravel samples

----- Limits of existing glaciers

—— Elevations in feet
Contour interval 500'


Raspberry Creek
Armadillo Peak
7000
6500
6000
5500
5000
4500
4000
Bourgeaux Creek
Kitsu Plateau
"Point" Ck.
Destall Pass
"Wet" Ck.
"Fan"
Goat Mtn.
Swarm Ridge
Artifact Creek
Obsidian Ridge
Kitsu Peak
Stewbomb Creek
1.33
20
9
18
1.01
1.23
1.20
1.18
2
12
23
1.34
1.17, 1.36-7
7
1.16
1.06, 1.29
1.38
19
6
3
22
1.26
1.10, 1.25
1.04
1.03, 1.28
21
SCALE
0 1 2 3 4 5 KILOMETRES

## Sample treatment

To ensure uncontaminated surfaces, all rocks were scrubbed with a stiff-bristled brush under running de-ionized water. A fresh flake was then detached for analysis. Those few that were too small to make flaking practical, were analyzed on their weathered outer surfaces, providing these were not so irregular that the rock could not be placed correctly over the active detection area. This decision was based on the previous work of Nelson, D'Auria and Bennett (1975), who indicated that no significant amount of chemical alteration of the relevant trace elements takes place in the cortex of an obsidian rock.

## Research Design

A blind experiment was conducted, in which the number and the locations of the obsidian flows under study were unknown. The locations of the rock samples submitted by J.G. Souther (samples 1.01 to 1.38) were completely unknown. The locations of the obsidian samples collected by the archaeologists were known. However, since they were sampled from very large erosional contexts such as coarse river gravels and moraines, and past erosive action made "mixtures" commonplace, these were judged unlikely to represent pure obsidian flows.

Duplicate analyses of some samples were occasionally performed. An analysis was repeated if the original result gave a low total number of counts, indicating that the sample missed the active detection area in the instrument. In all, 32 of the original 174 rock samples were analysed twice, and the complete data set used for chemical type characterization consisted of 206 obsidian spectra.

## Analytical Conditions

Chemical type differentiation of the obsidian samples was accomplished through the use of energy-dispersive x-ray fluorescence (ED-XRF).

The apparatus and method used here were developed by Nelson, D'Auria and Bennett (1975). The equipment used consisted of an Au-anode x-ray tube, a liquid-nitrogen cooled Si(Li) detector, and a pulse amplifier, all supplied by Kevex Corp. (California), plus a Nuclear Data (ND66) multichannel pulse-height analyzer. A Ag secondary target and filter were chosen for this application. The sample chamber held up to 16 samples for automatic sequential analysis. Sample changing and data collection were done automatically under the control of an IBM PC-XT microcomputer. The samples were placed into aluminium sample cups (3.5 cm diameter) with 0.00015" mylar spectrofilm screens and analyzed in air for 10 minutes.

The use of a Ag secondary target, under operating conditions of 40 keV and 20 mA, permitted the detection of x-rays in the energy range of 2.8 keV to 22.2 keV. This corresponds to the range of K-alpha x-rays from the elements in the portion of the periodic table between Ar and Mo (Z=18 to 42). Typical spectra observed for the Edziza obsidians are shown in Figure 5 (p. 34-36).

A narrow-beam collimator (2.6 mm diameter) was placed in front of the detector, so that the active detection area was an irregular ellipsoid of approx. 0.5 $cm^2$. The characteristic x-rays emitted by the elements in an obsidian sample were detected by the Si(Li) detector and these data were stored in 512-channel groups in the pulse-height analyzer. From there the spectra were automatically written onto a magnetic tape and transferred to the SFU mainframe computer for further analysis.

## Data Reduction

The spectra were analysed for peak energies and intensities using a curve-fitting computer program GAMANAL (Gunnick and Niday 1972). This program fits a polynomial function to each peak it recognizes, calculates the peak area by integration, and calculates and subtracts from the total peak the background continuum. It also compares the mathematically derived function with the experimental data. This allows for fine-tuning of the calibration parameters for a best fit. The difference between an ideal-shaped peak and the peak actually detected can also be used as a measure of the instrument's efficiency in detecting the element in question.

GAMANAL holds two advantages over more primitive peak extraction routines. One is that it recognizes weak peaks more easily. More importantly, it resolves overlapping peaks (for example, Nb K-alpha + Y K-beta) and separates them with a resolution of 0.02 keV. It was not able to separate the Rb K-beta from the Y K-alpha peak since these occur within 2.9 eV of each other. This separation was accomplished mathematically during later stages of the analysis. The disadvantages of GAMANAL are that it is more time-consuming than the simple peak-extraction routine of the ND66 pulse-height analyzer, and that it fails when it encounters a steeply-rising continuum such as that under the Compton and Rayleigh scatter peaks. For this reason, these scatter peaks were characterized by the sum of the five highest channels over each peak.

Peaks corresponding to the K-alpha and some K-beta x-ray emissions of the following elements were detected: K, Ca, Ti, Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, and Nb. A peak which corresponds to the L emission line of Pb was also detected.

## Reproducibility

To determine which of the thirteen elements detected would be most useful for flow discrimination given a reasonable measurement duration, a time-test was performed. A single specimen was analysed nine consecutive times for durations of 120 seconds to 6 hours. Its position was not changed between the analyses. Peak areas were then plotted against time on a log-log graph (Fig. 3). It was found that peak area was strongly linearly correlated with duration of analysis for the K-alpha emission lines of Fe, Rb, Y, Zr, and Nb. These correspond to the strongest five peaks in the obsidian spectrum. However, the peak areas corresponding to the elements K, Ca, Ti, Mn, Zn, Ga, Pb, and Sr, showed considerable scatter from linearity in all analyses of less than one hour's duration. This scatter is due to very low detection efficiencies of the instrumental setup for the elements at the low-energy end of the spectrum (the elements K to Mn), and to poor counting statistics and low computer peak-extraction efficiencies associated with weak peaks (Ga, Pb, and Sr). Reliable detection and extraction of these weak peaks would have required an analysis period of 1 to 1.5 hours per sample with this instrumental setup. This was judged impractical.

It was decided, therefore, to attempt to differentiate the full set of obsidian samples into distinct chemical types on the basis of the five strongest peaks detected in each spectrum (which correspond to the K-alpha emission lines of Fe, Rb, Y, Zr, and Nb), and to use a 10-minute measurement period per sample. Should these five elements have proved inadequate for successful flow discrimination, measurements of the lighter elements K, Ca, Ti, and Mn could have been performed using a Zn secondary target. This target would have detected them with a higher efficiency (see Cormie 1981:61-62,101-102). However, this was later found to be unnecessary.

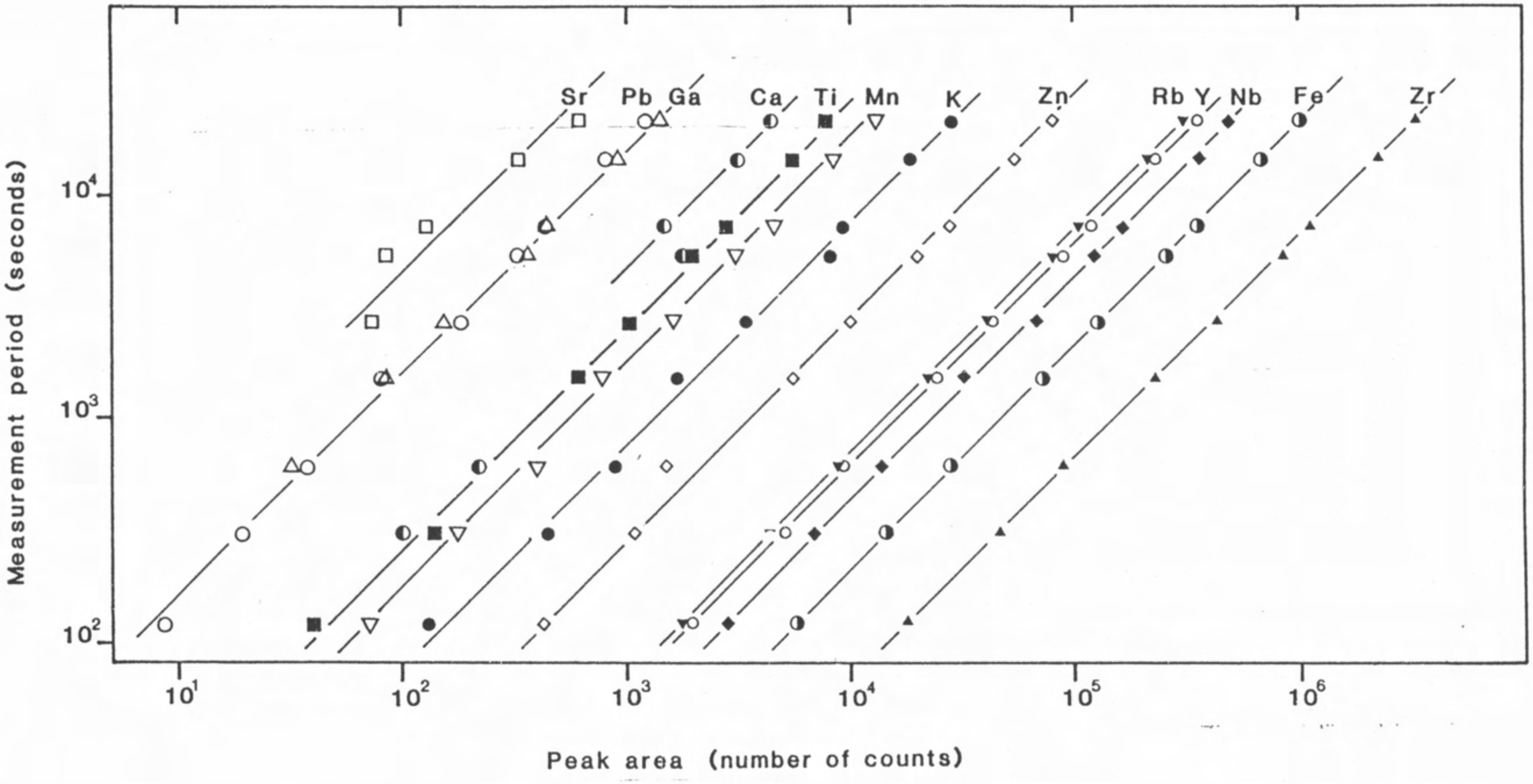


Figure 3: Time-test results: element peak areas as a function of the measurement period for nine consecutive analyses of an obsidian rock sample JSTD.

Instrumental reproducibility was empirically determined for this study by 15 non-consecutive analyses of a single specimen (Table 2). The results indicate that regardless of the normalization used (for a discussion of normalization procedures, see below), only the elements Fe, Rb, Y, Zr, and Nb, and the Rayleigh scatter peak, had a standard deviation of less than or equal to 5% from the mean. Except for Zn (which had a 7% standard deviation), all other elements deviated by ten or more percent from the mean. For many elements (Ca, Ti, Ga, Sr) this deviation approached or exceeded 40%. This reproducibility test confirmed that the five elements chosen on the basis of the time-test for chemical characterization purposes had the lowest standard deviations among the thirteen elements detected. It also suggested that these deviations were sufficiently low that a 10-minute measurement period per sample was reasonable.

## TABLE 2

### Instrumental Reproducibility - 15 Nonconsecutive Analyses of JSTD

| Element/ Compton Ratio | Mean | Standard Deviation | % Deviation |
|---|---|---|---|
| K | 6.74 | 0.75 | 11 |
| Ca | 0.68 | 0.26 | 38 |
| Ti | 1.71 | 0.89 | 52 |
| Mn | 3.34 | 0.67 | 20 |
| Fe | 264.35 | 13.78 | 5 |
| Zn | 13.77 | 0.99 | 7 |
| Ga | 2.49 | 1.06 | 43 |
| Pb | 3.24 | 0.59 | 18 |
| Rb | 80.13 | 2.69 | 3 |
| Sr | 0.57 | 0.22 | 39 |
| Y | 87.62 | 3.90 | 4 |
| Zr | 843.14 | 30.45 | 4 |
| Nb | 123.34 | 6.59 | 5 |
| Rayleigh | 704.31 | 8.15 | 1 |

| Element/Zr Ratio | Mean | Std. Dev. | % Deviation |
|---|---|---|---|
| K | 7.99 | 0.82 | 10 |
| Ca | 0.19 | 0.31 | 163 |
| Ti | 2.02 | 1.04 | 51 |
| Mn | 3.97 | 0.87 | 22 |
| Fe | 313.46 | 9.89 | 3 |
| Zn | 16.34 | 1.12 | 7 |
| Ga | 2.93 | 1.25 | 43 |
| Pb | 3.85 | 0.75 | 19 |
| Rb | 95.05 | 1.40 | 1 |
| Sr | 0.46 | 0.25 | 54 |
| Y | 103.90 | 1.99 | 2 |
| Nb | 146.26 | 4.99 | 3 |
| Rayleigh | 907.75 | 37.75 | 4 |

## Other Methods

X-ray electron spectroscopy (XES, or ESCA) was also investigated during the early stages of this study. This method detected elements (for example, Na and Si) which could not be detected with the ED-XRF setup above. The ESCA method was applied to flow discrimination on the basis of bulk elements. It was partly successful in distinguishing the two flows tested. Thus, it may be used to distinguish between some of the flows which are not very closely related. However, it was not sufficiently sensitive to distinguish reliably between flows which are very similar in their bulk element compositions. These results are summarized and compared with the results of ED-XRF analysis and WD-XRF analysis in Appendix B.

## Data Normalization

The grouping of the 204 obsidian spectra into several discrete chemical types was based on the variation in the relative intensities of the elemental peaks in the ED-XRF spectra. Once the GAMANAL peak extraction was completed, all 204 obsidian spectra were analysed on an IBM 4341 mainframe computer at Simon Fraser University using MIDAS, a computer program for data manipulation and statistical analysis (Fox and Guire 1976).

All element peaks were normalized to the Compton scatter peak. The Compton scatter peak was chosen for normalization because it is proportional to the average atomic number of the sample being analyzed. A normalization to the Compton peak thus provides a semi-quantitative measure of the absolute concentrations of the elements identified.

In the original work of Nelson, D'Auria and Bennett (1975), normalization to the Zr peak rather than the Compton peak was used. The Zr peak was chosen for normalization by Nelson, D'Auria and Bennett as "it is relatively intense in all the source types studied and is unlikely to be subject to weathering or surface contamination effects" (ibid:89). During the course of this work, however, it became apparent that the intensity of the Zr peak varied a great deal between the chemical types observed (compare types 7 and 10 in Figure 5), and so the decision was made to use the Compton peak instead.

The Zr normalization was done as well, for two reasons. First, methodological consistency with previously reported work on Mt. Edziza obsidian (ibid.) was judged important. Secondly, this procedure permitted a comparison of the discrimination success achieved with the two different methods of normalization. This comparison showed whether both methods gave the same result, and which method was more successful in separating the full data set into discrete chemical types.

## Scatterplots

Cartesian scatterplots of the data (Figure 4) were examined for the elements Fe, Rb, Y, Zr, and Nb, expressed as ratios with respect to the Compton peak. Scatterplots for the elements Fe, Rb, Y, Nb, expressed as ratios with respect to the Zr peak, were also examined. Scatterplots are a method of graphical data representation in which two variables can be examined at a time, and which allows clusters of points to be recognized by inspection.

This simple graphical procedure separated the data set into ten distinct chemical groups. The four chemical types corresponding to those already reported by Nelson, D'Auria and Bennett (1975) were numbered 1 to 4, accordingly. The remaining six types were arbitrarily assigned numbers 5 to 10.

Examination of the scatterplots presented in Figure 4 confirms that the spectra are clustered into ten distinct groups. Figure 4a separates the data points into six subsets. Two of these subsets represent mixtures of more than one type: types 4 and 5 form a single cluster, and types 1, 2, 6, and 8 form a single large cluster. Figure 4b shows the same data points, but the elements are normalized to the Zr peak. This scatterplot shows that the cluster formed by types 4 and 5 has split into two widely separated groups. Type 6 has also split from types 1, 2, and 8. Figures 4c and 4d are included to show that types 6 and 3 are both distinct from the cluster which represents types 1, 2, and 8, regardless of the normalization used to distinguish them. Figures 4e and 4f are presented to show the separation of type 1 from types 2 and 8. Finally, figures 4g and

4h show that types 2 and 8 may be separated on the basis of their Nb/Zr ratios. However, these two types overlap in both their Fe/Zr ratios and their Rb/Zr ratios. Also, they cannot be distinguished on the basis of their element/Compton ratios.

On the basis of the above results, all relative element ratios of each cluster representing a single chemical type were described statistically: the means and the standard deviations for each element ratio of each type were calculated. The mean and standard deviation values of these element ratios in all ten Mount Edziza chemical obsidian types are presented in Table 3.

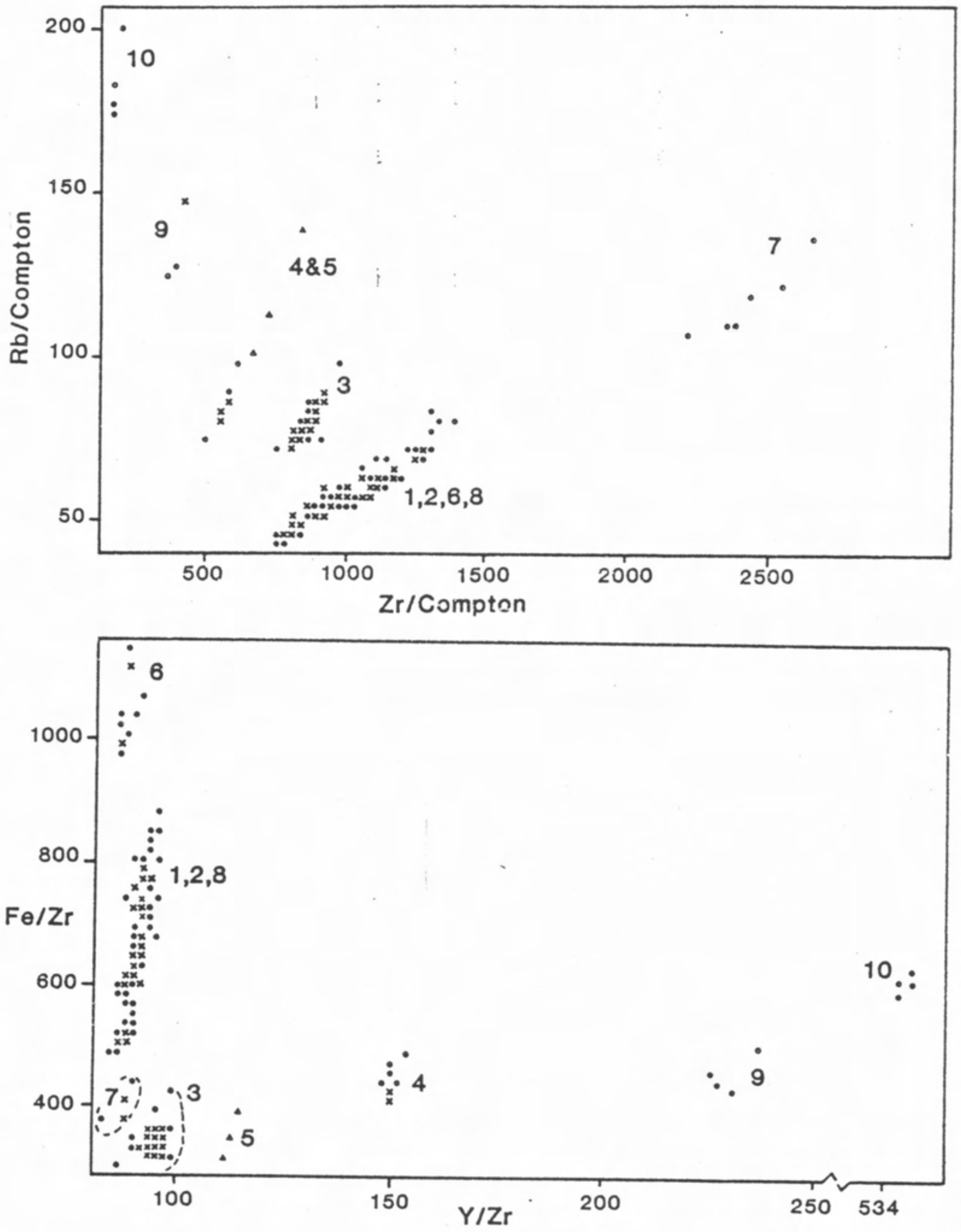


Figure 4: Normalized scatterplots showing the separation of all obsidian samples into ten chemically distinct clusters.
a) Zr/Compton vs Rb/Compton
b) Y/Zr vs Fe/Zr

The above two scatterplots demonstrate the individual clustering of types 3, 4, 5, 6, 7, 9, and 10. Closed circles represent a single data point; crosses represent two or more overlapping data points.

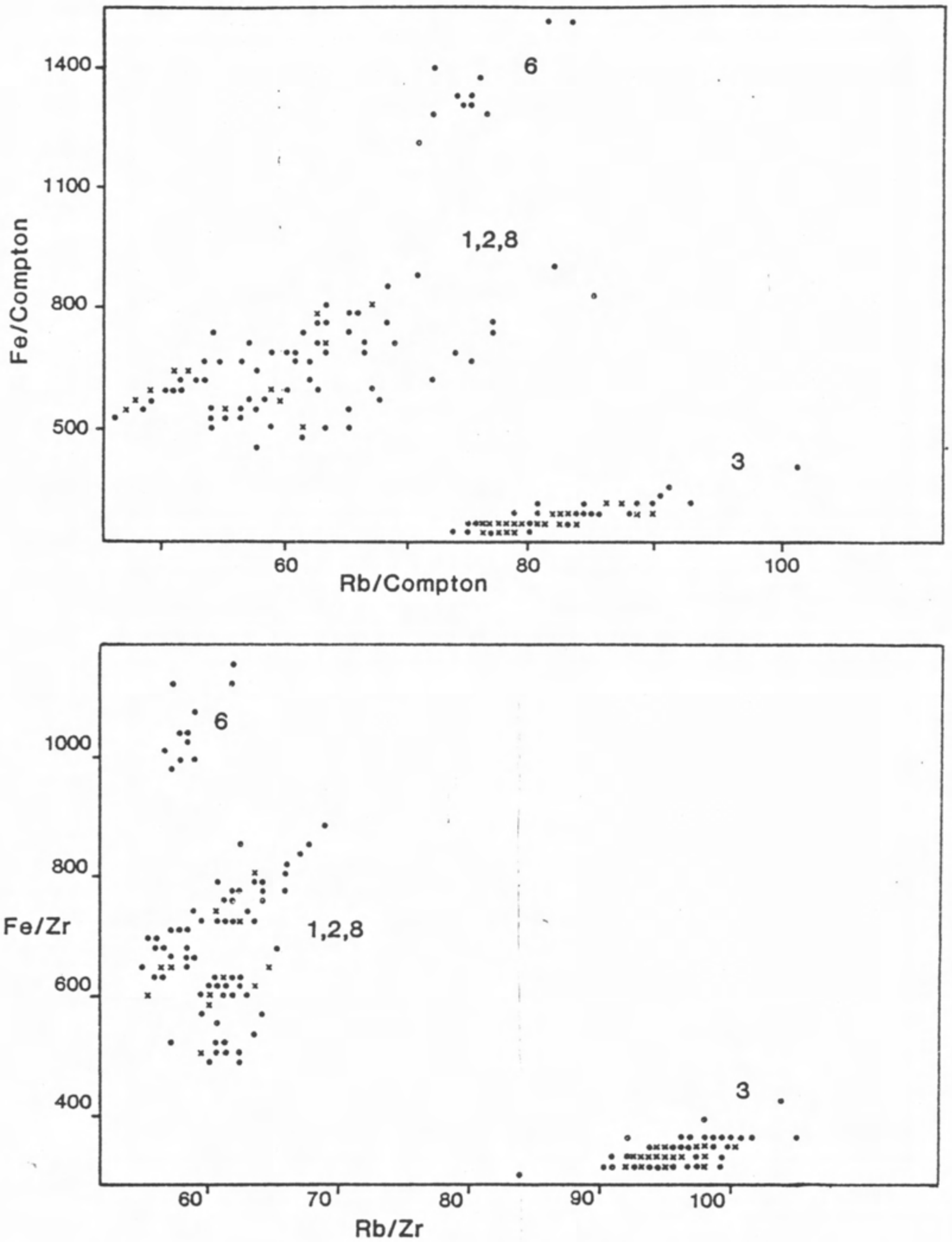


Figure 4: Normalized scatterplots showing the separation of all obsidian samples into ten chemically distinct clusters.
c) Rb/Compton vs Fe/Compton
d) Rb/Zr vs Fe/Zr

The above two scatterplots demonstrate the individual clustering of types 3 and 6 from the cluster consisting of types 1, 2, and 8. This separation is apparent under both methods of data normalization. Closed circles represent a single data point; crosses represent two or more overlapping data points.

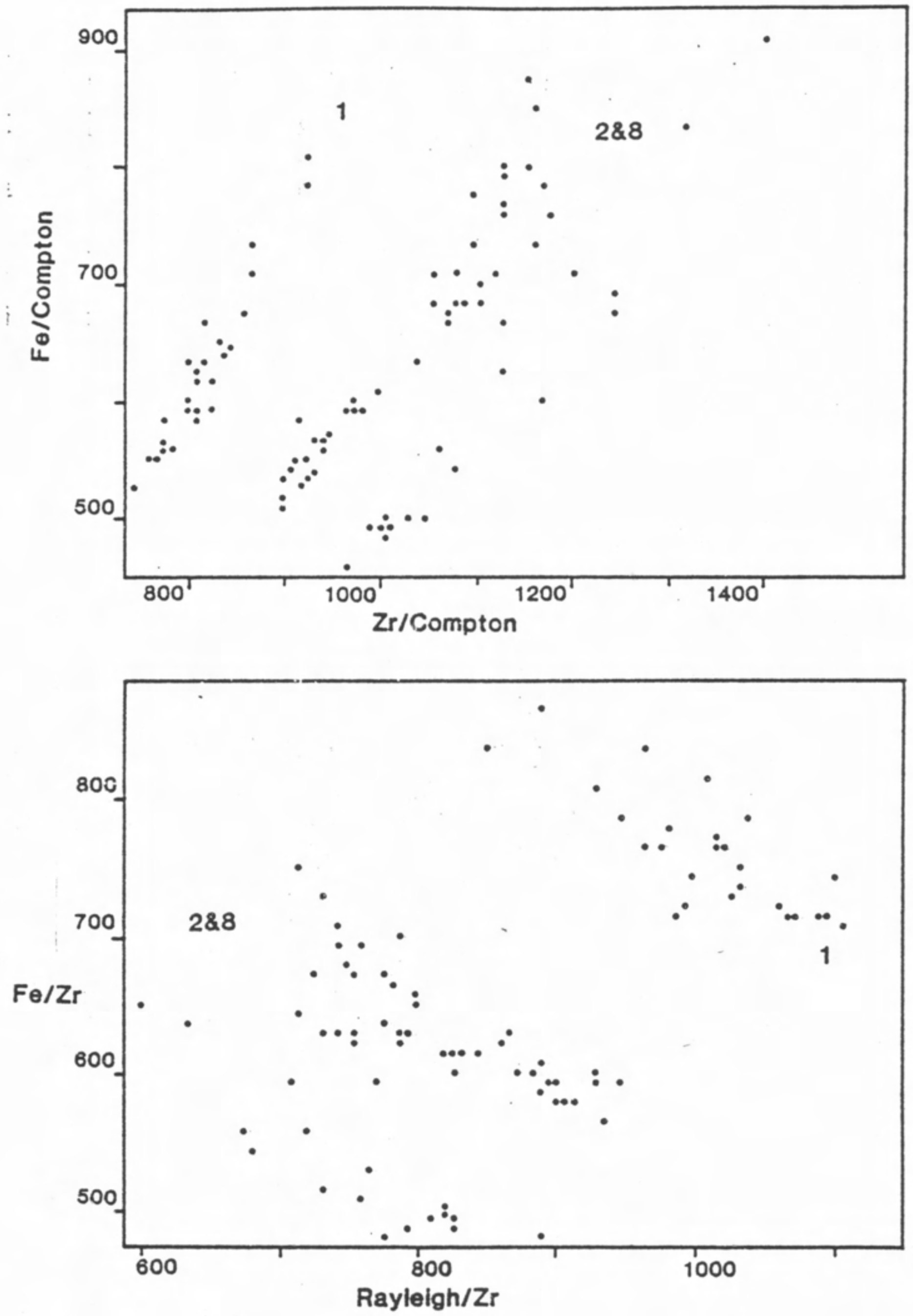


Figure 4: Normalized scatterplots showing the separation of all obsidian samples into ten chemically distinct clusters.
e) Zr/Compton vs Fe/Compton
f) Rayleigh/Zr vs Fe/Zr

The above two scatterplots demonstrate the individual clustering of type 1 from the cluster consisting of types 2 and 8. This separation is apparent under both methods of data normalization.

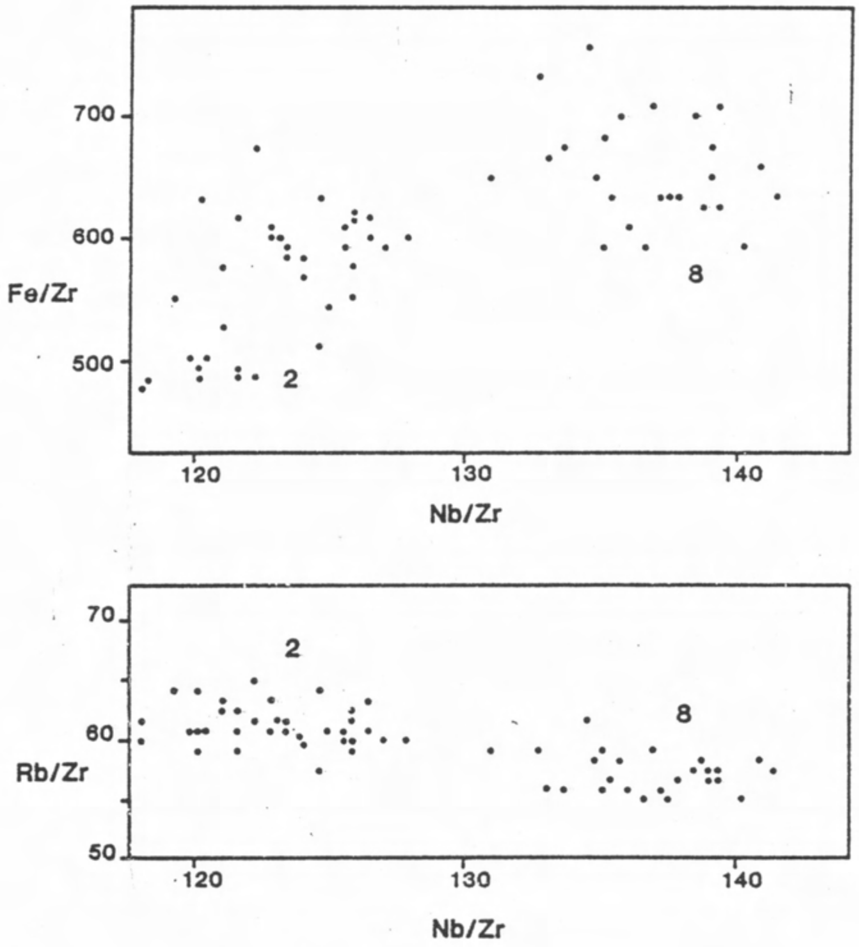


**Figure 4:** Normalized scatterplots showing the separation of all obsidian samples into ten chemically distinct clusters.
g) Nb/Zr vs Fe/Zr
h) Nb/Zr vs Rb/Zr

The above two scatterplots demonstrate the separation of type 2 from type 8. This separation is possible only on the basis of the Nb/Zr ratio; the Fe/Zr and the Rb/Zr ratios of these two types overlap.

# TABLE 3

## Relative element concentrations in ten Mount Edziza obsidian flows

| Flow # | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| n | 26 | | 34 | | 80 | | 9 | | 3 | | 11 | | 6 | | 24 | | 4 | | 4 | |
| | x | s | x | s | x | s | x | s | x | s | x | s | x | s | x | s | x | s | x | s |
| A: element/Compton ratios | | | | | | | | | | | | | | | | | | | | |
| K | 9.2 | 2.0 | 8.4 | 1.4 | 7.4 | 1.2 | 7.9 | 1.9 | 7.1 | 1.8 | 13.6 | 2.0 | 9.8 | 1.6 | 9.6 | 1.5 | 6.8 | 1.0 | 5.7 | 1.0 |
| Ca | 1.0 | 1.3 | 0.7 | 1.1 | 0.2 | 0.5 | 0.9 | 1.1 | 0.0 | 0.0 | 5.5 | 0.9 | 0.0 | 0.0 | 0.8 | 1.4 | 0.2 | 0.4 | 0.6 | 1.2 |
| Ti | 5.7 | 1.3 | 4.6 | 0.5 | 2.0 | 0.8 | 1.8 | 0.8 | 1.0 | 0.9 | 11.4 | 2.0 | 4.5 | 0.8 | 5.9 | 0.7 | 0.3 | 0.6 | 0.3 | 0.6 |
| Mn | 7.9 | 1.1 | 6.9 | 1.0 | 3.4 | 0.9 | 2.5 | 0.6 | 2.8 | 1.1 | 27.5 | 2.5 | 12.5 | 1.5 | 9.2 | 1.3 | 1.6 | 0.3 | 0.3 | 0.7 |
| Fe | 628.2 | 69.9 | 562.4 | 62.5 | 273.0 | 26.4 | 239.8 | 26.6 | 250.5 | 55.7 | 1349.6 | 96.9 | 955.2 | 126.8 | 746.6 | 69.5 | 170.9 | 22.0 | 94.7 | 5.2 |
| Zn | 18.1 | 2.3 | 19.5 | 2.8 | 14.3 | 1.8 | 11.5 | 1.2 | 13.9 | 2.8 | 24.2 | 2.3 | 43.2 | 6.1 | 24.9 | 3.0 | 12.7 | 1.0 | 10.2 | 0.9 |
| Ga | 3.3 | 1.0 | 3.3 | 1.0 | 2.9 | 0.9 | 3.1 | 0.7 | 2.5 | 2.2 | 4.0 | 0.7 | 3.3 | 1.8 | 3.7 | 1.1 | 2.9 | 1.1 | 2.7 | 0.6 |
| Pb | 1.8 | 0.7 | 2.3 | 1.0 | 3.1 | 0.5 | 2.0 | 0.6 | 4.3 | 0.7 | 3.2 | 0.6 | 7.5 | 0.8 | 3.3 | 0.4 | 5.3 | 0.5 | 6.4 | 0.8 |
| Rb | 51.9 | 4.4 | 61.3 | 5.7 | 81.8 | 5.0 | 87.4 | 6.4 | 119.6 | 20.4 | 75.5 | 3.8 | 119.1 | 10.8 | 64.6 | 4.9 | 139.7 | 12.6 | 186.1 | 11.4 |
| Sr | 0.0 | 0.0 | 0.1 | 0.4 | 0.0 | 0.0 | 3.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Y | 73.4 | 4.8 | 85.5 | 8.6 | 75.0 | 3.7 | 83.8 | 5.3 | 83.2 | 8.8 | 110.1 | 3.3 | 213.6 | 16.5 | 102.5 | 6.7 | 87.5 | 6.4 | 86.5 | 3.4 |
| Zr | 818.2 | 44.6 | 999.3 | 92.6 | 852.4 | 38.0 | 560.7 | 32.0 | 737.5 | 77.1 | 1292.8 | 28.6 | 2469.5 | 155.6 | 1131.0 | 70.1 | 384.4 | 27.7 | 161.8 | 7.1 |
| Nb | 104.3 | 4.9 | 123.1 | 11.5 | 124.5 | 4.8 | 140.4 | 7.9 | 143.5 | 12.5 | 211.2 | 4.2 | 324.7 | 18.8 | 154.9 | 7.8 | 148.3 | 9.1 | 147.8 | 6.3 |
| Ray. | 819.4 | 13.8 | 822.4 | 14.0 | 766.0 | 12.1 | 760.8 | 8.3 | 751.5 | 13.9 | 941.3 | 14.6 | 894.8 | 28.0 | 843.5 | 12.3 | 739.8 | 6.0 | 721.7 | 6.8 |
| B: element/Zr ratios | | | | | | | | | | | | | | | | | | | | |
| K | 11.2 | 2.0 | 8.4 | 1.4 | 8.7 | 1.2 | 14.0 | 2.8 | 9.6 | 1.4 | 10.5 | 1.5 | 3.9 | 0.5 | 8.5 | 1.4 | 17.5 | 1.4 | 35.0 | 6.1 |
| Ca | 1.2 | 1.6 | 0.7 | 1.1 | 0.2 | 0.6 | 1.6 | 2.0 | 0.0 | 0.0 | 4.2 | 0.7 | 0.0 | 0.0 | 0.7 | 1.2 | 0.5 | 0.9 | 3.9 | 7.8 |
| Ti | 7.0 | 1.3 | 4.6 | 0.6 | 2.4 | 0.9 | 3.1 | 1.3 | 1.3 | 1.1 | 8.8 | 1.5 | 1.8 | 0.3 | 5.2 | 0.6 | 0.8 | 1.6 | 1.8 | 3.6 |
| Mn | 9.7 | 1.0 | 6.9 | 1.1 | 3.9 | 1.0 | 4.5 | 1.0 | 3.7 | 1.2 | 21.3 | 1.7 | 5.0 | 0.3 | 8.1 | 0.9 | 4.1 | 0.5 | 1.9 | 3.8 |
| Fe | 765.8 | 45.0 | 564.3 | 54.1 | 319.8 | 19.0 | 426.6 | 25.0 | 337.0 | 38.9 | 1043.3 | 60.9 | 385.5 | 28.0 | 659.8 | 42.1 | 443.4 | 30.9 | 585.1 | 11.1 |
| Zn | 22.1 | 1.7 | 19.5 | 1.8 | 16.8 | 1.5 | 20.4 | 1.2 | 18.7 | 1.8 | 18.7 | 1.7 | 17.4 | 1.4 | 21.9 | 1.9 | 33.1 | 1.3 | 62.8 | 2.8 |
| Ga | 4.0 | 1.1 | 3.3 | 1.0 | 3.4 | 1.0 | 5.5 | 1.1 | 3.3 | 2.9 | 3.1 | 0.5 | 1.3 | 0.6 | 3.3 | 1.0 | 7.5 | 3.1 | 16.8 | 3.2 |
| Pb | 2.1 | 0.9 | 2.3 | 0.9 | 3.6 | 0.6 | 3.5 | 1.0 | 5.8 | 0.3 | 2.4 | 0.4 | 3.0 | 0.2 | 3.0 | 0.3 | 13.7 | 0.8 | 39.5 | 4.0 |
| Rb | 63.3 | 2.3 | 61.4 | 1.7 | 96.0 | 3.1 | 155.7 | 3.9 | 161.5 | 10.7 | 58.4 | 1.8 | 48.2 | 1.6 | 57.1 | 1.6 | 363.1 | 10.1 | 1149.4 | 22.7 |
| Sr | 0.1 | 0.4 | 0.1 | 0.4 | 0.0 | 0.0 | 6.2 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Y | 89.7 | 1.8 | 85.6 | 2.1 | 88.0 | 2.3 | 149.4 | 1.6 | 112.7 | 0.5 | 85.1 | 1.9 | 86.5 | 3.0 | 90.6 | 1.6 | 227.7 | 5.9 | 534.4 | 5.4 |
| Nb | 127.6 | 2.6 | 123.2 | 2.7 | 146.1 | 3.5 | 250.4 | 3.4 | 194.8 | 4.5 | 163.4 | 1.6 | 131.6 | 4.8 | 137.0 | 2.8 | 385.9 | 5.0 | 913.1 | 7.3 |
| Ray. | 1004.6 | 63.2 | 829.3 | 72.5 | 900.6 | 45.7 | 1360.7 | 76.4 | 1027.4 | 120.3 | 728.6 | 24.5 | 363.9 | 31.4 | 748.3 | 44.5 | 1931.9 | 137.0 | 4466.7 | 210.3 |

## Mount Edziza Obsidian Type Spectra

Figure 5 shows ten ED-XRF spectra characteristic of the ten chemical types distinguished above. It is observed from the graphs that several spectra are very similar to each other, while others are graphically distinct. Because obsidian is made up primarily of $SiO_2$ , a very low-Z substance, obsidian spectra in general show scatter peaks (Compton and Rayleigh) which are higher than the elemental peaks. The five chemical types #1, 2, 6, 7, and 8, are all characterized by extremely high Fe and Zr K-alpha peaks; in type 7 the Zr peak is even higher than the Compton scatter peak. Types 3, 4, and 5 also show high Fe and Zr peaks; however, Fe is considerably lower than Zr, and both are much lower than the Compton and Rayleigh scatter peaks. Spectra of types 9 and 10 are quite unlike the other eight; the elemental peaks are all much lower than the Compton, and the high Fe/high Zr configuration so typical of the other types is difficult or impossible to observe. Relative increases in Rb and Pb are observed instead.

## KEY TO NUMBERED PEAKS IN THE OBSIDIAN SPECTRA SHOWN IN FIGURE 5:

1. K K-alpha
2. Ca K-alpha (and K K-beta)
3. Ti K-alpha
4. Mn K-alpha
5. Fe K-alpha
6. Zn K-alpha
7. Ga K-alpha
8. Pb L-line
9. Rb K-alpha
10. Sr K-alpha
11. Y K-alpha (and Rb K-beta)
12. Zr K-alpha
13. Nb K-alpha (and Y K-beta)
14. Ag target Compton scatter
15. Ag target Rayleigh scatter

The prominent unnumbered peaks are from the K-beta emission lines of Fe, Zn, Zr, and Nb.

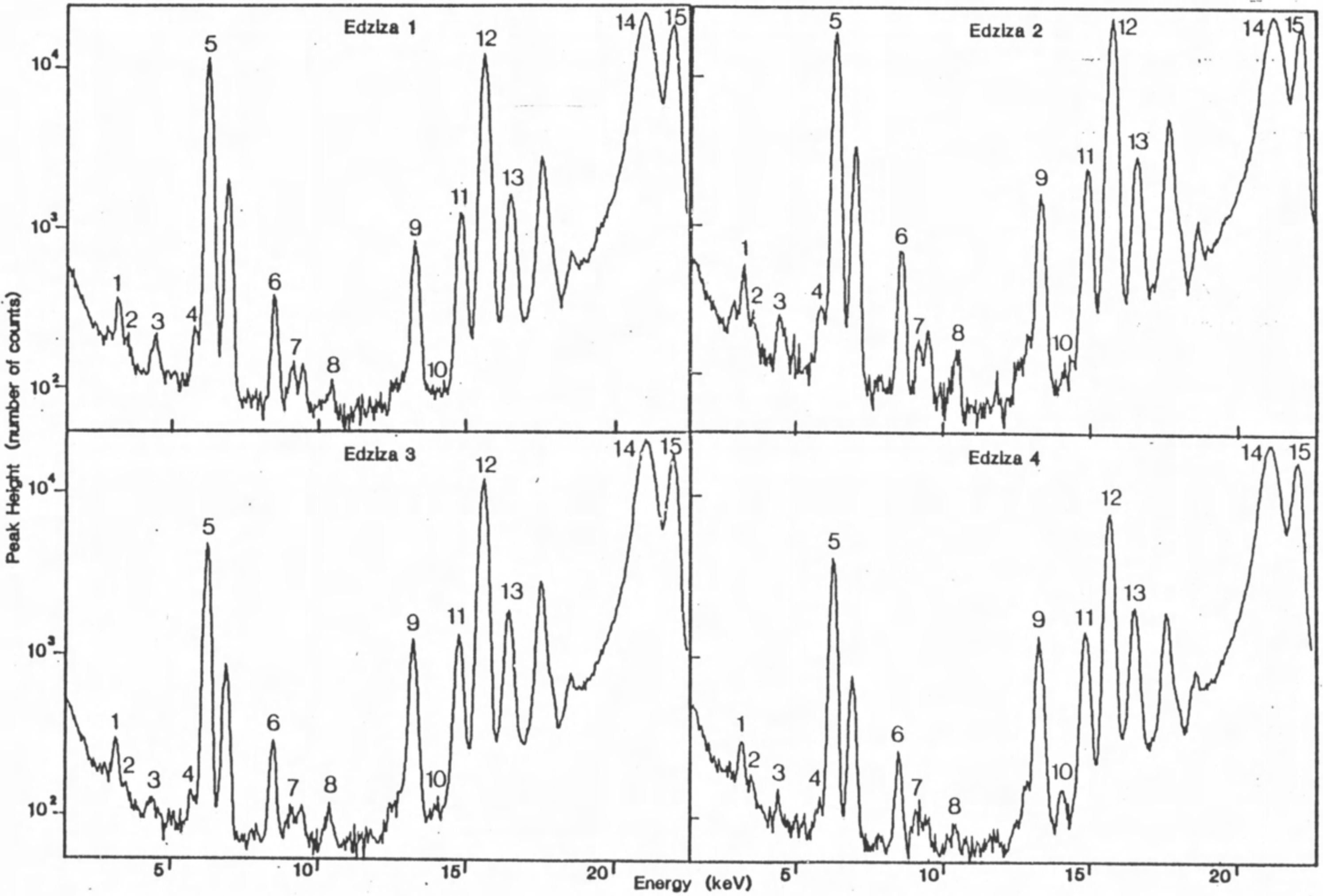


Figure 5: Typical ED-XRF spectra of ten chemical types of Mount Edziza obsidian.
a) chemical types 1 to 4.

## KEY TO NUMBERED PEAKS IN THE OBSIDIAN SPECTRA SHOWN IN FIGURE 5:

1. K K-alpha
2. Ca K-alpha (and K K-beta)
3. Ti K-alpha
4. Mn K-alpha
5. Fe K-alpha
6. Zn K-alpha
7. Ga K-alpha
8. Pb L-line
9. Rb K-alpha
10. Sr K-alpha
11. Y K-alpha (and Rb K-beta)
12. Zr K-alpha
13. Nb K-alpha (and Y K-beta)
14. Ag target Compton scatter
15. Ag target Rayleigh scatter

The prominent unnumbered peaks are from the K-beta emission lines of Fe, Zn, Zr, and Nb.

35b

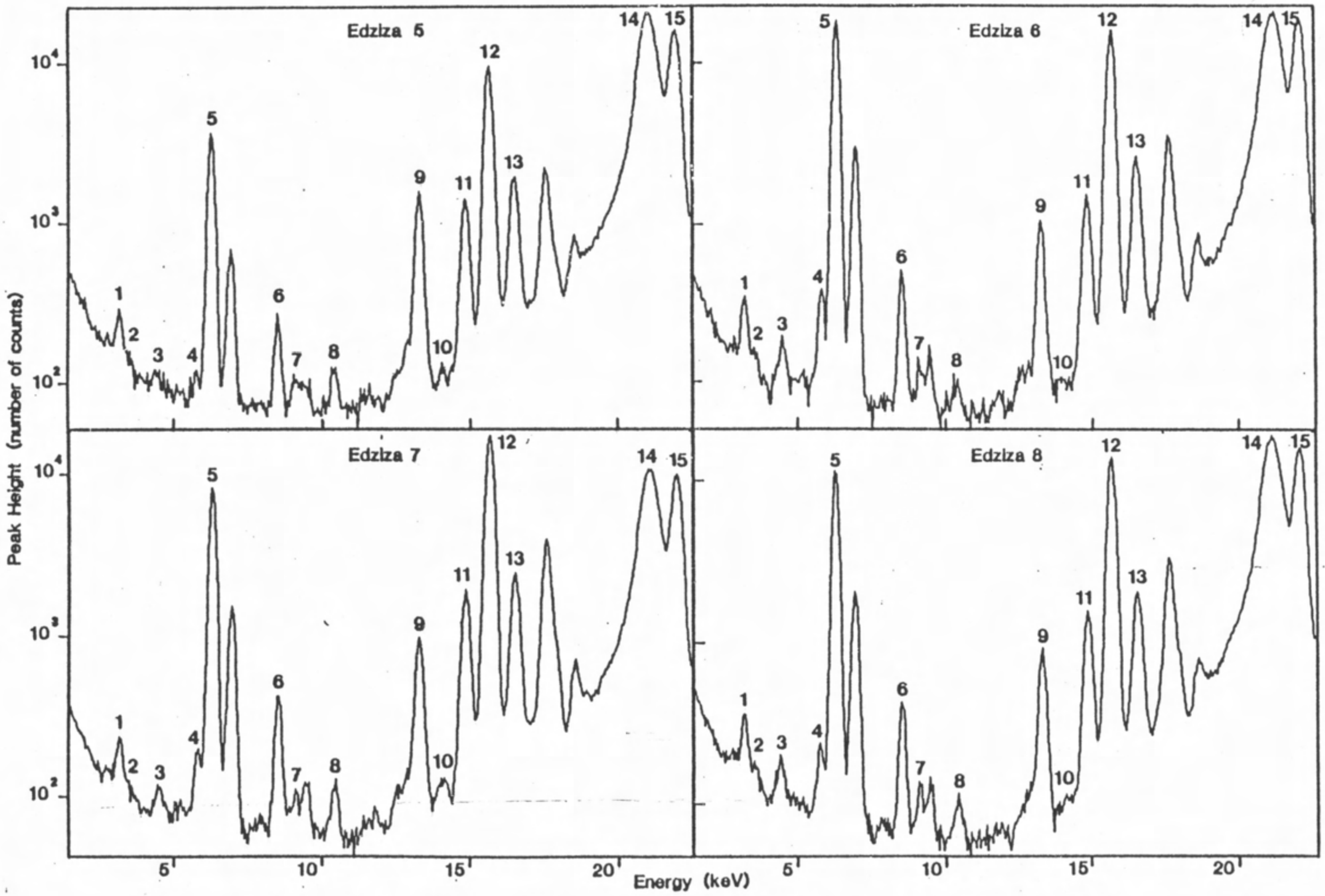


Figure 5: Typical ED-XRF spectra of ten chemical types of Mount Edziza obsidian.
b) chemical types 5 to 8.

KEY TO NUMBERED PEAKS IN THE OBSIDIAN SPECTRA SHOWN IN FIGURE 5:

1. K K-alpha
2. Ca K-alpha (and K K-beta)
3. Ti K-alpha
4. Mn K-alpha
5. Fe K-alpha
6. Zn K-alpha
7. Ga K-alpha
8. Pb L-line
9. Rb K-alpha
10. Sr K-alpha
11. Y K-alpha (and Rb K-beta)
12. Zr K-alpha
13. Nb K-alpha (and Y K-beta)
14. Ag target Compton scatter
15. Ag target Rayleigh scatter

The prominent unnumbered peaks are from the K-beta emission lines of Fe, Zn, Zr, and Nb.

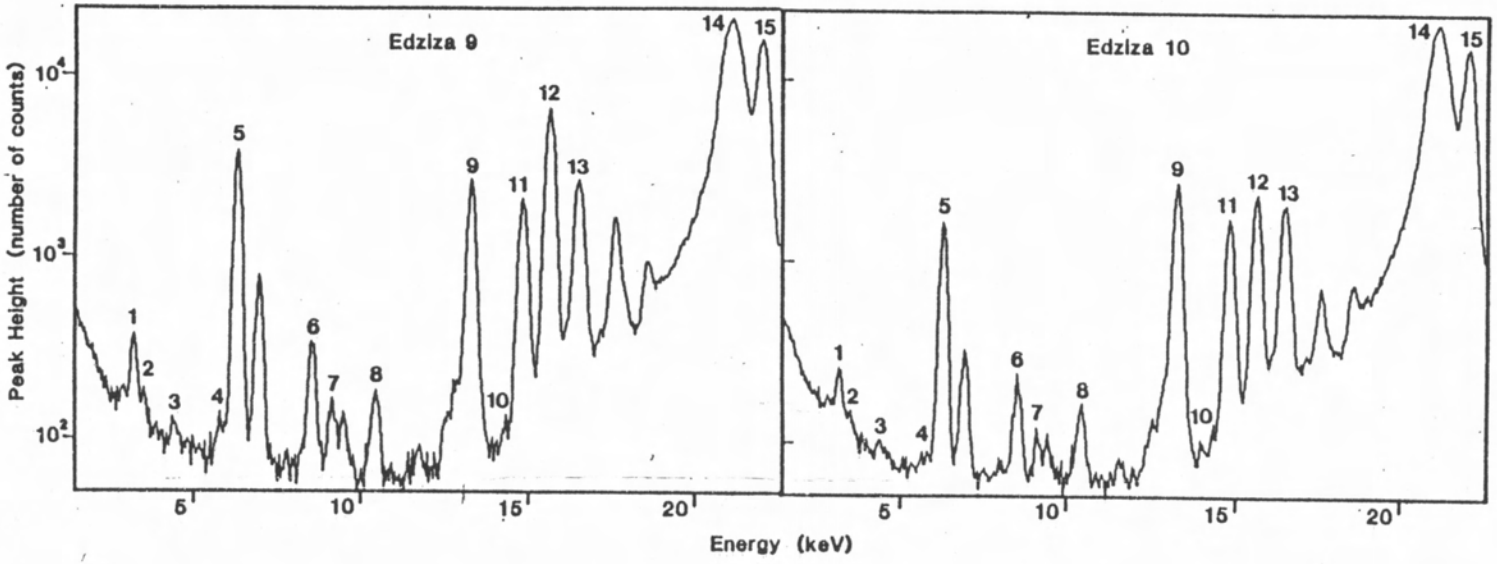


Figure 5: Typical ED-XRF spectra of ten chemical types of Mount Edziza obsidian.
c) chemical types 9 and 10.

## Statistical Treatment

As mentioned above, the average element/Compton and element/Zr ratios for each chemical type were calculated, and the statistical mean (x) and the standard deviation (s) of these element ratios are presented in Table 3 for all ten chemical types. The standard deviation refers to the distribution of the data points within each group, and is thus a measure of their scatter.

To verify that the ten chemical types identified on the basis of scatterplots are distinct on a quantitative statistical basis as well as a qualitative graphical basis, the element ratios were compared between the types.

The natural grouping of the points into ten discrete chemical types was confirmed to be non-overlapping at two standard deviations through the use of the A-coefficient statistic. The success of the A-coefficient is measured by its ability to distinguish two multivariate populations on the basis of the distance between the means of a given variable in both populations. Mathematically, the A-coefficient is expressed as follows:

$$A = \frac{x_{ik} - x_{jk}}{2s_{ik} + 2s_{jk}} \; ; \quad i \neq j$$

x = statistical mean
s = standard deviation
i,j = obsidian groups
k = element

Multivariate data sets are considered distinct if the distance between the group means of at least one of the variables is greater than an arbitrary rejection criterion. This rejection criterion was set here at two standard deviations from the mean of each element ratio. Separation between the two populations is thus achieved when the A-coefficient value for any one variable present in both populations is greater than 1 (Cormie 1981). A separation of two obsidian chemical types confirmed by this method indicates that for at least one element ratio, the distributions of the element ratio in the two types do not overlap at two standard deviations.

The A-coefficient was calculated comparing the mean element value in each chemical type with the mean values for the same element in the remaining nine types. The A-coefficient was calculated for all 13 relative element concentrations (element/Compton ratios). A similar set of A-coefficients was also calculated for the element/Zr ratios of all ten chemical types, for comparative purposes. All results are presented in Table 4.

The A-coefficient calculations confirm that all ten chemical types are statistically distinct according to the criterion defined above. In two cases, the distinction is based on a single A-coefficient. Types 1 and 2 are barely separable (the A-coefficient for their Fe/Zr ratios equals 1.02), although the scatterplots (see p. 30) show the type 1 cluster is clearly separated from the cluster composed of types 2 and 8. Since the A-coefficient is a univariate statistic, it can fail to confirm that clusters are distinct if their distributions are not normal, as is the case here. Types 2 and 8 are separable solely on the basis of their Nb/Zr ratios. The relative chemical similarities of these three types (1, 2, and 8) suggest that they may represent three obsidian flows which are closely related geologically. This possibility is investigated and confirmed in the section below.

## TABLE 4

## A-Coefficients for the ten chemical groups of Mount Edziza obsidian

| Groups: | 1&2 | 1&3 | 1&4 | 1&5 | 1&6 | 1&7 | 1&8 | 1&9 | 1&10 | 2&3 | 2&4 | 2&5 | 2&6 | 2&7 | 2&8 | 2&9 | 2&10 | 3&4 | 3&5 | 3&6 | 3&7 | 3&8 | 3&9 | 3&10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A: A-coefficients for element/Compton ratios | | | | | | | | | | | | | | | | | | | | | | | | |
| K | .12 | .28 | .17 | .28 | .54 | .07 | .06 | .42 | .59 | .19 | .07 | .20 | .75 | .22 | .21 | .34 | .56 | .08 | .05 | .97 | .42 | .40 | .15 | .40 |
| Ca | .06 | .22 | .01 | - | 1.03 | - | .04 | .23 | .07 | .15 | .06 | - | 1.21 | - | .02 | .17 | .02 | .23 | - | 1.91 | - | .15 | .00 | .12 |
| Ti | .33 | .90 | .97 | 1.09 | .87 | .30 | .04 | 1.46 | 1.43 | .96 | 1.08 | 1.25 | 1.37 | .02 | .54 | 1.93 | 1.87 | .09 | .32 | 1.70 | .80 | 1.29 | .64 | .62 |
| Mn | .27 | 1.15 | 1.66 | 1.21 | 2.72 | .90 | .26 | 2.38 | 2.22 | .92 | 1.41 | 1.00 | 2.96 | 1.16 | .52 | 2.12 | 2.01 | .28 | .15 | 3.49 | 1.91 | 1.31 | .74 | .96 |
| Fe | .25 | 1.84 | 2.01 | 1.50 | 2.16 | .83 | .42 | 2.49 | 3.56 | 1.63 | 1.81 | 1.32 | 2.47 | 1.04 | .70 | 2.32 | 3.45 | .31 | .14 | 4.37 | 2.23 | 2.47 | 1.06 | 2.83 |
| Zn | .13 | .47 | .97 | .42 | .66 | 1.49 | .64 | .85 | 1.27 | .56 | 1.00 | .50 | .46 | 1.33 | .46 | .90 | 1.26 | .49 | .05 | 1.22 | 1.83 | 1.11 | .30 | .79 |
| Ga | .01 | .10 | .07 | .12 | .19 | .01 | .10 | .11 | .20 | .09 | .06 | .12 | .21 | .00 | .11 | .09 | .18 | .04 | .07 | .31 | .06 | .19 | .02 | .08 |
| Pb | .16 | .55 | .09 | .89 | .54 | 1.92 | .72 | 1.40 | 1.53 | .27 | .10 | .58 | .27 | 1.45 | .38 | .96 | 1.14 | .52 | .48 | .02 | 1.70 | .13 | 1.03 | 1.26 |
| Rb | .47 | 1.60 | 1.64 | 1.37 | 1.45 | 2.22 | .69 | 2.60 | 4.26 | .96 | 1.08 | 1.12 | .75 | 1.76 | .16 | 2.15 | 3.66 | .24 | .74 | .36 | 1.18 | .87 | 1.65 | 3.18 |
| Sr | .10 | .31 | 1.97 | - | - | .51 | .09 | - | - | .42 | 1.89 | - | - | .48 | .19 | - | - | 2.41 | - | - | .62 | .23 | - | - |
| Y | .45 | .09 | .51 | .36 | 2.24 | 3.29 | 1.26 | .63 | .76 | .43 | .06 | .07 | 1.03 | 2.55 | .55 | .07 | .04 | .49 | .33 | 2.50 | 3.44 | 1.32 | .62 | .77 |
| Zr | .66 | .21 | 1.68 | .33 | 3.24 | 4.12 | 1.36 | 3.00 | 6.35 | .56 | 1.76 | .77 | 1.21 | 2.96 | .40 | 2.56 | 4.20 | 2.08 | .50 | 3.31 | 4.18 | 1.29 | 3.56 | 7.66 |
| Nb | .56 | 1.00 | 1.38 | 1.11 | 5.77 | 4.62 | 1.91 | 1.51 | 1.91 | .04 | .44 | .42 | 2.81 | 3.33 | .81 | .60 | .69 | .61 | .54 | 4.74 | 4.21 | 1.16 | .83 | 1.03 |
| Rayleigh | .05 | 1.03 | 1.32 | 1.23 | 2.14 | .90 | .46 | 2.01 | 2.37 | 1.08 | 1.38 | 1.28 | 2.08 | .86 | .40 | 2.08 | 2.43 | .13 | .28 | 3.27 | 1.60 | 1.58 | .72 | 1.17 |
| B. A-coefficients for element/Zr ratios | | | | | | | | | | | | | | | | | | | | | | | | |
| K | .42 | .40 | .29 | .25 | .11 | 1.49 | .40 | .93 | 1.47 | .05 | .67 | .21 | .36 | 1.21 | .02 | 1.64 | 1.78 | .66 | .17 | .33 | 1.38 | .03 | 1.67 | 1.79 |
| Ca | .09 | .22 | .07 | - | .69 | - | .09 | .14 | .15 | .14 | .16 | - | 1.00 | - | .00 | .06 | .18 | .27 | - | 1.56 | - | .12 | .08 | .22 |
| Ti | .62 | 1.05 | .75 | 1.17 | .33 | 1.67 | .45 | 1.08 | .53 | .72 | .38 | .93 | 1.00 | 1.57 | .25 | .86 | .33 | .17 | .27 | 1.35 | .25 | .92 | .33 | .07 |
| Mn | .68 | 1.46 | 1.34 | 1.41 | 2.14 | 1.84 | .42 | 1.97 | .81 | .71 | .59 | .71 | 2.54 | .57 | .31 | .92 | .51 | .14 | .05 | 3.16 | .43 | 1.10 | .04 | .21 |
| Fe | 1.02 | 3.49 | 2.42 | 2.56 | 1.31 | 2.60 | .61 | 2.12 | 1.61 | 1.67 | .87 | 1.22 | 2.08 | 1.09 | .50 | .71 | .16 | 1.21 | .15 | 4.53 | .70 | 2.78 | 1.24 | 4.41 |
| Zn | .38 | .82 | .29 | .49 | .50 | .75 | .02 | 1.82 | 4.47 | .41 | .16 | .11 | .11 | .32 | .34 | 2.23 | 4.71 | .66 | .29 | .30 | .11 | .76 | 2.92 | 5.30 |
| Ga | .18 | .14 | .32 | .09 | .30 | .79 | .18 | .42 | 1.48 | .04 | .53 | .00 | .07 | .62 | .00 | .52 | 1.62 | .48 | .02 | .13 | .65 | .04 | .50 | 1.59 |
| Pb | .04 | .52 | .38 | 1.49 | .11 | .41 | .33 | 3.47 | 3.85 | .46 | .34 | 1.39 | .06 | .33 | .27 | 3.34 | 3.80 | .04 | 1.17 | .62 | .41 | .37 | 3.71 | 3.94 |
| Rb | .25 | 3.03 | 7.44 | 3.79 | .62 | 1.94 | .81 | 12.14 | 21.72 | 3.60 | 8.38 | 4.05 | .43 | 1.97 | .64 | 12.82 | 22.27 | 4.24 | 2.37 | 3.87 | 5.03 | 4.12 | 10.13 | 20.38 |
| Sr | .00 | .28 | 2.50 | - | - | .32 | .33 | - | - | .31 | 2.70 | - | - | .35 | .37 | - | - | 2.98 | - | - | .56 | .03 | - | - |
| Y | .54 | .20 | 8.97 | 5.05 | .61 | .33 | .14 | 9.05 | 31.20 | .28 | 8.79 | 5.25 | .05 | .09 | .68 | 8.96 | 30.20 | 8.01 | 4.44 | .34 | .14 | .33 | 8.59 | 29.26 |
| Nb | .42 | 1.54 | 10.18 | 4.75 | 4.25 | .27 | .89 | 17.04 | 39.81 | 1.88 | 10.40 | 5.00 | 4.67 | .56 | 1.28 | 17.14 | 39.69 | 7.55 | 3.06 | 1.70 | .88 | .73 | 14.19 | 35.72 |
| Rayleigh | .65 | .42 | 1.28 | .06 | 1.57 | 3.39 | 1.19 | 2.32 | 6.33 | .30 | 1.76 | .51 | .52 | 2.24 | .35 | 2.63 | 6.43 | 1.88 | .38 | 1.23 | 3.48 | .85 | 2.82 | 6.97 |

(continued)

## TABLE 4 (continued)

### A-Coefficients for the ten chemical groups of Mount Edziza obsidian

| Groups: | 4&5 | 4&6 | 4&7 | 4&8 | 4&9 | 4&10 | 5&6 | 5&7 | 5&8 | 5&9 | 5&10 | 6&7 | 6&8 | 6&9 | 6&10 | 7&8 | 7&9 | 7&10 | 8&9 | 8&10 | 9&10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. A-coefficients for element/Compton ratios | | | | | | | | | | | | | | | | | | | | | |
| K | .11 | .73 | .26 | .25 | .20 | .39 | .86 | .39 | .38 | .07 | .26 | .54 | .56 | 1.15 | 1.32 | .02 | .58 | .79 | .57 | .78 | .27 |
| Ca | - | 1.13 | - | .03 | .25 | .07 | - | - | - | - | - | - | 1.04 | 2.12 | 1.17 | - | - | - | .16 | .03 | .13 |
| Ti | .23 | 1.76 | .90 | 1.39 | .54 | .53 | 1.81 | 1.06 | 1.51 | .23 | .22 | 1.26 | 1.02 | 2.16 | 2.14 | .47 | 1.57 | 1.52 | 2.16 | 2.10 | .01 |
| Mn | .08 | 4.02 | 2.45 | 1.79 | .55 | .89 | 3.43 | 1.92 | 1.35 | .45 | .71 | 1.88 | 2.40 | 4.61 | 4.26 | .60 | 3.14 | 2.88 | 2.42 | 2.27 | .66 |
| Fe | .07 | 4.49 | 2.33 | 2.64 | .71 | 2.29 | 3.60 | 1.93 | 1.98 | .51 | 1.28 | .88 | 1.81 | 4.96 | 6.15 | .53 | 2.64 | 3.26 | 3.15 | 4.36 | 1.40 |
| Zn | .30 | 1.83 | 2.17 | 1.60 | .29 | .31 | 1.01 | 1.64 | .95 | .15 | .50 | 1.13 | .06 | 1.78 | 2.22 | 1.01 | 2.16 | 2.36 | 1.55 | 1.90 | .69 |
| Ga | .09 | .30 | .04 | .17 | .05 | .14 | .24 | .09 | .18 | .05 | .03 | .14 | .06 | .29 | .49 | .08 | .06 | .11 | .19 | .30 | .05 |
| Pb | .91 | .51 | 2.06 | .72 | 1.50 | 1.62 | .44 | 1.11 | .43 | .41 | .72 | 1.60 | .10 | .95 | 1.18 | 1.79 | .86 | .34 | 1.05 | 1.30 | .44 |
| Rb | .60 | .58 | .92 | 1.00 | 1.38 | 2.77 | .91 | .01 | 1.08 | .30 | 1.04 | 1.50 | .63 | 1.97 | 3.64 | 1.74 | .44 | 1.51 | 2.15 | 3.72 | .97 |
| Sr | - | - | .26 | 2.10 | - | - | - | - | - | - | - | - | - | - | - | .55 | - | - | - | - | - |
| Y | .02 | 1.52 | 2.98 | .78 | .16 | .15 | 1.11 | 2.58 | .62 | .14 | .13 | 2.62 | .38 | 1.16 | 1.66 | 2.40 | 2.76 | 3.14 | .57 | .76 | .05 |
| Zr | .81 | 6.04 | 5.09 | 2.79 | 1.48 | 5.10 | 2.63 | 3.72 | 1.34 | 1.68 | 3.42 | 3.19 | .82 | 8.07 | 15.85 | 2.96 | 5.69 | 7.09 | 3.82 | 6.28 | 3.20 |
| Nb | .08 | 2.91 | 3.44 | .45 | .23 | .26 | 2.04 | 2.90 | .28 | .11 | .11 | 2.47 | 2.28 | 2.32 | 3.03 | 3.15 | 3.13 | 3.53 | .19 | .25 | .02 |
| Rayleigh | .21 | 3.93 | 1.85 | 2.00 | .74 | 1.30 | 3.33 | 1.71 | 1.76 | .29 | .72 | .55 | 1.82 | 4.89 | 5.12 | .64 | 2.28 | 2.49 | 2.84 | 3.19 | .71 |
| B. A-coefficients for element/Zr ratios | | | | | | | | | | | | | | | | | | | | | |
| K | .53 | .41 | 1.52 | .65 | .41 | 1.17 | .16 | 1.52 | .19 | 1.43 | 1.70 | 1.62 | .34 | 1.19 | 1.61 | 1.23 | 3.56 | 2.35 | 1.61 | 1.77 | 1.16 |
| Ca | - | .49 | - | .15 | .20 | .12 | - | - | - | - | - | - | .92 | 1.18 | .02 | - | - | - | .05 | .18 | .20 |
| Ti | .38 | 1.03 | .42 | .54 | .41 | .14 | 1.44 | .20 | 1.10 | .09 | .05 | 2.02 | .84 | 1.31 | .69 | 1.90 | .28 | .00 | 1.00 | .41 | .10 |
| Mn | .18 | 3.09 | .23 | .97 | .14 | .27 | 3.03 | .46 | 1.08 | .11 | .18 | 3.98 | 2.50 | 3.91 | 1.74 | 1.29 | .66 | .38 | 1.50 | .66 | .25 |
| Fe | .70 | 3.59 | .39 | 1.74 | .15 | 2.19 | 3.54 | .36 | 1.99 | .76 | 2.48 | 3.70 | 1.86 | 3.27 | 3.18 | 1.96 | .49 | 2.55 | 1.48 | .70 | 1.69 |
| Zn | .29 | .29 | .57 | .25 | 2.56 | 5.27 | .00 | .20 | .45 | 2.35 | 4.78 | .21 | .46 | 2.45 | 4.92 | .70 | 2.95 | 5.40 | 1.77 | 4.36 | 3.64 |
| Ga | .27 | .73 | 1.19 | .52 | .25 | 1.31 | .04 | .29 | .00 | .36 | 1.11 | .75 | .08 | .62 | 1.84 | .62 | .84 | 2.02 | .52 | 1.62 | .74 |
| Pb | .86 | .40 | .22 | .22 | 2.91 | 3.64 | 2.21 | 2.56 | 2.05 | 3.53 | 3.91 | .48 | .35 | 4.68 | 4.21 | .05 | 5.42 | 4.37 | 4.73 | 4.22 | 2.71 |
| Rb | .20 | 8.55 | 9.63 | 8.90 | 7.40 | 18.63 | 4.15 | 4.60 | 4.25 | 4.86 | 14.78 | 1.50 | .19 | 12.89 | 22.28 | 1.37 | 13.44 | 22.59 | 13.10 | 22.44 | 11.98 |
| Sr | - | - | 1.75 | 3.22 | - | - | - | - | - | - | - | - | - | - | - | .62 | - | - | - | - | - |
| Y | 8.83 | 9.23 | 6.89 | 9.17 | 5.28 | 27.84 | 5.66 | 3.73 | 5.12 | 9.01 | 35.69 | .14 | .77 | 9.16 | 30.86 | .44 | 7.96 | 26.78 | 9.13 | 31.69 | 13.67 |
| Nb | 3.50 | 8.55 | 7.21 | 9.14 | 8.02 | 30.88 | 2.55 | 3.40 | 3.98 | 10.06 | 30.49 | 2.48 | 3.01 | 16.76 | 42.01 | .36 | 13.00 | 32.37 | 16.06 | 38.67 | 21.47 |
| Rayleigh | .85 | 3.13 | 4.62 | 2.53 | 1.34 | 5.42 | 1.03 | 2.19 | .85 | 1.76 | 5.20 | 3.26 | .14 | 3.73 | 7.96 | 2.53 | 4.66 | 8.49 | 3.26 | 7.30 | 3.65 |

All other chemical types are distinguished on the basis of two or more element ratios. However, in two additional cases, involving the separation of types 3 and 5, and the separation of types 4 and 5, this discrimination was successful on the basis of element/Zr ratios only. None of the element/Compton ratios were able to successfully discriminate between these two group pairs. Inspection of the scatterplots (Fig. 4a, Rb/Compton <u>versus</u> Zr/Compton) shows that in at least one case (types 3 and 5) the two chemical groups in question are actually clustered into two tight, distinct, and non-overlapping clusters. As in the case of the A-coefficient based on the Fe/Zr ratios in types 1 and 2, the failure of the A-coefficient to discriminate between types 3 and 5 is due to the shapes of the two distributions. Also, although groups 4 and 5 (Fig. 4a, same scatterplot) form a single elongated cluster, they also do not overlap. Type 5 makes up the top three points in the distribution (triangles), while type 4 makes up the remaining points below. The failure of the Compton A-coefficient to discriminate between them is likely due to the very small data set associated with type 5 and the ensuing large statistical errors in its distribution. Figure 4b shows that types 4 and 5 cluster into widely separated groups. Their spectra (Fig. 5) are also dissimilar.

In sum, the discrimination of the obsidian samples into ten chemical groups was successful in 44 out of 45 group pairs, or with 98% success, at two standard deviations, on the basis of their element/Zr ratios. The success rate of the element/Compton ratios in discriminating the ten chemical groups from each other was 91%. While these ratios could not discriminate between the four pairs of groups noted above (1&2, 2&8, 3&5, and 4&5), all ten groups in 41 other paired combinations were discriminated successfully.

Different element ratios separated the chemical types with varying rates of success. The Compton-normalized element ratios Fe/Compton and Zr/Compton, and the Zr-normalized element ratios Rb/Zr and Nb/Zr were the most successful. Each of them confirmed the separation of more than 75% of all type pairs. Other element ratios which had a greater than 50% rate of success in group discriminations were the element/Compton ratios for Ti, Mn, Rb, Nb, and the Rayleigh scatter peak, and the element/Zr ratios for Fe, Pb, Y, and the Rayleigh peak. The poorest rate of success was achieved with the elements Ca, Ga, and Sr, regardless of the normalization used.

## Correlation of Chemical Types with Geological Obsidian Flows

Once the chemical analysis established the existence of ten distinct chemical types of obsidian within the Edziza Volcanic Complex, it became necessary to correlate these with specific obsidian flows, many of which are known to exist within the Mount Edziza Volcanic Complex. As stated previously, the Complex consists of 15 geological formations, formed during five major magmatic cycles over the last 10 million years (Souther and Hickson 1984). The rocks which make up each formation have originated from one or several different volcanic vents, and consist of thick strata of olivine basalts interbedded with trachyte and comendite. It is not uncommon to find several obsidian flows within a single formation, as the obsidian forms in a thin quenched basal layer underneath these trachyte and comendite flows (ibid.).

Since a high degree of chemical homogeneity of a single obsidian flow is usual (Cann, Dixon and Renfrew 1964; for an exception, see Bowman, Asaro and Perlman 1973), the chemical analysis of noncontiguous obsidian outcrops within a limited geographic region can also help to establish whether they belong to the same or two distinct obsidian flows. This is especially true when their stratigraphic position places them within a single formation, but when there is little in the way of physical characteristics to distinguish them.

For these reasons, two advantages will accrue from the correlation of the ten chemical types of Mt. Edziza obsidian identified above with the geologically known obsidian flows within the Complex. First, each chemical type will be associated with a specific geological formation. Since the limits of the geological formations are known, this yields data on the maximum possible limits for the natural distributions of each flow.

Second, the number of chemically distinct flows present in each formation will be determined. Where possible, correlation of chemical types with each stratified layer of obsidian may help to establish the order in which the chemical types have erupted.

The original locations of all samples within each of the ten chemical groups was examined carefully. This was done in order to check whether the samples in each group were geographically clustered, and whether they were correlated with distinct geological formations (and therefore with distinct obsidian flows) of the Complex. Such a clustering of samples from specific locations into specific chemical types was found. It indicated that the ten chemical types reflected realistically the actual groupings of obsidian rock samples in their natural environment. The horizontal and vertical data for the samples collected from the geological sections were made available at this point; in several instances the relative positions of several obsidian samples collected over a single transect were found useful. The geographical information from these and the samples from secondary deposits confirmed that the data separation into ten chemical types was successful and geologically justified.

The geographic locations of each chemical type identified in this study are presented in Figure 6. These locations are discussed below in more detail. Associations with geological formations are based on a generalized geological map of the Mount Edziza Volcanic Complex (Souther and Hickson 1984), and on a yet-unpublished detailed geological map of the Complex made available for inspection through the courtesy of J.G. Souther. Except as indicated, the geographic names in use here have been accepted by the Canadian Board of Stratigraphic Nomenclature for formal use (J. Souther, pers. comm.). Informal names conferred on certain landmarks by archaeologists are indicated in quotation marks.

FIGURE 6a: Natural geographic distributions of the ten Mount Edziza obsidian flows identified: areas north of Raspberry Pass.

LEGEND:

◆ Outcrop occurrence

◐ Occurrence in a gravel sample

---- Limits of existing glaciers

—— Elevations in feet
Contour interval 500'

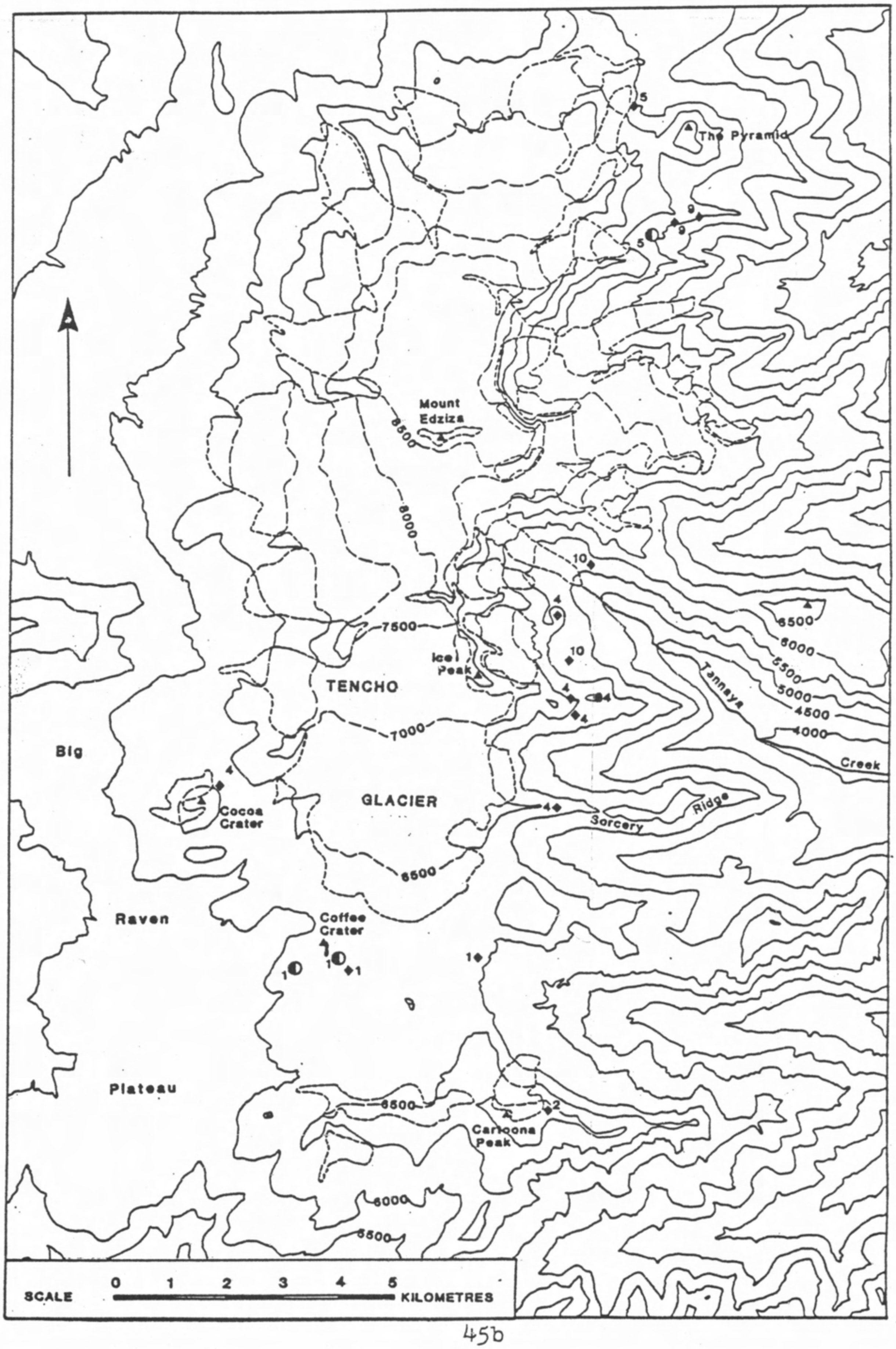

The Pyramid
5
9
9
5
Mount
Edziza
8500
8000
7500
10
4
10
Icel
Peak
4
4
4
TENCHO
7000
GLACIER
6500
6500
6000
5500
5000
4500
4000
Tanneya
Creek
Sorcery
Ridge
4
Big
4
Cocoa
Crater
Raven
Coffee
Crater
1
1
1
1
Plateau
6500
2
Cartoona
Peak
6000
5500
SCALE
0
1
2
3
4
5
KILOMETRES

FIGURE 6b: Natural geographic distributions of the ten Mount Édziza obsidian flows identified: areas south of Raspberry Pass.

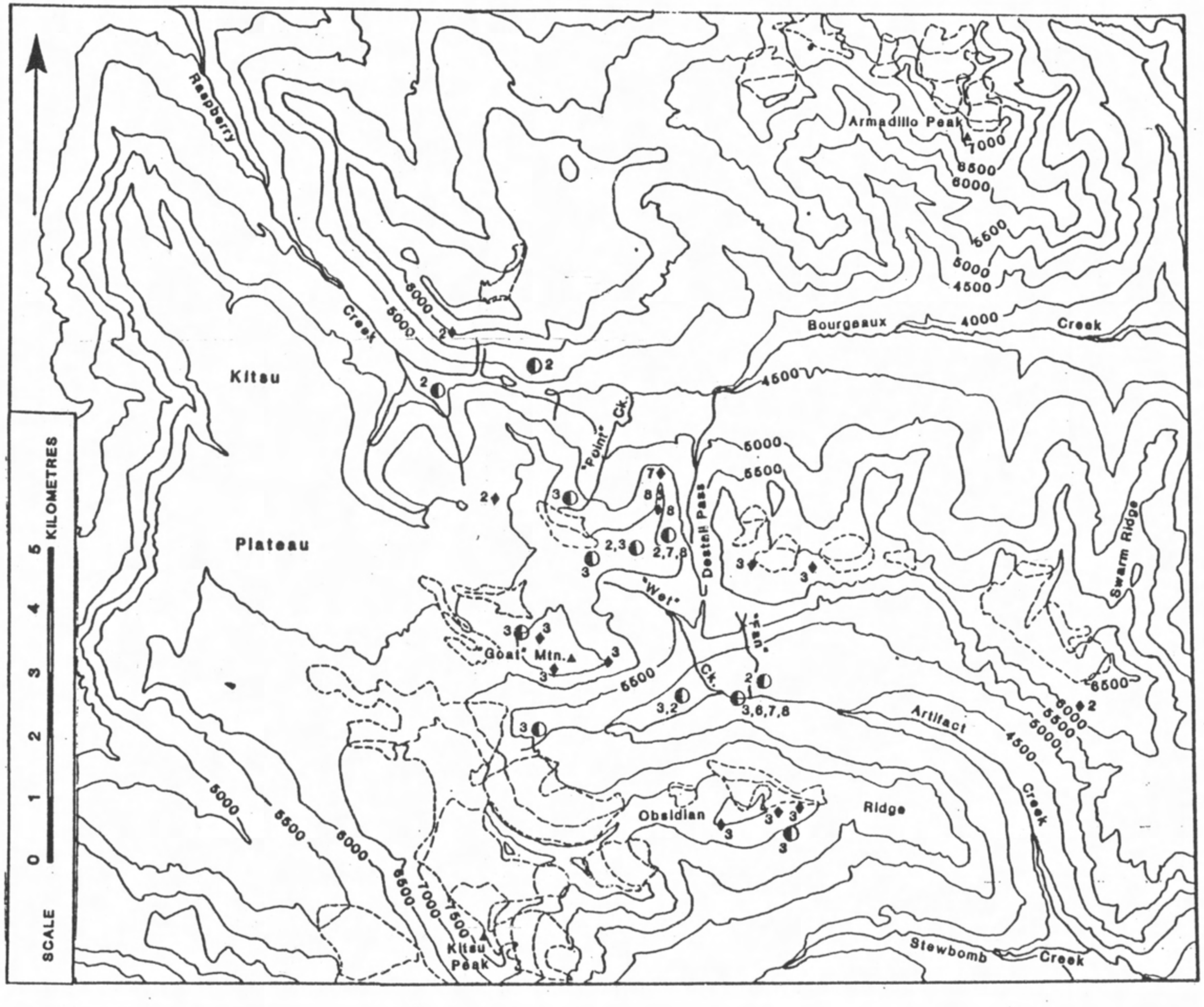
LEGEND:

◆ Outcrop occurrence

◐ Occurrence in a gravel sample

---- Limits of existing glaciers

— Elevations in feet
Contour interval 500'


Raspberry
Creek
Armadillo Peak
7000
6500
6000
5500
5000
4500
Bourgeaux
4000
Creek
4500
Kitsu
Plateau
"Point" Ck.
Destell Pass
"Wet" Ck.
"Fan"
"Goat" Mtn.
Swarm Ridge
Artifact
Creek
Obsidian
Ridge
Kitsu Peak
7500
Stewbomb
Creek
2,3
2,7,8
3,2
3,6,7,8
SCALE
0
1
2
3
4
5
KILOMETRES

**Edziza #1 - Armadillo Formation**
(n=26)
Samples: 1.02,1.11,1.12, 16.01-16.13, 17.01-17.09

This type is limited to the immediate vicinity of Coffee Crater, a prominent Holocene cinder cone on the Big Raven Plateau, and just south of Tencho Glacier. The gravel samples were collected from a large surface scatter located 2.5 km southeast of the Crater, and from a scatter west of the Crater. Other obsidian samples collected further northwest, northeast, and southeast of Coffee Crater, were of different chemical types.

**Edziza #2 - Armadillo Formation**
(n=34)
Samples: 1.01,1.15(2x), 1.26(2x), 1.27(2x), 1.33(2x), 2.02, 6.06, 9.01-9.11, 12.02-12.03, 19.01-19.05, 20.01-20.05.

This type is the most widely distributed of all the obsidian flows examined. Its northernmost occurrence is at Cartoona Peak. The most easily accessible quantities of this obsidian are found in the gravel slides in Raspberry Pass, and in the talus gravel at the base of "Fan Creek", a small northern tributary of Artifact Creek. Both of these are pure unmixed deposits. The "Fan Creek" locality is significant because it contains large clasts of good quality obsidian which are useable in artifact production, and it is readily accessible at the bottom of Artifact Valley. This contrasts with most other valley-bottom sources, which contain only poor-quality small pebbles, and probably were not exploited for tool materials, for example the above-mentioned gravels in Raspberry Pass.

Type 2 obsidian also occurs mixed with type 3 obsidian in gravel deposits at two locations: on a ridge east of "Goat Mountain" (2 out of 3 pebbles), and at locality 6 (1 out of 6 pebbles). A very minor quantity of this type (1 pebble), mixed with types 7 and 8, is also found in the pebble-sized gravels in Destall Pass (of poor quality, and therefore of no archaeological significance). These almost negligible amounts suggest that type 2 is scarcer in the regions immediately west of Destall Pass. It was not found in Artifact Creek or anywhere south of it.

Stratigraphically, type 2 is found underlying type 3 obsidian on the slopes of Kitsu Plateau (west of "Goat Mountain"), and on the ridge north of Artifact Creek. East of "Goat Mountain", clasts of this type are found on a ridge above outcrops of types 7 and 8, and so this flow probably overlies them (although direct stratigraphic confirmation of this in the form of a bedrock sample from above types 7 and 8 is not available). Outcrop samples of this chemical type are found at elevations of 5900-6200' (Fig. 6b), except at Cartoona Peak, where it is found at 7100' (Fig. 6a).

### Edziza #3 - Spectrum Formation
(n=80)
Samples: 1.03-4,6,10,17,17,25,28,29,34,37,-1.38, 3.01-3,6,9-12,17,18,
3-20,23,-3.24, 6.01-6.05, 7.01-7.07, 12.01, 18.01-18.08,
21.01-21.04, 22.01-22.15, 23.01-23.05.

This is the most common of all the Edziza obsidian types identified in prehistoric tools. Its outcrops are confined to high elevations of 6300 - 6900', and are found on "Goat Mountain", along Obsidian Ridge, and in small patchy remnants along the highly eroded ridge just above "Fan Creek". It is also found in great quantities in the high-altitude surface scatters surrounding the "Goat Mountain" peak, on the south-facing slopes of Obsidian Ridge, and in the gravels and surface scatters of upper Artifact Creek valley. Concentrated low-elevation sources made up purely of type 3 obsidian are found at two locations: in the lower till of "Artifact Valley Moraine" at the head of that valley, and in "Point Valley Moraine". For a detailed description of these obsidian sources, see Fladmark (1982:103-128).

The obsidian in Artifact Creek gravels is of a relatively poor quality, as these pebbles are mechanically weakened through alluvial transport and contain numerous incipient fractures. Analysis of samples collected from Artifact Creek near its confluence with "Fan Creek" indicates that type 3 obsidian is predominant (70-80%) in these gravels. It is mixed with small quantities of types 6, 7, and 8.

Type 3 obsidian is found within the Spectrum Formation, the uppermost formation in that region. It lies directly over the Armadillo Formation. Stratigraphic data show that it overlies types 2, 7, and 8. Indirect evidence indicates that it also overlies type 6 (see below).

### Edziza #4 - Ice Peak Formation

(n=9)
Samples: 1.05,1.07,1.09, 1.14 (2x), 1.22 (2x), 1.32 (2x).

This obsidian is found at approximately 6300-6500' near Cocoa Crater, on Sorcery Ridge, and east of Ice Peak. Since it is found both to the east and to the west of Tencho Glacier, it is probable that its distribution extends continuously under that glacier. It is one of the more inaccessible obsidians. The two types found nearest to it are type 1 (to the south), and type 10, but it is spectroscopically unlike either of them. In terms of horizontal coordinates, type 4 is found directly above type 10, but they are stratigraphically separated from each other by about 500' of elevation.

### Edziza #5 - Pyramid Formation

(n=3)
Samples: 1.13, 1.21 (2x).

This type is found only very near The Pyramid, a prominent volcanic cone north of Mt. Edziza (Fig. 6a). The only bedrock sample of this type was collected at 6100' west of the cone, while a loose gravel sample was picked up to the south of the Pyramid at a slightly lower elevation. Although its natural distribution is limited, this type is archaeologically significant in that it has been identified in a number of artifacts (Godfrey-Smith and D'Auria 1984; E. Nelson, pers. comm.). This obsidian is probably more easily accessible to people approaching the Edziza Complex from the north than any of the other types.

**Edziza #6 - probably Armadillo Formation**
(n=11)
Samples: 3.02-4,5,7,8,13,14,16,21,-3.22.

This obsidian type was found only at one sampling location: the outwash gravels of Artifact Creek, collected at 4600' near its confluences with "Fan" and "Wet" creeks. Its geological association is uncertain, as no outcrop samples examined corresponded to this type. However, its XRF spectrum is generically similar to the other Armadillo types. Its absolute element compositions (see Fig. 8a [p. 82] in Section 2) confirm this similarity. Types 7 and 8 were also found in very small quantities (one pebble each) in this sample.

Since this type was not identified in any of the samples from further up the Artifact Valley or in upper "Fan Creek", it is suggested here that it comes from a low-elevation stratum which belongs within the lower Armadillo Formation. Its much greater proportion in this sample relative to types 7 and 8 suggests that these two types are stratigraphically above it. Also, the complete absence of type 2 obsidian in this low-elevation outwash gravel sample contrasts with other gravel samples collected in the upper Artifact valley, and with the sample collected from the talus slope at the base of "Fan Creek", which is composed purely of type 2 obsidian. On the basis of the outcrop samples available, and the relative proportions of each chemical type present in high-elevation and in low-elevation gravel samples, the stratigraphic relationship of the obsidian types found on the ridge north of Artifact Creek (in order of descending elevations) is inferred as follows: 3, 2, 7, 8, and 6.

**Edziza #7 - Armadillo Formation**
(n=6)
Samples: 1.23 (2x), 2.14, 2.18 (2x), 3.19.

This is a minor type. It occurs in only 2 pebbles of the Destall Pass sample and in only one pebble of the Artifact Ck./"Fan" Ck. low-elevation gravel sample. Its archaeological significance is probably minimal, as both of these samples are made up of only small, mechanically weakened pebbles, none of which appear to be of useful flakeable quality. A geological sample of this type was collected at 5700' on the ridge which forms the west wall of Destall Pass. Two other samples collected from thin glassy outcrops higher up along the same transect are of type 8. Their stratigraphic relationship is therefore clear: type 7 underlies type 8.

**Edziza #8 - Armadillo Formation**
(n=24)
Samples: 1.19,1.20, 2.01,2.03-2.13,2.15-2.17,2.19,2.20, 3.15.

This type was found in 17 pebbles of the Destall Pass sample and in only 1 pebble of the Artifact Ck./"Fan" Ck. sample. The same arguments made above with regard to the limited archaeological significance of type 7 apply equally well in this case. The stratigraphic position inferred for this type is that it lies above type 7 (see above) but underlies type 2, since naturally weathered scattered pebbles of type 2 obsidian were found at higher elevations than the two type 8 outcrop samples (see Fig. 6b).

**Edziza #9 - Pyramid Formation**
(n=4)
Samples: 1.18, 1.35 (each analysed twice).

This is a very small flow located at 6000-6100' directly south of the Pyramid cone. It is found at a lower elevation than type 5, the only other obsidian type in its vicinity. It is also completely unlike type 5 in its relative element concentrations (see Table 3), and has a very different characteristic spectrum (see Fig. 5).

### Edziza #10 - Ice Peak Formation

(n=4)
Samples: 1.30, 1.31 (each analysed twice).

This is also a small and localized flow. Its outcrops are found at 5700', stratigraphically separated from type 4 by a thickness of 500' of non-glassy rock. It is possible that both these obsidian types may be found in the gravels of Tennaya Creek. However, this is very rough, deeply dissected terrain with steep ridges and narrow valleys, and it is unlikely to have been intensively exploited in the past. Since these outcrops are located near the present limits of Tencho Glacier, it is likely that they were exposed only relatively recently, and re-glaciated during any cooling trends. The archaeological significance of this flow is thus judged very low.

### Obsidian Flow Identification Summary

In summary, distinct geographic and/or stratigraphic positions have been demonstrated or inferred for each of the ten chemical types studied. On the basis of these demonstrable geographic groupings, the conclusion is reached that each chemical type does in fact correspond to a single discrete obsidian flow within the Edziza Volcanic Complex. This provides a powerful and simple tool for the correlation or distinction of discontinuous obsidian outcrops whose stratigraphic positions and physical characteristics are ambiguous. Until now, isotopic age determinations provided the only reliable means of correlation for such obsidian flows within the Mount Edziza Volcanic Complex (Souther, Armstrong, and Harakal 1984). It is hoped that the results obtained here will aid in clarifying the number of distinct obsidian flows present within some formations, and their stratigraphic order.

Ten obsidian flows have been identified. It is suggested that five of these (1, 2, 6, 7, and 8) are associated with the Armadillo Formation. Flow 3 is associated with the Spectrum Formation, and the remaining four flows are associated with the Ice Peak (flows 4 and 10) and the Pyramid (flows 5 and 9) formations.

Flows 1, 4, 5, 9, and 10 are found only on the upper plateau regions north of Raspberry Pass. These regions are more inaccessible, barren and inhospitable to humans than the regions to the south, a fact which probably diminishes their significance in archaeological studies. Flows 3, 6, 7, and 8 are found only south of Raspberry Pass, while flow 2 is found both in Raspberry Pass as well as considerably further north and slightly to the south of it.

One surprising result of this analysis is that of the fourteen localities where loose gravel samples were collected, all but four were found to be composed of only a single chemical type of obsidian. Since many of these are located at relatively low elevations, this result was unexpected. Since the low-elevation gravel scatters were probably created by erosional and glacial reworking, downslope tumbling of eroded clasts, and fluvial action, it was expected that most would be composed of a mixture of obsidian types.

The high-elevation concentrated obsidian scatters composed of a single type are as follows: localities 16 and 17 at Coffee Crater, made of type 1 obsidian; and localities 7, 21, and 23 at "Goat Mountain" and Obsidian Ridge, made up of type 3 obsidian. Also, single-type obsidian deposits were found in five low-elevation areas: at localities 9 and 20, representing the slide at the west end of Raspberry Pass and the general scattered clasts in the Raspberry Pass, made up of type 2 obsidian; at locality 19 in the talus slope at the base of "Fan Creek", made up of type 2 obsidian; and at localities 18 and 22, in "Point" Valley Moraine and Artifact Valley Moraine, made up of type 3 obsidian.

The four sampling locations which were found to consist of more than one type of obsidian were localities 2, 3, 6, and 12 (see Figure 2b). Locality 2 is in the slide on the west side of Destall Pass. Of the 20 pebbles making up this sample, 17 are of type 8 obsidian, 2 are of type 7, and one pebble is of type 2. Locality 3 is in the outwash gravels of Artifact Creek near its confluences with "Wet" and "Fan" creeks. Of the 24 pebbles sampled here, 11 are type 3, 11 are type 6, one is type 7, and one is type 8. Again it must be noted that the absence of type 2 obsidian in this outwash gravel sample is surprising, particularly in view of its presence in the gravel sample in the nearby locality 19. Finally, locality 12 represents a very small sample (3 pebbles) collected to the north of the 1977 reconnaissance campsite, of which two pebbles were type 2 and one pebble was type 3.

Reasonably easy access to low-elevation gravel concentrations of obsidian from flows 2 and 3 is possible at the following locations: in the gravels of Raspberry Pass (not of flakeable quality, however) and in the talus slope at the base of "Fan Creek"; in "Point" Valley Moraine, Artifact Valley Moraine, and in the outwash gravels of Artifact Creek near its confluences with "Wet Creek" and with "Fan Creek". Also available at low elevations (in Destall Pass and in the gravels of Artifact Creek) are small quantities of obsidian pebbles from flows 2, 6, 7, and 8. The pebbles at these localities are not of flakeable quality, however, and the significance of flows 6, 7, and 8 to archaeological studies is therefore judged to be low.

By far the most common and the most easily accessible is the obsidian from flow 3. This chemical type predominates in Artifact Creek gravels, while pure quantities of it are present within the moraines at the head of "Point" and Artifact Creeks. This is also the most coloristically varied (apart from black, its colours range from red and brown, through green, grey, and blue, to almost purplish) and the most vitreous among the ten flows.

# SECTION 2

## QUANTITATIVE CHEMICAL ANALYSIS OF TEN MOUNT EDZIZA OBSIDIAN FLOWS

The purpose of this section was to determine the chemical composition of each of the ten obsidian flows identified in Section 1. Such quantitative data are generally far more useful than the semi-quantitative result obtained above, for the following reasons: absolute element concentrations do not depend on the analytical conditions used to obtain them, and thus they are easier to reproduce; they can be compared to the element concentrations of other obsidian sources from around the world; on the basis of their chemical compositions, widely separated obsidian sources can be classified into characteristic chemical categories (for example: calc-alkaline, alkaline, peralkaline, or peraluminous) which are found all over the world.

In order to make the Edziza obsidian source a part of the worldwide database of obsidian chemical compositions, the absolute major, minor, trace, and some rare earth element concentrations of the ten flows were determined. A standard whole igneous rock analysis for major (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P) and minor ( Ba, Co, Cr, Cu, Mn, Mo, Ni, Pb, Rb, Sr, Va, Y, Zn, Zr, Nb) elements was done with wavelength-dispersive x-ray fluorescence (WD-XRF). Approximate concentrations for three rare earth elements (Ce, La, Nd) were also determined using the WD-XRF method. This work was performed at the XRF laboratory of the Department of Oceanography, University of British Columbia, following standard procedures employed there.

### Sample Selection and Preparation

Three pebbles from each flow were selected for analysis. In order to avoid random sampling errors, the pebbles chosen were those whose element ratios fell within one standard deviation of the flow mean. The three pebbles were washed in distilled water, dried, and crushed to pea-sized fragments with an agate mortar and pestle. The fragments were then combined into a single sample for each flow, and ground in a Herzog tungsten-carbide ball mill for a total of 6 minutes. The obsidian powder was sieved in a 200-mesh, 20 cm diameter standard brass sieve (USA Standard testing sieve, ASTME-11 Specification, W.S. Tyler Inc.). Between each sample, the sieve was washed under a very high pressure stream of running water from both sides to remove embedded particles. The brass receiving pan was also washed under running water. Both the sieve and the pan were rinsed with distilled $H_2O$, the excess water was wiped off, and the sieve and pan were dried in a 90° C oven for 5 minutes. They were then cooled to room temperature before use.

The powdered samples were prepared as pressed pellets for minor, trace, and rare earth element analysis and fused into glass disks for the determination of major element concentrations. Two pellets and two glass disks were prepared for each of the ten Edziza flows, the control obsidian standard, and the procedure-testing samples. All results quoted below represent averages of these duplicate analyses.

## Preparation of Pressed Pellets

4.0 g of powdered obsidian sample + 0.5 g binder (Chemplex Spectrographic X-ray Mix Powder, a commercial grinding and briquetting additive) were weighed out. The mixture was transferred to a plastic vial, and a plastic mixing ball was added. The vials were capped and sealed with Parafilm, and shaken for 10 minutes in a mechanical mixer (Spex Mixer/Mill, Cat. #8000, Spex Industries Inc.). The resultant mixture was poured into a plastic weighing boat, 5 drops (0.25 g) of polyvinyl alcohol solution (2 g PVA + 1000 ml $H_2O$) were added, and this mixture was thoroughly stirred to a sticky mud-like consistency. The PVA was added because without it the obsidian powder formed pellets too friable to stand up to the analytical conditions of vacuum and continuous rotation. The mixture was poured into a pelletizing press (Spex, with a 1 1/4 " die), tamped down, backed with boric acid (BDH Chemicals), and pressed to 10 tons.

## Preparation of Glass Disks

Glass disks were prepared following the method of Norrish and Hutton (1969). 3.6 g of Johnson-Matthey Spectroflux 105 + 0.4 g of obsidian powder were heated in a covered platinum-gold crucible in a furnace at 1000° C for 20 minutes. Upon removal from the oven the crucible was placed in an aluminium heat sink and cooled to room temperature. The crucible and contents were then reweighed and the weight loss (typically about 0.025 g) was made up with Johnson-Matthey Spectroflux 100. This mixture was then heated to 500°C over a Meker burner. The melt was quickly poured out onto an aluminium mold and flattened with a flat brass plunger held at 350° C. The resultant glass disk on its mold was left to cool on the hot plate for 5 minutes, then removed to an asbestos mat where it cooled slowly to room temperature. The disk was then removed from the mold and trimmed.

Samples were analysed in a Philips PW 1400 wavelength-dispersive x-ray spectrometer using a Rh x-ray target. Analysis time for the glass disks was 15 minutes each (45 sec./peak + 45 sec./background, at each element), and for the pellets 19 minutes each (30 sec./peak + 30 sec./background, at each element).

## Problems addressed

### a. Natural Surface Leaching of Constituent Elements

A test for the effects of leaching due to weathering on element concentrations was performed. Since element leaching is confined to the thickness of the hydration band in obsidian, literature hydration data were reviewed (Friedman and Obradovich 1981, Michels, Tsong and Nelson 1983). The estimate was made that the maximum possible hydration thickness was unlikely to exceed 40 μm (corresponding to an age of 1.1 m.y., Friedman and Obradovich 1981). In view of the fact that the Mount Edziza Volcanic Complex experienced extensive and repeated glaciations during the past million years, and the hydration rate would have been slower during periods of extreme cold, the actual hydration thickness on any naturally occurring obsidian pebble is probably less than 20 μm. This corresponds to a maximum age of 150,000 years (ibid.), or to a maximum age of 50,000 years (group B, Michels, Tsong and Nelson 1983).

Assuming an idealized situation in which an element is leached out completely within the hydration rind (100% leaching), and a hydration thickness of 20 microns on a rectangular pebble of the dimensions 2x3x5 cm, the resultant depletion of that element in a whole rock sample (obtained by powdering this rectangular pebble) would equal to 0.41%. However, sputter induced optical emission experiments (Tsong et al. 1978) have demonstrated that the actual hydration effects are much smaller than this extreme case of 100% leaching. The greatest effect (a 20% depletion within the hydration band) was observed in the light elements Na and K, and it became negligible for elements heavier than Al (ibid.). This indicates that natural surface leaching within the hydration rind of an obsidian pebble is not significant for the elements Fe, Rb, Y, Zr, and Nb.

The standard deviation from the mean in the semi-quantitative results for Fe, Rb, Y, Zr, and Nb is between 1% - 5%, and it is much larger than this in the lighter elements K, Ca, Ti, and Mn. Thus any element depletion due to surface leaching is well within the experimental error in the semi-quantitative results, and it should not be detectable in a whole rock quantitative analysis.

To test the correctness of the above, all cortex was cut away with a low-speed geological diamond saw from visibly weathered pebbles of two abundant flows (Edziza #2 and #3). The cortex and inner portion of each pebble were then prepared separately and analysed in duplicate as above. There was no significant difference in the results (Table 5a). This confirmed that all the naturally weathered pebbles selected for quantitative analysis can be prepared without the need for cortex removal.

### b. Laboratory Procedures

The sample preparation procedures (grinding, sieving, and pelletizing with polyvinyl alcohol) were tested. A standard rock specimen (NBS Obsidian Rock Standard SRM-278, an obsidian from Clear Lake, Newberry Crater, Oregon, powdered to <200 mesh) was ground and sieved, and processed into pellet and glass disk samples as above. Another sample of SRM-278 was not subjected to the grinding and sieving, but it was pelletized with PVA. The results of these preparations were compared to the results obtained from existing pressed pellet and glass disk specimens of SRM-278, previously prepared by UBC Oceanography laboratory staff. These control specimens were prepared without grinding, sieving, and without the addition of PVA to the pellets. In addition, two other standard geological specimens, G-2 and BCR-1, were prepared with PVA. All results were also compared with the element values recommended in the literature. These results are summarized in Table 5b.

Comparison of the results from the control specimens and the glass disks prepared by the method outlined above, determined that the grinding and sieving did not affect the major element concentrations. Similarly, the addition of PVA to pressed pellets did not affect the trace element results. However, the pellets which were ground and sieved became contaminated with small amounts of cobalt. This cobalt contamination is due to the grinding process (S. Calvert, pers. comm.). To avoid this problem, grinding in an agate mill rather than a tungsten-carbide mill is suggested for samples in which the Co concentration is significant. The Co concentrations detected in the ten Edziza obsidian flows were not significantly different from the Co-contamination level in the re-ground SRM-278 sample. This indicates that the actual Co concentration (in ppm) in the Edziza obsidians is very low. Because of the contamination due to grinding, the determination of Co is excluded from the WD-XRF results reported here for the ten Mount Edziza obsidian flows.

### c. Experimental precision and accuracy

Precision of measurement is a measure of the reproducibility obtained by the instrument from one sample to the next. It is determined by conducting a number of non-consecutive analyses of one sample, and then checking the standard deviation of these analyses. The smaller the standard deviation, the more precise the measurement. The analytical precision for the major elements was determined through ten analyses each of two geological rock standards, G-2 and BCR-1. The analytical precision for the trace elements was determined through ten analyses each of the geological rock standards AGV-1 and NIM-S, and of Edziza #3. The experimental means and standard deviations were calculated for all four rock standards and for Edziza #3, and are presented in Table 5c. For the major elements, the experimental precisions are 0.3% and 0.1% for $SiO_2$ and $Al_2O_3$, respectively, and typically between 0.05 and 0.01 in the other oxides. For the trace elements, the experimental precisions are typically between 4 and 1 part per million. Ba and Mn, when present in very high concentrations, have analytical precisions of over 20 ppm.

The analytical accuracy is a measure of how closely do the experimental measurements reflect the true element concentrations in a sample. Accuracy of experimental results can thus be determined through a comparison of experimentally-obtained values for standard rocks with the literature values recommended for them by the U.S. National Bureau of Standards. Recommended literature values, and the difference between the recommended and the experimental element concentrations, are quoted here for all four geological standards analysed (Table 5c).

A measure of the experimental accuracy obtainable from duplicate analyses can also be derived by comparing the recommended literature values in Table 5b with the experimental values obtained for the major elements of sample SRM-278 Control, and for the trace elements in samples SRM-278 PVA, G-2 PVA, and BCR-1 PVA.

## TABLE 5a

Effect of surface weathering on element concentrations in two Edziza obsidian flows

| | Edziza #1 | | Edziza #3 | |
|---|---|---|---|---|
| | Weathered | Not weathered | Weathered | Not weathered |
| % | | | | |
| $SiO_2$ | 77.1 | 75.6 | 76.1 | 77.4 |
| $TiO_2$ | 0.38 | 0.39 | 0.18 | 0.18 |
| $Al_2O_3$ | 8.59 | 9.59 | 11.51 | 10.70 |
| $Fe_2O_3$ | 6.04 | 5.95 | 2.99 | 2.98 |
| MnO | 0.07 | 0.07 | 0.03 | 0.03 |
| MgO | 0.01 | 0.01 | 0.02 | 0.01 |
| CaO | 0.28 | 0.28 | 0.26 | 0.245 |
| $Na_2O$ | 4.27 | 4.23 | 4.22 | 4.04 |
| $K_2O$ | 4.06 | 4.41 | 4.71 | 4.33 |
| $P_2O_5$ | 0.02 | 0.02 | 0.02 | 0.01 |
| Total | 100.33 | 100.53 | 100.09 | 99.95 |
| ppm | | | | |
| Ba | 31 | 31 | 34 | 34 |
| Cr | 5 | 9 | 3 | 6 |
| Cu | bdl | bdl | bdl | bdl |
| Mn | 845 | 853 | 460 | 453 |
| Ni | 14 | 15 | 14 | 14 |
| Pb | 20 | 20 | 35 | 32 |
| Rb | 125 | 127 | 202 | 198 |
| Sr | 10 | 11 | 11 | 11 |
| V | bdl | bdl | bdl | bdl |
| Y | 124 | 124 | 125 | 126 |
| Zn | 300 | 299 | 240 | 239 |
| Zr | 984 | 984 | 1020 | 1014 |
| Nb | 106 | 106 | 124 | 125 |

Notes: 1. bdl = below detection limit.
2. for experimental precisions, see Table 5c (p. 65).

## TABLE 5b

Effect of sample preparation on element values

Glass Disks:

| | SRM-278 | | |
|---|---|---|---|
| | Control | G+S | Literature |
| % | | | |
| $SiO_2$ | 73.2 | 74.2 | 73.1 |
| $TiO_2$ | 0.245 | 0.25 | 0.24 |
| $Al_2O_3$ | 14.31 | 14.215 | 14.15 |
| $Fe_2O_3$ | 2.115 | 2.115 | 2.04 |
| MnO | 0.035 | 0.03 | 0.05 |
| MgO | 0.27 | 0.28 | ? |
| CaO | 1.00 | 0.98 | 0.98 |
| $Na_2O$ | 3.935 | 4.37 | 4.84 |
| $K_2O$ | 4.16 | 4.15 | 4.16 |
| $P_2O_5$ | 0.04 | 0.05 | 0.04 |
| Total | 99.37 | 100.50 | |

Pressed Pellets:

| | SRM-278 | | | G-2 | | BCR-1 | |
|---|---|---|---|---|---|---|---|
| | PVA | PVA+G+S | Lit. | PVA | Lit. | PVA | Lit. |
| ppm | | | | | | | |
| Ba | 860 | 861 | 1150? | 1752 | 1900 | 688 | 680 |
| Co | 2 | 47 | 2 | 9 | 5 | 33 | 36 |
| Cr | 11 | 9 | 6 | 5 | 8 | 13 | 15 |
| Cu | 4 | 10 | 6 | 11 | 10 | 22 | 16 |
| Mn | 432 | 439 | 402 | 254 | 265 | 1357 | 1350 |
| Ni | 11 | 9 | 4 | 3 | 4 | 15 | 10 |
| Pb | 18 | 20 | 16 | 31 | 30 | 22 | 14 |
| Rb | 130 | 127 | 128 | 169 | 170 | 48 | 47 |
| Sr | 69 | 68 | 64 | 455 | 480 | 326 | 330 |
| V | 10 | 11 | ? | 51 | 36 | 425 | 420 |
| Y | 43 | 42 | | 12 | 11 | 36 | 40 |
| Zn | 52 | 49 | 55? | 81 | 84 | 122 | 125 |
| Zr | 284 | 278 | | 294 | 300 | 187 | 185 |
| Nb | 19 | 19 | | 12 | 13 | 14 | 19 |
| Ce | 43 | 49 | | | | | |
| La | 29 | 26 | | | | | |
| Nd | 27 | 27 | | | | | |

Notes: 1. PVA = polyvinyl alcohol added to obsidian powder.
2. G+S = sample was ground in a tungsten-carbide mill and sieved in a 200-mesh brass sieve.
3. for experimental precisions, see Table 5c (p. 65).

# TABLE 5c

Analytical precision and accuracy
for all major and minor element analyses

| | BCR-1 | | | | G-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | | Experimental | | Lit-Exp | | Experimental | | Lit-Exp |
| | Lit. | x | s | | Lit. | x | s | |
| % | | | | | | | | |
| $SiO_2$ | 54.53 | 54.0 | 0.3 | 0.5 | 69.22 | 68.8 | 0.3 | 0.4 |
| $TiO_2$ | 2.26 | 2.24 | 0.02 | 0.02 | 0.48 | 0.50 | 0.01 | 0.02 |
| $Al_2O_3$ | 13.72 | 13.52 | 0.11 | 0.2 | 15.40 | 15.48 | 0.10 | 0.08 |
| $Fe_2O_3$ | 13.44 | 13.61 | 0.05 | 0.17 | 2.67 | 2.70 | 0.007 | 0.07 |
| MnO | 0.18 | 0.15 | 0.01 | 0.03 | 0.03 | 0.034 | 0.005 | 0.004 |
| MgO | 3.48 | 3.35 | 0.04 | 0.13 | 0.75 | 0.77 | 0.03 | 0.02 |
| CaO | 6.97 | 7.00 | 0.04 | 0.03 | 1.96 | 1.97 | 0.02 | 0.01 |
| $Na_2O$ | 3.30 | 3.25 | 0.05 | 0.05 | 4.06 | 4.04 | 0.07 | 0.02 |
| $K_2O$ | 1.70 | 1.72 | 0.02 | 0.02 | 4.46 | 4.51 | 0.03 | 0.05 |
| $P_2O_5$ | 0.36 | 0.36 | 0.006 | 0 | 0.13 | 0.125 | 0.005 | 0.005 |

| | AGV-1 | | | | NIM-S | | | | Edziza #3 | | Detection Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Experim. | | | | Experim. | | | Experim. | | |
| | Lit. | x | s | L-E | Lit. | x | s | L-E | x | s | |
| ppm | | | | | | | | | | | |
| Ba | 1200 | 1037 | 29 | 160 | 2400 | 2812 | 69 | 410 | 42 | 6 | 22 |
| Co | 16 | 13 | 4 | 3 | 4 | 7 | 3 | 3 | 29 | 2 | 30 |
| Cr | 10 | 9 | 2 | 1 | 12 | 33 | 2 | 21 | 11 | 1 | 14 |
| Cu | 59 | 66 | 4 | 7 | | bdl | | | bdl | | 17 |
| Mn | 728 | 741 | 22 | 12 | 80 | 84 | 4 | 4 | 458 | 2 | 14 |
| Ni | 15 | 14 | 2 | 1 | | bdl | | | 10 | 1 | 16 |
| Pb | 33 | 41 | 2 | 8 | 5 | 4 | 2 | 1 | 32 | 2 | 40 |
| Rb | 67 | 68 | 0.7 | 1 | 530 | 517 | 0.9 | 13 | 199 | 0.7 | 7 |
| Sr | 660 | 683 | 4 | 23 | 62 | 64 | 1 | 1 | 11 | 1 | 7 |
| V | 125 | 144 | 7 | 19 | 10 | 55 | 3 | 45 | bdl | | 12 |
| Y | 19 | 23 | 1 | 4 | 3 | bdl | | >2 | 124 | 1 | 1 |
| Zn | 86 | 87 | 3 | 1 | 10 | 10 | 2 | 0 | 237 | 2 | 12 |
| Zr | 230 | 219 | 2 | 11 | 33 | 25 | 1 | 8 | 1019 | 3 | 8 |
| Na(%) | 4.32 | 4.02 | .01 | .30 | 0.43 | 0.39 | .01 | .04 | | | 0.14% |
| Nb | 16 | 18 | 1 | 2 | | bdl | | | 145 | 1 | 6 |
| Mo | | bdl | | | | bdl | | | bdl | | 6 |

Notes:
1. no recommended literature values are available for Edziza #3.
2. x = experimental mean of ten analyses.
3. s = one standard deviation from the mean; this is a measure of the analytical precision.
4. Lit-Exp and L-E = literature - experimental, absolute value; this is a measure of the experimental accuracy, ie. how close the experimental values are to true values.

## Results

The results of the wavelength dispersive x-ray fluorescence analysis of the ten Mount Edziza obsidian flows are presented in Table 6. All values quoted represent an average of two analyses, each performed on a different glass disk or pellet sample. As stated above (see p. 57), two glass disks and two pellets were prepared for each of the ten Edziza flows.

Major element concentrations are expressed as oxides in percent by weight, on a volatile-free basis ($H_2O$ and $CO_2$ are lost during the heating process in glass disk preparation). Total Fe content is expressed as $Fe_2O_3$. All major element concentrations except $Na_2O$ were determined by glass disk analysis. Since Na is particularly volatile and is easily lost during the preparation of glass disks (Norrish and Hutton 1969), the $Na_2O$ concentration was determined by pressed pellet analysis.

All trace and rare earth element concentrations were determined by pressed pellet analysis. They are expressed in parts per million by weight. Rare earth element data were rounded to ten parts per million.

The detection limit quoted for each trace and rare earth element is defined as equal to six standard deviations from the background count (the count obtained when the concentration is known to be 0 ppm) at the element in question. This detection limit is a strict statistical definition; for practical purposes, any concentration value equal to or greater than half the quoted detection limit is reasonably reliable (B. Cousens, pers. comm.), with a probability of >99%.

## TABLE 6
### Absolute chemical concentrations of ten Mount Edziza obsidian flows

| Flow #: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Detection Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % | | | | | | | | | | | |
| $SiO_2$ | 76.3 | 77.0 | 76.8 | 77.2 | 78.7 | 68.3 | 75.6 | 76.3 | 77.0 | 77.9 | |
| $TiO_2$ | 0.39 | 0.32 | 0.18 | 0.15 | 0.12 | 0.64 | 0.16 | 0.35 | 0.09 | 0.06 | |
| $Al_2O_3$ | 9.09 | 9.02 | 11.10 | 11.35 | 10.46 | 9.91 | 7.23 | 8.52 | 12.16 | 12.19 | |
| $Fe_2O_3$ | 6.00 | 5.77 | 2.99 | 2.66 | 2.64 | 10.74 | 8.35 | 6.82 | 1.78 | 1.24 | |
| MnO | 0.07 | 0.06 | 0.03 | 0.03 | 0.02 | 0.22 | 0.11 | 0.08 | 0.01 | 0.01 | |
| MgO | 0.01 | 0.02 | 0.02 | 0.12 | 0.02 | 0.01 | 0.02 | 0.04 | 0 | 0 | |
| CaO | 0.28 | 0.23 | 0.25 | 0.26 | 0.18 | 0.77 | 0.15 | 0.25 | 0.23 | 0.31 | |
| $Na_2O$ | 4.25 | 4.21 | 4.13 | 4.39 | 4.22 | 5.91 | 5.58 | 4.46 | 4.12 | 4.18 | |
| $K_2O$ | 4.24 | 4.25 | 4.52 | 4.26 | 4.02 | 4.18 | 3.88 | 4.19 | 4.41 | 4.07 | |
| $P_2O_5$ | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.05 | 0.03 | 0.02 | 0.01 | 0.01 | |
| Total | 100.68 | 100.91 | 100.02 | 100.40 | 100.36 | 100.68 | 101.07 | 100.98 | 99.78 | 99.94 | |
| ppm | | | | | | | | | | | |
| Ba | 31 | 32 | 34 | 56 | 36 | 21 | 46 | 35 | 30 | 40 | 22 |
| Mn | 850 | 770 | 457 | 373 | 331 | 2280 | 1170 | 920 | 223 | 204 | 7 |
| Ni | 15 | 18 | 14 | 16 | 15 | 19 | 42 | 21 | 14 | 10 | 16 |
| Pb | 20 | 23 | 34 | 20 | 31 | 28 | 53 | 27 | 35 | 43 | 40 |
| Rb | 126 | 155 | 200 | 208 | 271 | 182 | 283 | 161 | 321 | 493 | 7 |
| Sr | 11 | 12 | 11 | 18 | 12 | 11 | 20 | 13 | 10 | 10 | 7 |
| Y | 124 | 147 | 126 | 140 | 133 | 188 | 363 | 181 | 143 | 150 | 1 |
| Zn | 300 | 331 | 240 | 183 | 216 | 398 | 723 | 404 | 195 | 190 | 12 |
| Zr | 984 | 1208 | 1017 | 662 | 845 | 1546 | 2879 | 1396 | 454 | 215 | 8 |
| Nb | 106 | 125 | 124 | 139 | 141 | 211 | 305 | 158 | 145 | 155 | 6 |
| Ce | 220 | 270 | 250 | 180 | 150 | 360 | 670 | 300 | 100 | 40 | 60 |
| La | 110 | 140 | 130 | 90 | 80 | 190 | 340 | 150 | 50 | 20 | 60 |
| Nd | 160 | 180 | 150 | 120 | 110 | 230 | 380 | 210 | 90 | 60 | 60 |

Notes:
1. Cr, Cu, Mo, and V: below the detection limit (14, 17, 6, and 12 ppm respectively) in all flows
2. Co concentration (in ppm) is estimated to be very low in all flows (see text)
3. For measurement uncertainties, see Table 5c (p. 65).

## Discussion

The WD-XRF analysis of the ten Mount Edziza obsidian flows identified in Section 1 resulted in absolute element concentrations for ten major elements (expressed as oxides in percent by weight), fifteen trace elements, and three rare earth elements (expressed in parts per million by weight). Of the fifteen trace element determinations, four elements (Cr, Cu, Mo, and V) were found to be below the detection limit in all ten of the Mount Edziza obsidians. Additionally, the Co determination was rejected from the results, because of Co contamination of all samples during the grinding process in a tungsten-carbide mill. However, the Co concentrations detected in the ten Mount Edziza obsidian samples were comparable to the Co concentration level (47 ppm) in a similarly processed test sample whose true Co concentration is known to be very low (2 ppm). This suggests that the true Co concentrations in the Mount Edziza obsidian flows are also very low.

A significant feature of these element determinations is the very large range of element concentration values obtained for both the major and the trace elements in the ten obsidian flows. In many cases this range approaches or even exceeds a factor of ten. For example, among the major elements compare the Ti and the Fe concentrations in flows 6 and 10; the MnO concentration in flows 6, 7, 9, and 10; and the MgO concentration in flows 4, 9, and 10. Among the trace elements, the most striking range is exhibited by the Zr concentration, which varies by a factor of 14 between flows 7 and 10. A large range is also exhibited by the Zn values (compare flows 4 and 7), the Rb values (flows 1 and 10), and the Ce and La values (compare flow 7 with flows 9 and 10).

Apart from being viewed simply as a self-contained set of absolute element values pertaining to a closed set of related obsidian flows, these results may also be discussed in the light of some previous research on two related topics. First, they may be compared to the chemical analyses recently reported for the basalt comendite series of the Mount Edziza Volcanic Complex by Souther and Hickson (Souther and Hickson 1984). Since the Mount Edziza obsidians form a part of this basalt comendite series, the element results obtained here should reflect the results obtained for the salic rocks (68-80% $SiO_2$) of that series. Second, they may be compared to other significant obsidian sources from around the world, characterized chemically at different times, by various researchers, and by different methods. Such a comparison can be useful in several ways. It can help to determine the petrological class of obsidians to which the Mount Edziza flows belong; it can relate the range of variation in the chemical compositions exhibited by these ten related flows to the ranges of chemical variation observed within other major multi-flow obsidian sources, ie. intra-source variation; and finally, it will demonstrate some of the inter-source variation in the chemical compositions of unrelated obsidian flows, thus placing the results obtained here into a broader perspective.

### a: A comparison of the obsidian flows with the basalt comendite series of the Mount Edziza Volcanic Complex.

Comparisons of the chemical compositions of igneous rocks are usually accomplished by first relating all major and trace element concentrations in a sample to its $SiO_2$ content, and then by examining the element values in the two sets of rocks being compared, for all rock samples which fall within the same range of $SiO_2$ contents. In this case, although the rocks of the basalt comendite series from the Mount Edziza Volcanic Complex (Souther and Hickson 1984) range in their $SiO_2$ content from 45% to 80%, it is relevant to compare the ten obsidian flow results with the element concentrations of the basalt comendite rocks only within the 68-80% range of $SiO_2$ content. The normal procedure adopted towards such comparisons is to construct plots known as "Harker variation diagrams", where all major and trace elements are plotted on the y-axis as a function of the $SiO_2$ concentration (plotted on the x-axis). Harker variation diagrams not only permit the comparison between two data sets to be accomplished simply on a graphical basis, they also help to recognize consistent trends in major and trace element concentration changes with increasing $SiO_2$ concentrations. These trends are important in confirming postulated genetic relationships for a suite of rocks from a small geographic area. In order to facilitate this comparison, Harker diagrams for the major and trace elements of the ten Mount Edziza obsidian flows have been constructed (Figure 7).

All the major element values observed in the ten Mount Edziza obsidian flows are generally consistent with the major element values of the basalt comendite series in the same range of $SiO_2$ concentration (Souther and Hickson 1984:88). Some minor differences are observed, however. For example, the Edziza obsidians' Al values are 7-12%, compared to 8-15% for the basalt comendite series, while the Fe values are 1-11%, as opposed to 1-7%.

The trace elements Ba, Co, Cr, Cu, Ni, Sr, and V are near or below the detection limit in the rocks of the basalt comendite series. In the obsidian data, Cr, Cu, V, and presumably Co, are also below the detection limit, while values for Ni (10-42 ppm), Sr (10-20 ppm) and Ba (21-56 ppm) are very low. Concentrations for these elements, therefore, appear to be in agreement in both works.

FIGURE 7a: Harker variation diagrams for ten Mount Edziza obsidian flows identified: major elements.

LEGEND:

Circles represent from left to right: flows 6, 7, 8, 1, 2.

Diamonds represent from left to right: flows 3, 9, 4, 10, 5.

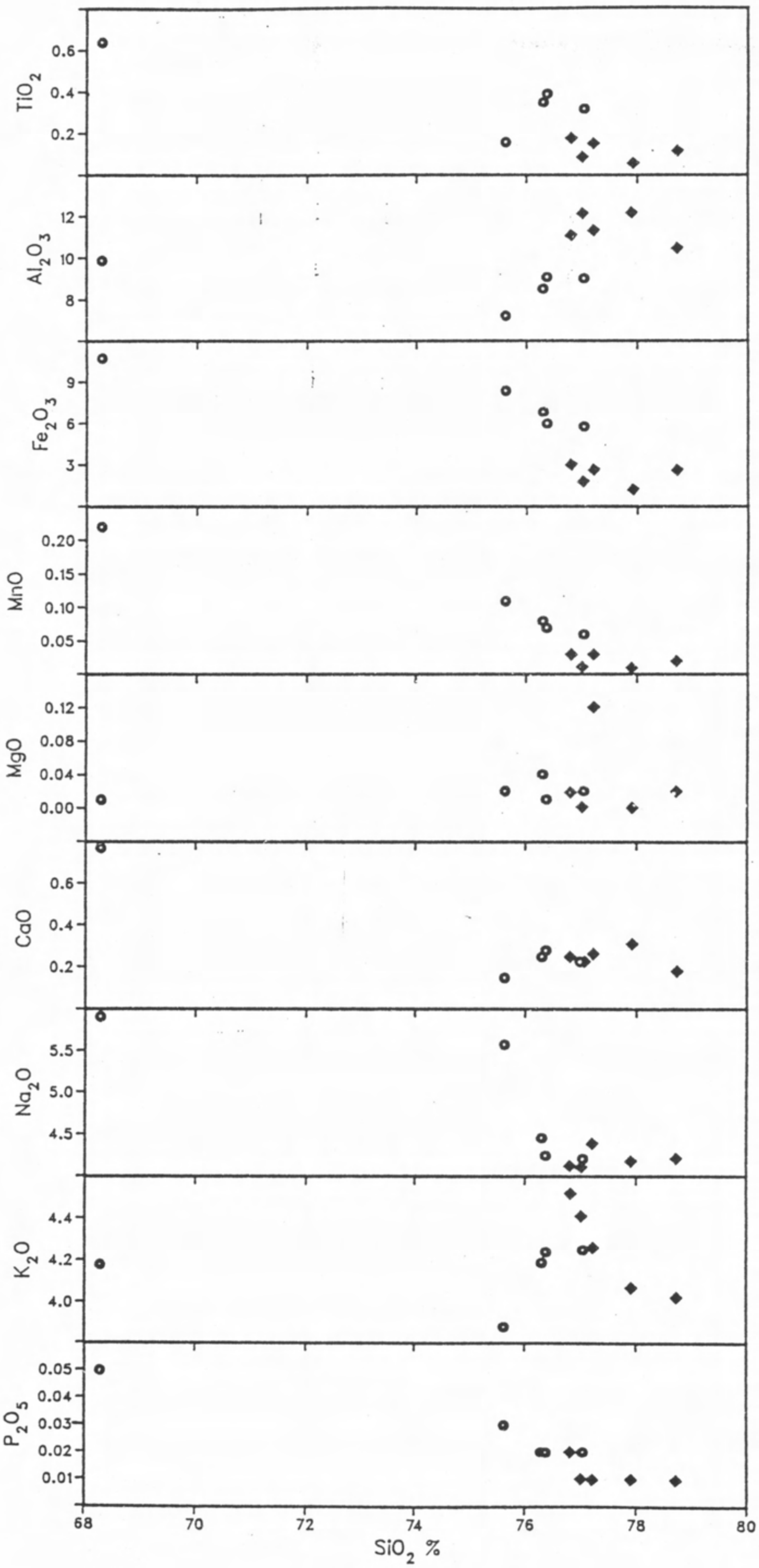
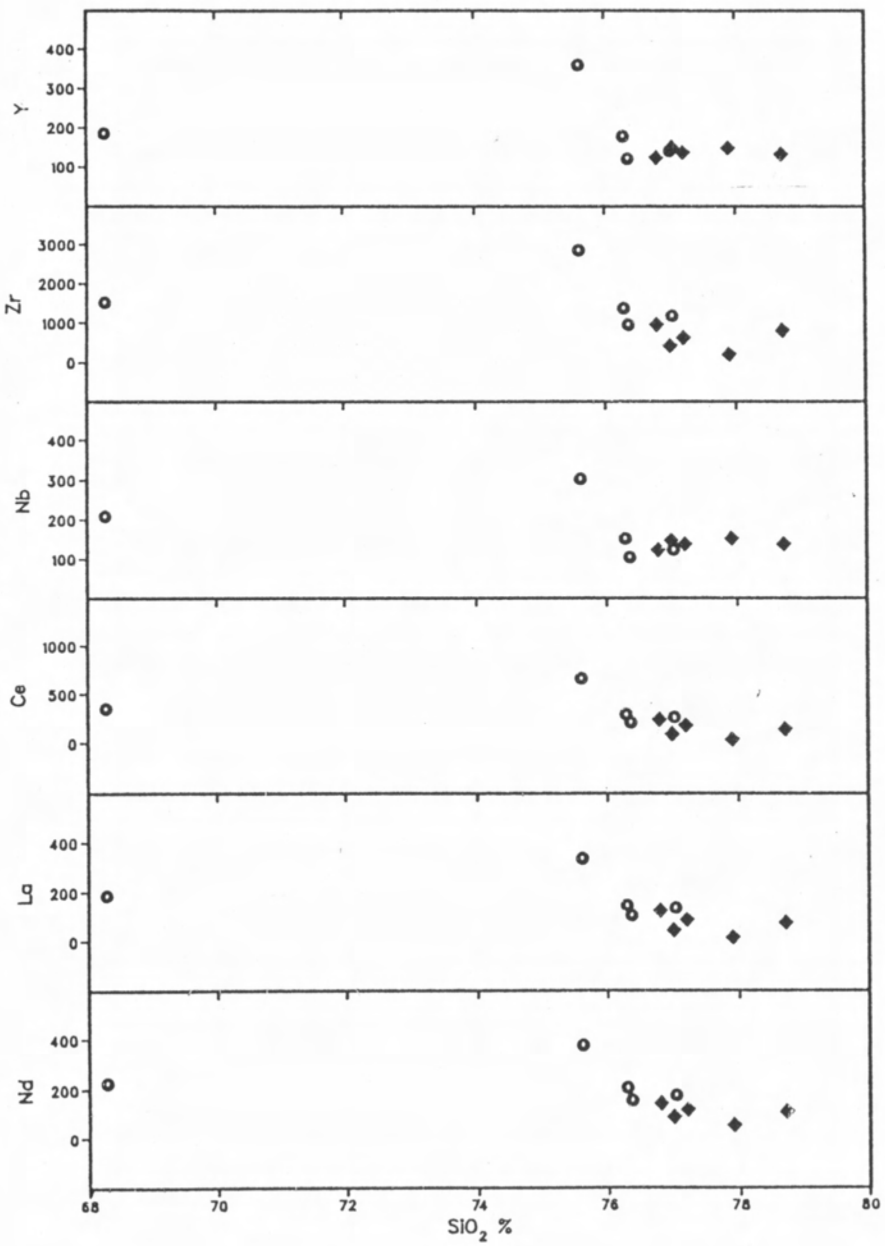

TiO$_2$
0.6
0.4
0.2
Al$_2$O$_3$
12
10
8
Fe$_2$O$_3$
9
6
3
MnO
0.20
0.15
0.10
0.05
MgO
0.12
0.08
0.04
0.00
CaO
0.6
0.4
0.2
Na$_2$O
5.5
5.0
4.5
K$_2$O
4.4
4.2
4.0
P$_2$O$_5$
0.05
0.04
0.03
0.02
0.01
68
70
72
74
76
78
80
SiO$_2$ %

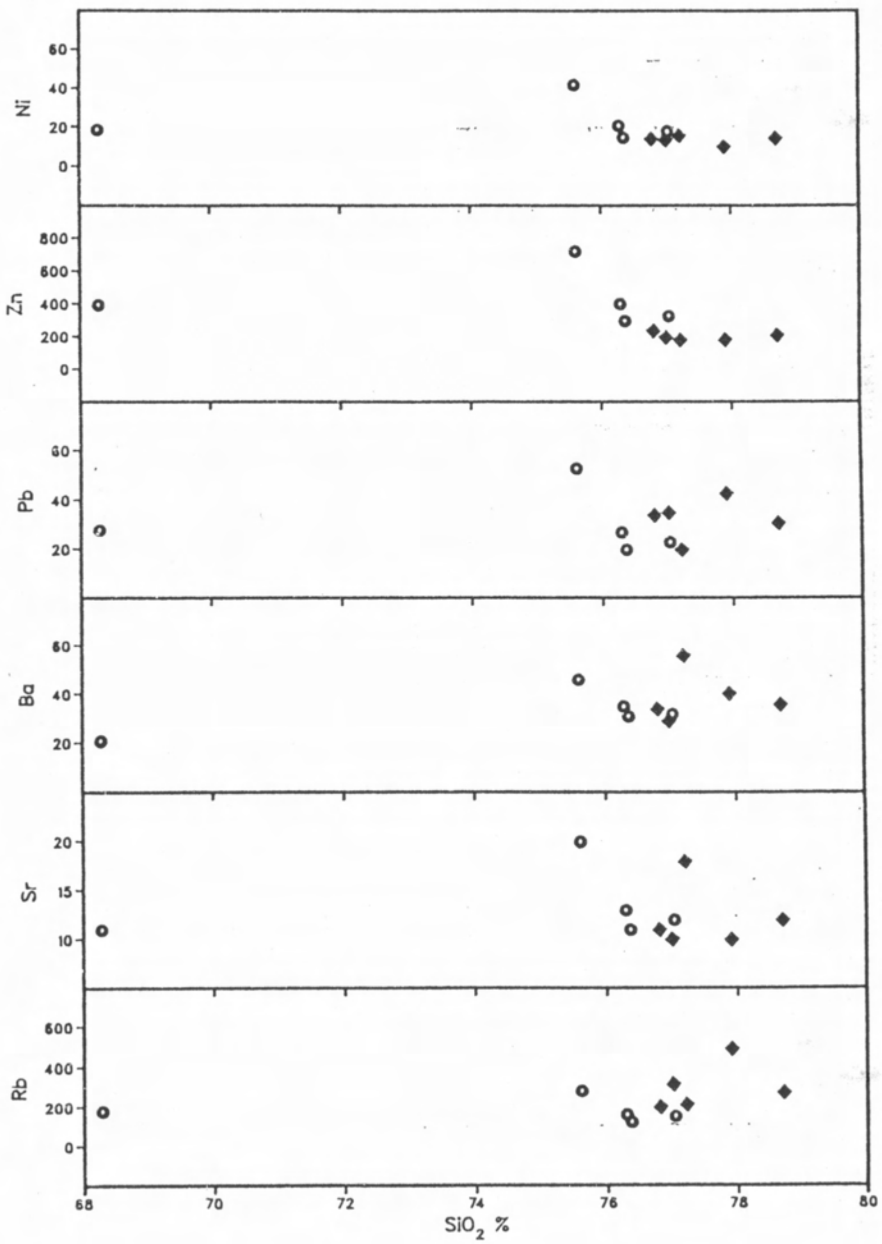
FIGURE 7b: Harker variation diagrams for ten Mount Edziza obsidian flows identified: trace and rare earth elements.

LEGEND:

Circles represent from left to right: flows 6, 7, 8, 1, 2.

Diamonds represent from left to right: flows 3, 9, 4, 10, 5.


Y
400
300
200
100
Zr
3000
2000
1000
0
Nb
400
300
200
100
Ce
1000
500
0
La
400
200
0
Nd
400
200
0
68
70
72
74
76
78
80
SiO$_2$ %


Ni
60
40
20
0
Zn
800
600
400
200
0
Pb
60
40
20
Ba
60
40
20
Sr
20
15
10
Rb
600
400
200
0
68
70
72
74
76
78
80
SiO$_2$ %

There are also large differences in the ranges of concentrations reported for La, Rb, and Y. In Souther and Hickson (1984:99) the values for these elements are, respectively, 0-115 ppm, 100-230 ppm, and 30-70 ppm. The obsidian data shows these concentrations to have much larger ranges: 20-340 ppm in La, 126-493 ppm in Rb, and 124-363 ppm in Y. Five of the obsidian flows have La values which fall within the range reported by Souther and Hickson, and six have Rb values which fall within that range. The concentrations for the element Y, on the other hand, are clearly different in the two works.

As both sets of data being compared above represent absolute element concentrations, it is unlikely that these differences are due to the the analytical methods used to obtain them. They may be due to sampling error, since the high-silica rocks formed a very small part only in Souther and Hickson's much more extensive study. It is also possible that they are due to some differences in the processes responsible for the formation of high-silica crystalline rocks, and those which lead to the solidification of the natural glass obsidian. Obsidian quenches very rapidly, (usually on the order of minutes), while solidification of crystalline rocks is much slower, during which time post-eruptive chemical changes may take place (for example, see Macdonald [1974:5,14]).

### b: A comparison of the chemical compositions of the Mount Edziza obsidian flows with other obsidian sources of the world.

For the purposes of relating the Mount Edziza obsidians to other significant sources of the world, the chemical compositions of several obsidians from Kenya (Bailey and Macdonald 1975, Weaver 1977), Ethiopia (Gibson 1972), Iceland (Klein, Kluger and Wieseneder 1979), Mayor Island (Ewart, Taylor and Capp 1968; Leach and Warren 1981), New Britain (Lowder and Carmichael 1970), and California (Noble et al 1972) are presented in Table 7. Average values for pantellerites, comendites, and rhyolites (Macdonald 1974) are also presented.

The Edziza obsidians represented by flows 1 to 8 are quite similar to the Kenyan and Mayor Island obsidian flows. With the exception of a high Ba content in the Fantale obsidian, the characteristics of these obsidians include very low Ba, Cu, Mo, Pb, and Sr values, and high values for Mn, Rb, Y, Zr, and Nb. Edziza 7 is most like Kenya M, while Edziza 1, 2, and 8 are similar to Kenya m, in the concentrations of the trace elements given for these two African obsidians. All the above sources are known as peralkaline, ie., rocks which, by definition, have a molecular excess of $Na_2O$ + $K_2O$ over $Al_2O_3$ (Macdonald 1974:1). Peralkaline rocks can be subdivided further, into the strongly peralkaline pantellerites, and the mildly peralkaline comendites. Pantelleritic chemistry is characterized by high total Fe, MnO, $Na_2O$, and $TiO_2$, and low $Al_2O_3$, CaO, and MgO; comendites are "generally transitional towards the non-peralkaline rhyolites in respect of these elements" (ibid.:13).

Among the Edziza obsidians, flows #1, 2, 7, and 8 have major-element values close to the pantellerite averages, while flows 3, 4, and 5 have major-element values close to the comendite averages. Edziza flow 6 has a

| KEY TO TABLE 7 | Reference |
|---|---|
| Average values: | |
| 1. Average Pantellerite | Macdonald 1974 |
| 2. Average Comendite | Macdonald 1974 |
| 3. Average non-peralkaline Rhyolite | Macdonald 1974 |
| Peralkaline Obsidian Sources: | |
| East Africa | |
| 4. Eburru, Kenya (m); | Bailey and Macdonald 1975 |
| 5. Eburru, Kenya (M); | Bailey and Macdonald 1975 |
| 6. Emuruangogolok, Kenya (S63); | Weaver 1977 |
| 7. Fantale, Ethiopia (Y346); | Gibson 1972 |
| New Zealand | |
| 8. Mayor Island, main dome (4a, P.29560); | Ewart, Taylor & Copp 1968 |
| 9. Mayor Island, honey variety (16); | Leach and Warren 1981 |
| Calc-alkaline and Alkaline-calcic Obsidian Sources: | |
| 10. Talasea, New Britain (343); | Lowder and Carmichael 1970. |
| 11. Landmannalaugar, Iceland, (#5); | Klein et al 1979 |
| Sub-alkaline Obsidian Source: | |
| 12. Glass Mountain, Mono County, California (MO3B); | Noble et al 1972 |

## TABLE 7

Major and minor element concentrations in different obsidian sources of the world.

| Source: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ----Averages---- | | | -------------Peralkaline------------- | | | | | | ------------------ | | |
| | Pan. | Com. | Rhy. | | | | | | | | | |
| % | | | | | | | | | | | | |
| $SiO_2$ | 71.2 | 74.0 | 74.06 | - | - | 62.61 | 69.56 | 73.40 | - | 75.33 | 70.95 | 76.38 |
| $TiO_2$ | 0.37 | 0.21 | 0.19 | - | - | 0.81 | 0.49 | 0.15 | - | 0.27 | 0.50 | 0.07 |
| $Al_2O_3$ | 9.11 | 11.59 | 13.37 | - | - | 11.01 | 9.62 | 9.05 | - | 12.58 | 14.81 | 12.65 |
| Total Fe | 6.90 | 3.13 | 1.81 | - | - | 11.06 | 7.61 | 6.15 | 3.6 | 2.46 | 3.19 | 1.07 |
| MnO | 0.21 | 0.08 | 0.07 | - | - | 0.44 | 0.17 | 0.19 | - | 0.07 | 0.14 | 0.05 |
| MgO | 0.09 | 0.04 | 0.13 | - | - | 0.15 | 0.02 | 0.01 | - | 0.24 | 0.65 | 0.01 |
| CaO | 0.45 | 0.36 | 0.42 | - | - | 0.90 | 0.47 | 0.21 | - | 1.25 | 0.22 | 0.56 |
| $Na_2O$ | 6.44 | 5.35 | 4.50 | - | - | 7.84 | 6.66 | 6.20 | 4.6 | 4.02 | 5.46 | 4.06 |
| $K_2O$ | 4.40 | 4.46 | 4.36 | - | - | 4.11 | 4.39 | 4.25 | - | 3.82 | 3.92 | 4.67 |
| $P_2O_5$ | 0.05 | 0.02 | 0.03 | - | - | 0.05 | - | 0.01 | - | 0.02 | 0.01 | 0.01 |
| Total | | | | - | - | 99.01 | 99.72 | 99.99 | - | 100.46 | 99.85 | 99.90 |
| ppm | | | | | | | | | | | | |
| Ba | - | - | - | - | - | 126 | 700 | 31 | 39 | 645 | 560 | 30 |
| Cu | - | - | - | - | - | - | - | 5.55 | - | - | - | - |
| Mn | - | - | - | - | - | - | - | 1450 | - | - | - | - |
| Mo | - | - | - | - | - | - | - | 24 | - | - | 6.5 | - |
| Pb | - | - | - | - | - | - | - | 41 | - | - | - | - |
| Rb | - | - | - | 131 | 417 | 218 | 120 | 162 | 139 | 55 | 16.5 | 192 |
| Sr | - | - | - | - | - | 13 | 12 | 4.7 | - | 200 | - | 5 |
| Y | - | - | - | 195 | 410 | 218 | 130 | 190 | - | 20 | - | 34 |
| Zn | - | - | - | 333 | 537 | - | - | - | - | - | 146 | - |
| Zr | - | - | - | 1038 | 3058 | 1380 | 1050 | 1520 | 1019 | 150 | - | 120 |
| Nb | - | - | - | 230 | 542 | 359 | 155 | 81 | - | - | - | 22 |
| Ce | - | - | - | - | - | 355 | 270 | 158 | 162 | 50 | 212 | 52 |
| La | - | - | - | - | - | 205 | 120 | 130 | 90 | 20 | 105 | - |
| Nd | - | - | - | - | - | - | - | 125 | 106 | - | 63 | - |

Notes: 1. For ease of comparison with Table 6, FeO and $Fe_2O_3$ values from original sources are summed as **Total Fe** (oxides).
2. Missing values not quoted in the original sources.

very high total Fe value, which places it very close to Macdonald's line dividing pantellerites and pantelleritic trachytes (ibid.:7), and thus it is probably intermediate to these two rock types.

The major element values in Edziza flows 9 and 10 suggest that these two flows are either very mildly peralkaline, or they are non-peralkaline rhyolites. Strictly speaking, both fall within the range (standard deviations from average values are not given) quoted by Macdonald for comendites (ibid.:10). However, their total Fe values are far below the comendite average Fe value, while their Al contents are higher. In fact, their total Fe values are below the average Fe content in the non-peralkaline rhyolites. They are also similar in major element concentrations to the average rhyolite lava quoted by Carmichael (sub-alkaline rocks, entry 10, in Irvine and Baragar 1971:546), and in the major and some trace element concentrations to the sub-alkaline obsidian source of Glass Mountain, California (Table 7, entry 12; after Noble et al 1972). Souther and Hickson also classify a highly salic rock with an $Al_2O_3$ content of 12.10% and total Fe content of 1.70% as a rhyolite rather than a comendite (Table III, #29, in Souther and Hickson 1984:87). In conformance with the above authors, therefore, the Edziza flows 9 and 10 are interpreted here as having a non-peralkaline chemistry.

The calc-alkaline and alkaline-calcic obsidians from New Britain and Iceland, respectively, are included in Table 7 to demonstrate the wide range of trace element values observed in obsidian rocks. Both have high Ba and/or Sr concentrations, and low Rb, Y, and Zr concentrations. None of the Edziza obsidian flows show such a pattern.

In summary, most of the Mount Edziza obsidian flows fit in the class of peralkaline obsidian composition. Flows 1, 2, 7, and 8 are interpreted as pantellerites; flows 3, 4, and 5 as comendites; and flow 6 as a pantelleritic trachyte (transitional to pantellerite). Two Edziza flows, 9 and 10, are interpreted as sub-alkaline in composition. The presence of transitional rock types within the Mount Edziza Volcanic Complex has been observed by Souther and Hickson: "the salic suite includes (...) members which appear to grade from one to another without any obvious mineralogical or chemical gaps" (Souther and Hickson 1984:84).

The chemical trend in the formation of lavas is that peralkaline lavas need longer residence times within a magmatic reservoir under the surface of the earth than do the alkaline lavas. In other words, the more strongly peralkaline the rock, the longer the residence time of its parent magma. In particular, pantelleritic (or strongly peralkaline) composition is indicative of prolonged magmatic evolution of the parent magma, and is characteristic in areas of rift tectonism (Cann 1983).

The chemical nature of Edziza flows 9 and 10 suggests that they have formed at an early stage of evolution of the Pyramid and Ice Peak formations, respectively. The other two flows within these formations (flows 5 and 4, respectively), being more strongly peralkaline, and thus requiring longer residence times, should be found stratigraphically above flows 9 and 10. In fact, this is the case. As discussed in Section 1, flow 4 is found 500' above flow 10 in the Ice Peak Formation, while flow 9 is found about 100' lower in elevation than flow 5 within the Pyramid Formation.

In addition to this, the most strongly peralkaline of the Mount Edziza obsidian flows (flows 7 and 8) are found within the Armadillo Formation. This is the oldest formation in the Mount Edziza Volcanic Complex which contains salic rocks, having a mean age of 6.3 Ma. At 159 cubic kilometres, it is also volumetrically the largest among the fifteen formations identified within the Complex (Souther et al 1984; Souther and Hickson 1984). The lifespan for this formation is at least 1.1 Ma, and might possibly be as long as 4 Ma. A long time span for the active life of the Armadillo Formation magma chamber is consistent with the oversaturated peralkaline nature of the obsidian flows within this formation. In contrast, both the Pyramid and the Ice Peak formations are young (1.1 Ma, and approximately 1 Ma, respectively), and their lifespans have a narrow range (0.25 Ma for the Pyramid) (Souther et al 1984).

### c. Geochemical Interpretations on the basis of absolute element concentrations

The element concentrations within a suite of igneous rocks can be used to discriminate between two different processes of igneous rock formation. The two processes are known as <u>partial melting</u> or <u>crustal anatexis</u>, and as <u>crystal fractionation</u> or <u>fractional crystallization</u>.

Partial melting is a process in which existing rock (old continental crust, sediments, new basaltic crust, etc.) remelts into magma because of volcanic heating. Since different minerals melt at different temperatures and pressures, some minerals in the parent rock are liquefied faster than others. High pressure forces the resultant liquid out onto the earth's surface, where it solidifies into a new daughter rock, distinct in its chemical composition from that of the parent material.

Various partial melting equations (for example, Shaw 1970) can be used to calculate the expected concentration of an element in the daughter rocks, given the initial chemical composition of the parent material, the proportions of the parent material involved in the partial melting process, the rate of removal of the resultant melt, temperature, pressure, and other data (Berman 1981; Johnson, Smith and Taylor 1978). These equations can also be used to verify a parent-daughter relationship between different rocks found in geographic proximity to each other (ibid.:65).

The crystal fractionation process is one which involves a completely molten lava, which changes in its chemical composition through time. In this process, known as the Bowen reaction series (Press and Siever 1978:347), specific minerals are formed in a known sequence of chemical compositions within a liquid magma, during a long and slow cooling process. These minerals are then removed from the melt, either through gravitational settling or through extrusion. This results in a residual melt of a different chemical composition than the original magma. Unless the melt cools and solidifies into rock, different mineral crystals continue to form and be removed, and thus the composition of the remaining magma continues to change in a gradual fashion. Rocks formed at different stages of crystal fractionation reflect this gradual change.

As in the case of the partial melting process, the crystal fractionation process can be modeled mathematically, using the Rayleigh fractionation model (Shaw 1970). This permits the derivation of various intermediate and end-member rocks from different original fractionating magmas, under different conditions of bulk composition, temperature, pressure, and rate of crystal removal. Souther and Hickson used mathematical modeling (of major elements) to derive various modes of crystal fractionation for the igneous rocks of the Mount Edziza Volcanic Complex.

The derivation of a genetic relationship among some of the Edziza obsidian flows would be useful in confirming that flow 6 is part of the Armadillo Formation. The simplest way of doing this is to plot major and minor element concentrations against the samples' $SiO_2$ content, as was done in the Harker diagrams above (Fig. 7). Relatively smooth compositional variations in such diagrams indicate that a postulated genetic relationship is correct. Such variations were observed by Berman for rocks of the Coquihalla Volcanic Complex (Berman 1981:157-158) and by Souther and Hickson for the basalt comendite series of the Mount Edziza Volcanic Complex (Souther and Hickson 1984:88, 99).

The Harker diagrams in Fig. 7 can be examined to verify which of the ten Mount Edziza obsidian flows are genetically related. For the major elements (Fig. 7a), the set of obsidian flows postulated to originate within the Armadillo Formation (circles, representing flows 6, 7, 8, 1, and 2) in general show consistently higher concentrations of Ti, Fe, Mn, and P, and consistently lower concentrations of Al, than the other five flows (diamonds, representing flows 3, 9, 4, 10, and 5). Since the latter five flows are thought to have originated from three different formations, a large amount of scatter in these points should not be cause for concern.

Trace elements can also show gradual and predictable changes, although the range of variation commonly observed in them usually permits only qualitative observations to be made. Certain trace elements will tend to be depleted, either very quickly in the early stages of fractionation (for example, Ni) or very gradually (Cd). Other trace elements (Rb, Y) will show increasing enrichment as the fractionation proceeds. Still others (La and Th) can show enrichment in the early stages of fractionation, but are depleted during the latter stage of the process (Souther and Hickson 1984:99). Certain trace elements (for example Zr, Nd, Ce, and Nb) are commonly considered as <u>hygromagmatophile</u> or <u>incompatible</u>, and they tend to remain in the melt during the entire fractionation process, with resultant terminal enrichment (Berman 1981). Others (for example, Ba and Sr) have a chemical affinity for the crystal phase, and are removed in the minerals fractionating out of the melt, so that their highest concentrations are found in the early-stage rocks.

As in the case of Harker diagrams, a suite of rocks from a single continuously fractionating magma should show a positive linear correlation between the chemical concentrations of two incompatible elements in these rocks (B. Cousens, pers. comm.; Berman 1981). If the data points do not form one straight line, then either they are not all members of a single fractionating suite, or the crystal fractionation model is not appropriate for the formation of the set of rocks being studied. In general, nearly-linear patterns are not consistent with partial melting processes, and partial melting processes cause a much greater departure from linearity in trace element correlation diagrams than crystal fractionation processes (Berman 1981).

In order to test the above, several incompatible elements determined for the Edziza obsidian flows were plotted in element correlation diagrams (Fig. 8). Figure 8a shows the relationship between the element Rb and the elements Nb, Y, Ce, and Nd. The pattern which emerges from these graphs suggests that flows 1, 2, 8, 6, and 7 are related in the manner predicted by a crystal fractionation model for a single fractionating suite. This confirms the suggestion made earlier in this thesis that flow 6 is a part of the Armadillo Formation along with the other four flows, and that at least three of these (flows 1, 2, and 8) are closely related chemically.

The data points for flows 3, 4, 5, 9, and 10 show more scatter, and a strong positive linear correlation is not observed for them. Where a linear correlation can be inferred, it is either weak (Rb _vs_ Nb, and Rb _vs_ Y, Fig. 8a) or negative (Fig. 8b). Thus, it is unlikely that these five flows are members of a single fractionating suite. Since they come from widely separated outcrops within the Mount Edziza Volcanic Complex, and have been assigned to different geological formations, this is a valid conclusion.

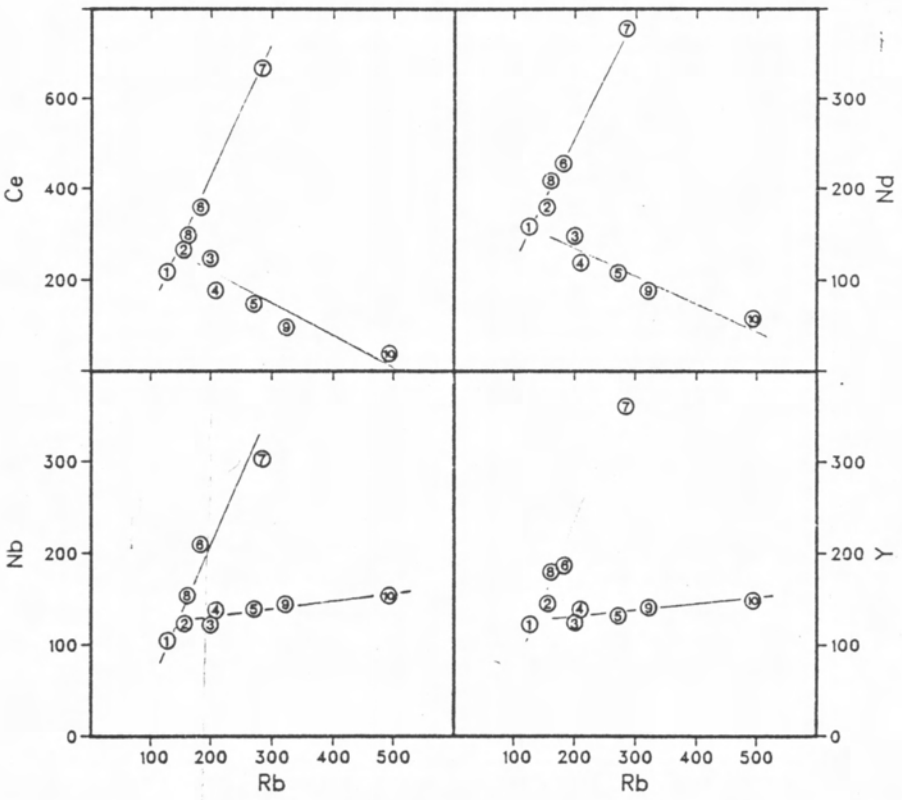


**Figure 8:** The relationships between several of the minor and trace elements in ten Mount Edziza obsidian flows.
a) Rb vs Ce, Nd, Nb, and Y.

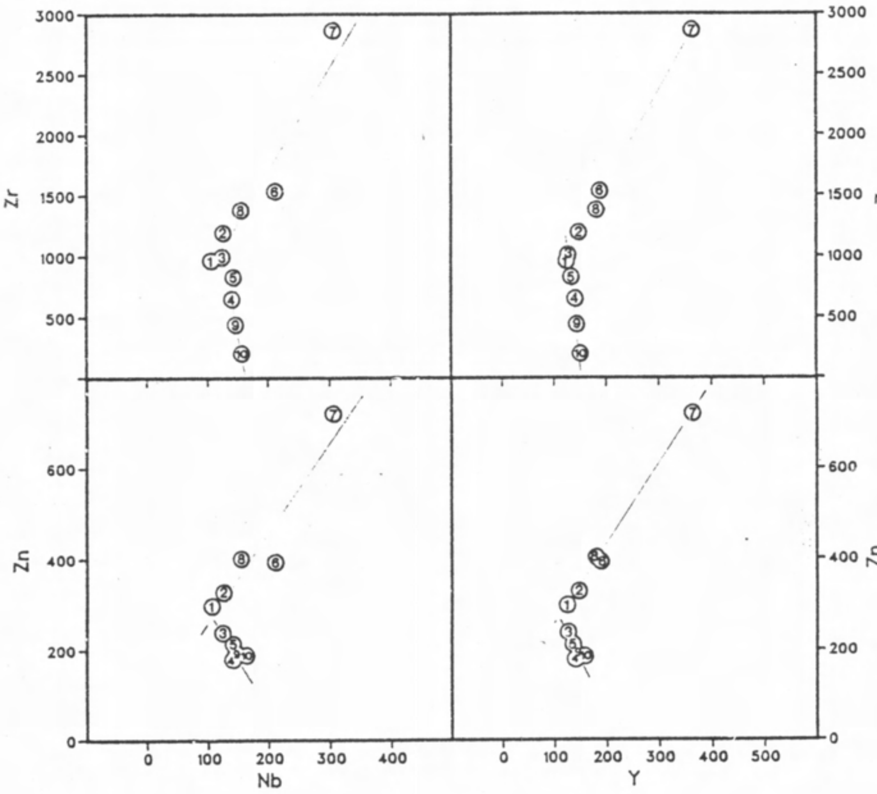


Figure 8: The relationships between several of the minor and trace elements in ten Mount Edziza obsidian flows.
b) Nb and Y vs Zr and Zn.

### d. Relative vs Absolute Element Concentrations

Graphs relating the relative element/Compton ratios and the absolute element concentrations of each obsidian flow were constructed for most of the elements detected by both methods. They are presented in Figure 9a (Ti, Mn, Fe, and Zn) and in Figure 9b (Rb, Y, Zr, and Nb).

These relative vs absolute concentration plots can be useful in relating the semi-quantitative data obtained with the ED-XRF spectrometer at SFU to the absolute element concentrations in obsidian flows not studied here. Such a comparison would only be valid for obsidian data consisting of several measurements, with each relative element ratio given by a mean and a standard deviation. It would not be useful for individual samples. Also, as can be observed from the graphs in Fig. 9, the absolute element concentrations obtained through the use of the graphs would be of low precision.

In most of the relative vs absolute element graphs a linear relationship is observed. The interpretation of such a relationship is that for the obsidian flows studied, the semi-quantitative element/Compton ratios measured with a Ag secondary target are directly proportional to the absolute concentrations of these elements. In most cases, the straight-line fit falls within one standard deviation for all ten groups. The graphs for the trace elements Zr, Zn, Y, and Nb show this to be the case.

Two exceptions to such a linear relationship were observed for the graphs of Fe and Rb. Instead of a straight line, the data points for these two elements best describe a curve. However, a straight-line fit falls within two standard deviations of all data points on these two graphs.

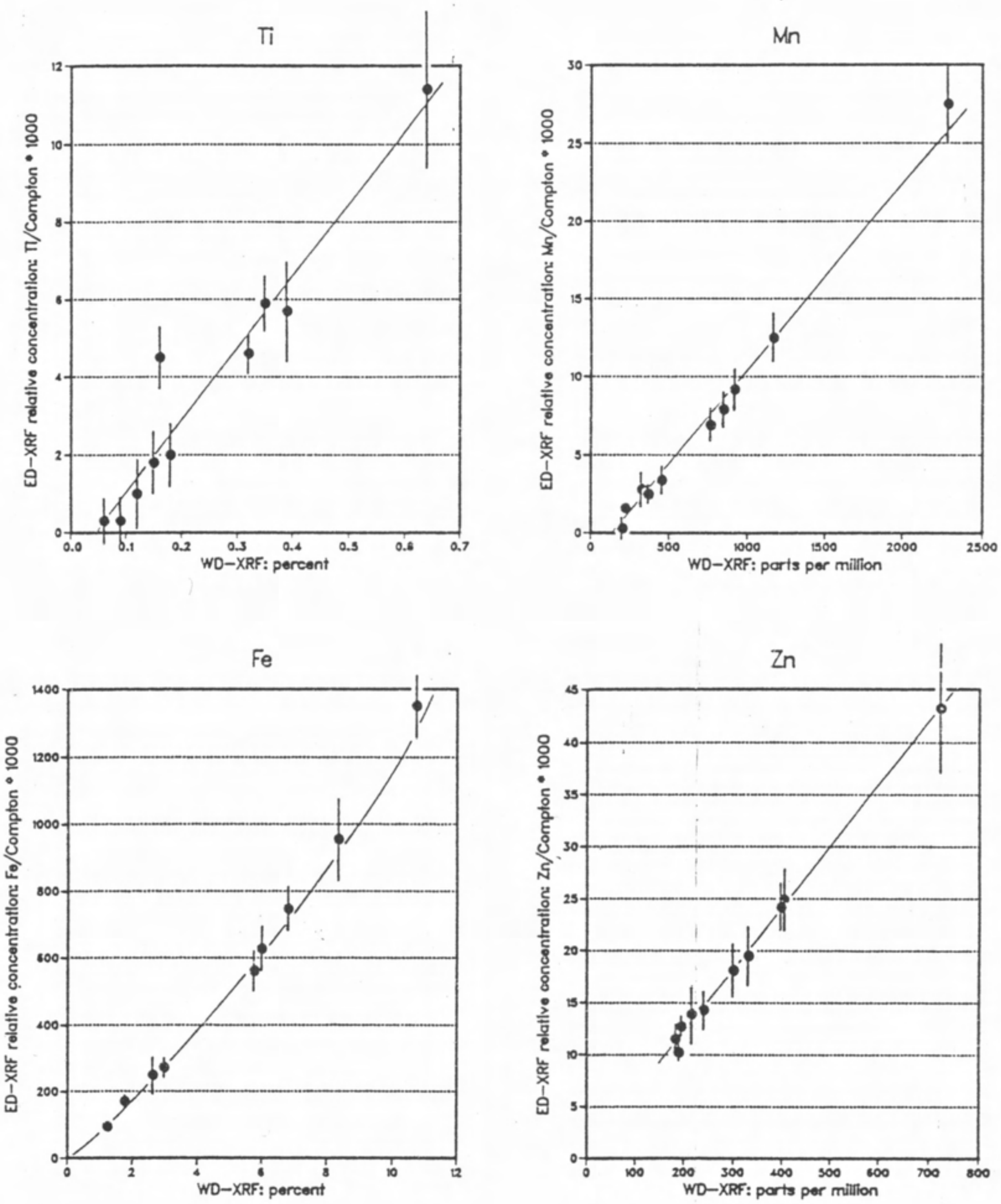


**Figure 9:** Comparison of the two analytical methods used in the chemical characterization study of the Mount Edziza obsidian flows.
a) ED-XRF relative concentrations vs WD-XRF absolute concentrations for Ti, Mn, Fe, and Zn.

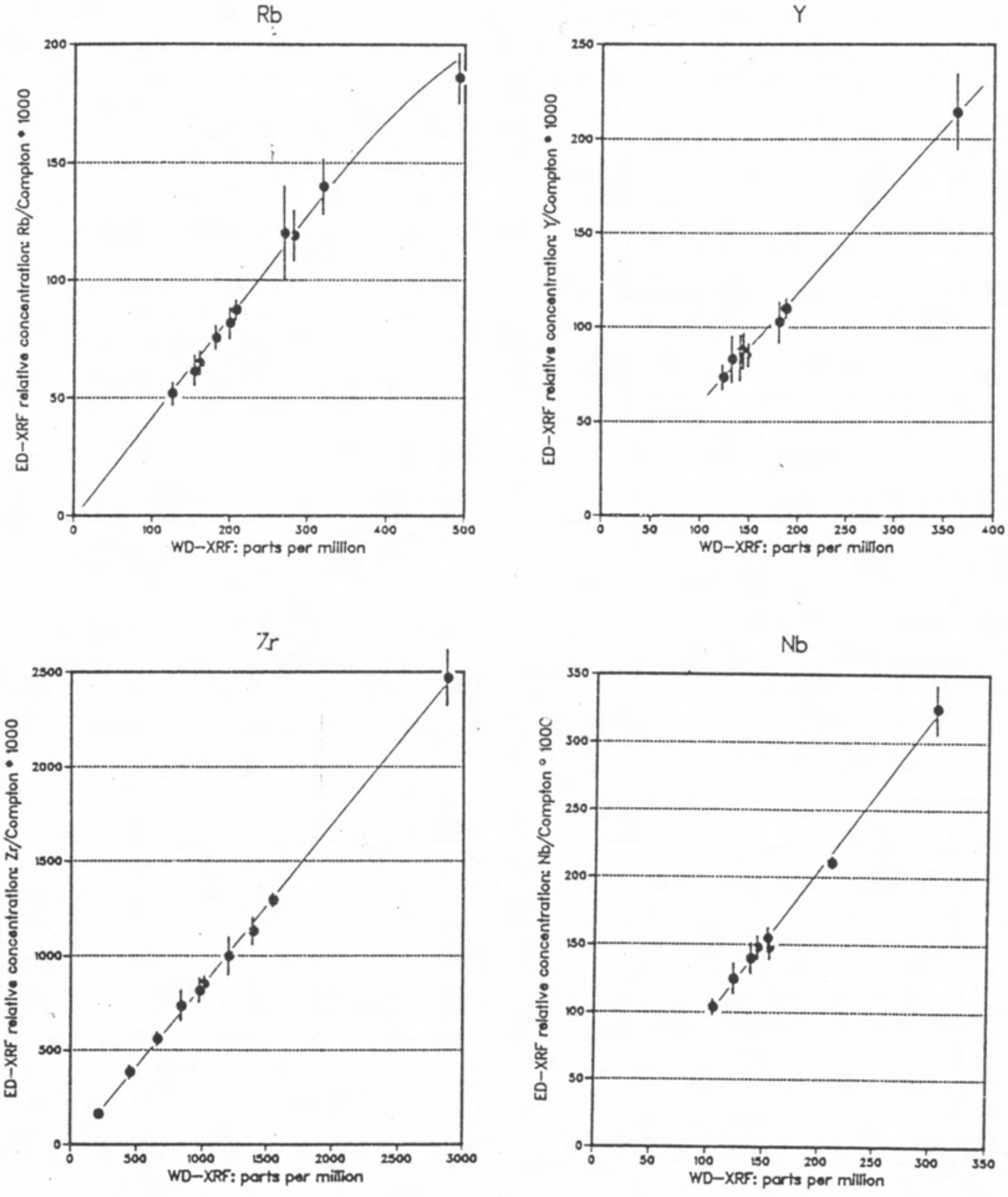


**Figure 9:** Comparison of the two analytical methods used in the chemical characterization study of the Mount Edziza obsidian flows.
b) ED-XRF relative concentrations vs WD-XRF absolute concentrations for Rb, Y, Zr, and Nb.

The failure of these two elements to show the expected linear relationship is due to an intrinsic limitation of the Compton normalization procedure. As already stated in Section 1, the Compton scatter peak observed in an XRF spectrum is inversely proportional to the average atomic number _Z_ of the specimen being analysed. When samples of a similar chemical composition (and therefore of similar average atomic number _Z_) are examined, the Compton scatter peak is approximately the same in all of them. Thanks to this, element normalization to the Compton scatter peak is a valid procedure when several related obsidian flows are being studied, since theoretically, the major element chemical composition (and therefore the average atomic number _Z_) of obsidian varies very little. In low-_Z_, lightweight samples the Compton scatter peak is high; as the average _Z_ of a sample increases, the Compton peak becomes smaller.

Obsidian is a relatively light substance, and its average _Z_ is low. The absolute element concentrations in Table 6 show that most of the ten Mount Edziza flows are composed of about 76% by weight $SiO_2$. However, one of the characteristics of the ten Mount Edziza obsidian flows which had already been pointed out above is the very large range of concentrations observed for $Fe_2O_3$. As Fe is one of the major constituent elements in obsidian, and $Fe_2O_3$ is much heavier than $SiO_2$ (atomic weight = 160 amu, as opposed to 60 amu), a small change in its concentration can be expected to change the average _Z_ of the obsidian considerably. For example, a 5% increase in the concentration of $Fe_2O_3$ results in a 15% increase in the average atomic weight of the obsidian. Such a change will naturally lead to a change in the height of the Compton scatter peak: the flows with the highest Fe content (flows 6 and 7) will have the lowest scatter peaks, while the flows with the lowest Fe contents (flows 10 and 9) will have the highest scatter peaks.

The curve for Fe (Fig. 9a) is supra-linear; that is, it rises faster than a straight line. The reason for this is as follows. As the Fe concentration increases, then the Compton scatter peak decreases, and so the relative Fe/Compton ratio increases faster than the real Fe concentration. The highest Fe/Compton ratio observed is that for flow 6, the obsidian flow with the lowest $SiO_2$ (68.26%) and the highest $Fe_2O_3$ (10.74%) concentrations observed in the ten flows.

The curve for Rb (Fig. 9b) is sub-linear: it curves down from a straight line. In fact, only the highest point on that graph does not fall on a straight-line fit; all others do. This point corresponds to flow 10, whose Fe concentration of 1.24% is the lowest observed in the ten Mount Edziza obsidian flows. The Compton scatter peak for this flow is therefore higher than in the other flows, and so the Rb/Compton ratio is lower than it would have been if the Compton did not vary inversely with a sample's average $\underline{Z}$.

A graph of Ti shows that the linear relationship between the relative element/Compton ratios and absolute element concentrations is not well supported by the data for poorly detected low element peaks. A similar result (not included here) has been obtained for the relative vs absolute concentrations of Pb. The scatter observed in these graphs is due both to counting scatter and to the large errors (20%) in the computer-generated fit to the data obtained from low peaks.

Graphs for the two lightest elements detected, K and Ca are not included. For these two peaks near the low-energy extreme of the x-ray continuum, the scatter and the detection efficiency of the ED-XRF results are so poor that these relative K and Ca concentrations have little bearing on the real element concentrations in the sample. Obsidian analysis with a

Zn secondary target (K-alpha emission energy = 8.6 keV) should improve dramatically the detection efficiency and decrease the scatter in the observed relative concentrations of K, Ca, Ti, and Mn. Relative element/Compton ratios, measured for these four elements with a Zn secondary target, could then be used to construct similar relative vs absolute concentrations as those presented here.

# SECTION 3

# A LOOK AT LOCAL OBSIDIAN EXPLOITATION PATTERNS THROUGH A STUDY OF FIVE ARCHAEOLOGICAL LITHIC ASSEMBLAGES.

## Introduction

One of the specific goals of the archaeological survey of the Mount Edziza Volcanic Complex conducted by Fladmark in 1981 was to determine the extent of aboriginal utilization of the Edziza obsidian sources. This objective was achieved with the documentation of 114 prehistoric sites. Of these, all but 29 were found within Raspberry, Bourgeaux, and Artifact valleys, on Kitsu Plateau, and on "Goat" Mountain. Also, 82 of the 114 sites were designated either as quarry-workshops or flaking stations devoted exclusively to the processing of raw obsidian rock into lithic tool preforms. The remaining 32 sites were campsites or multi-function sites.

The previously documented wide distribution of artifacts made from Mount Edziza obsidian, extending hundreds of kilometres away from the Complex, attested indirectly to its significance as the largest and most heavily exploited obsidian quarry in the Northwest. As a result of the 1981 survey, it became clear that the exploitation of the Mount Edziza Volcanic Complex as an obsidian source was both extensive and intensive, and that the obsidian exploitation was probably the single most important reason for prehistoric human presence within the Complex.

Section 1 of this thesis established that the Raspberry Pass - "Goat" Mountain - Artifact Valley area (Fig. 6b) was host to five distinct types of obsidian, and that in most sampling locations, the obsidian occurred as single-type unmixed deposits. Also, certain of the obsidian types - notably types 2 and 3 - show the heaviest concentrations in very different areas. Edziza 2 is the only obsidian type found in the Raspberry Pass scatters, which are of poor quality and of no use for tool manufacture, while Edziza 3 is the predominant obsidian type in Artifact valley, and the only type found on "Goat" Mountain. The identification of particular obsidian types in the artifacts from an archaeological site could thus be used as a guide to the obsidian procurement strategies practiced by the makers of these artifacts. For example, the presence of artifacts made from obsidian types 5 or 9, at sites in Artifact valley, would indicate that the raw material was procured at the Pyramid, well to the north of Artifact valley. Of course, since Artifact valley is itself full of obsidian, such a scenario is highly improbable. Among other things, however, type characterization of obsidian artifacts can yield information on whether raw material procurement was a well-organized, task-oriented process, or a more casual, "pick-it-up-as-you-need-it" affair.

## Description of the Sites and Assemblages chosen for study

Three sites were chosen for this study. Two of them (HiTp-63 and HiTp-1) are multi-function, multi-component sites, containing lithic workshop and campsite components, located in two different valleys. The natural obsidian type distributions near these sites are quite different, although their quality varies from poor to good. Accessibility to concentrated deposits of good quality obsidian from these sites also varies.

Analysis of artifacts from the two sites permit the following comparisons to be made: whether the obsidian type frequencies in the two different components within each site are the same; whether the obsidian type frequencies in the lithic workshop components of the two sites are the same; whether the obsidian type frequencies in the campsite components of the two sites are the same, and how do they differ from the frequencies in

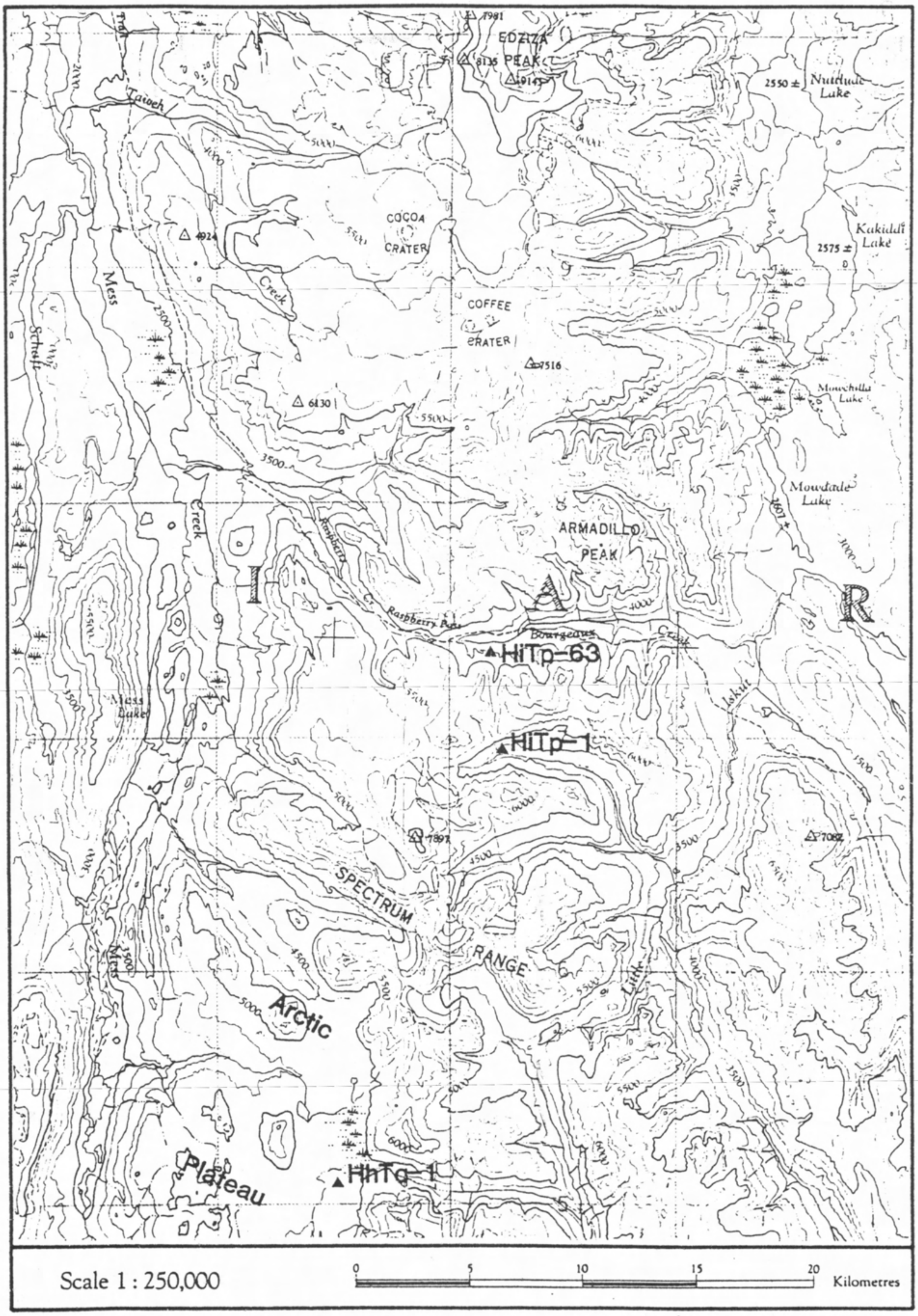


Figure 10: Location of the Archaeological Sites Discussed in the Text

the lithic workshop components; and finally, how do the obsidian type frequencies within each site relate to the natural obsidian type distributions in the immediate vicinity of that site.

A third site (HhTq-1) was also included in this study. It was chosen both because of its location, and because of the rather unusual lithic assemblage it contained. This site is located on the Arctic Plateau, far to the south of any obsidian sources within the Complex, and well isolated from any other archaeological sites in the Complex. It contained a diverse lithic assemblage which included microblades and a large well-flaked biface. Analysis of these artifacts was done to determine where the raw material for their manufacture was procured.

a. HiTp-1 (EP1, Wet Creek Site)

This site is located at the junction of Artifact Creek and its tributary "Wet" Creek, at an elevation of 4820' (1460 m). It is one of the two-component sites, composed of a lithic workshop component (House 1), and a campsite component (Area 2). The two components do not overlie each other, but are separated by a distance of some 70 m. Excavations of each component were performed (Fladmark 1982).

House 1. This is a large natural depression feature, presumed to be a single-occupation lithic workshop dedicated to biface preform manufacture. Upon excavation, this cultural depression was found to contain literally tens of thousands of obsidian detritus flakes, and over 70 biface preform fragments. Of the biface preforms, 8-10 are in an advanced state of manufacture.

This component is dated at 2860+-160 BP (SFU 141), by C14 dating on organic material associated with the lithics. It is also associated with a coastal-type ground slate or siltstone projectile point typologically dated at 2000-3000 years BP. No evidence of a microblade industry was found.

Both the biface preforms and the obsidian flaking detritus were sampled for analysis. Twenty reasonably complete bifaces were chosen. The debitage flakes were sampled from levels 2 to 5 of a 50 x 50 cm unit (N22-23, E18-19, SE) within the cultural depression feature. This unit was chosen because it was in the core area of most intensive lithic reduction activity within the cultural depression, and it contained the highest number of flakes (nearly 10,000) excavated from any quadrat. A 1% sample of levels 2, 4, and 5 was taken. Level 3 was sampled at 5% to ensure that the sample size exceeded the number of obsidian flows found in the study area. The total number of obsidian debitage flakes analysed as a result of this sampling scheme was 111.

Area 2. The main excavations of this component were conducted about 70 m SE of the House 1 excavations. Thirty-two modified tools and several thousand obsidian detritus flakes were recovered. The modified artifact assemblage was a diverse one, consisting of microblades and microblade cores, end- and side-scrapers, bifaces and retouched flakes, as well as biface preforms and flake cores. The high diversity of artifact classes in this assemblage places it within the "camp" class as defined by Fladmark (1982:245).

This component is associated with a minimum date of 1140+-80 BP (SFU 162), obtained on material directly overlying the assemblage but not actually within it. However, on the basis of the strong microblade component in this assemblage, a much older date of approximately 4000 BP is suggested (Fladmark 1982:248).

The artifact sample chosen for analysis consisted of 12 of the 32 modified tools. This sample consisted of: one microblade core and one microblade, three scrapers, one complete and three broken bifaces, a uniface, a retouched flake, and a core. This sample was chosen so that at least one of each class of artifact found in the assemblage would be submitted to analysis. No obsidian detritus was analysed.

b. HiTp-63 (EP80, Grizzly Run Site)

This site is located in Bourgeaux Creek valley, at an elevation of 4885' (1480 m). It is also a two-component site, represented by a campsite (Component 1) and a lithic workshop component (Component 2). Unlike the situation at the Wet Creek Site, the two components at this site are found in a stratigraphic sequence. The two components are separated from each other by a distinctive marker horizon composed of a coarse volcanic ash (Ash 3).

Component 1. This is a surface and shallow subsurface component, separated from the lower component by a layer of volcanic tephra.

The artifact assemblage excavated here consisted of a large variety of artifact classes, including bifaces and biface fragments, retouched flakes, side- and end-scrapers, a core, and a large "battered piece" tool. Several artifacts were made of raw materials other than obsidian, including basalt, rhyolite, and andesite. No microblades were found. Approximately 1300 obsidian detritus flakes were also recovered from eight 1x1 m excavation units. Again, as in the case of the Area 2 component of the Wet Creek site, the variety of artifact classes found here suggests that this was a brief 2-3 day campsite, occupied by a small group of people. Alternatively, the assemblage may have been left deliberately as a tool cache.

The dating of Component 1 is based on two criteria. First, the volcanic tephra layer separating this component from the underlying Component 2 is known to have originated in a 4630 BP eruptive event, and it provides a maximum age limit for Component 1. Also, a radiocarbon date of

3910 +-120 BP (SFU 147) is tentatively associated with this component. This date is accepted as a probable and a reasonable estimate for the age of the component (Fladmark 1982:278).

Since the size of the assemblage was small, all seven obsidian artifacts found in this component were analysed. They consisted of 4 biface fragments, 1 flake core, and two scrapers. The obsidian detritus flakes were not sampled for analysis.

Component 2. This was clearly a lithic workshop component, devoted to biface and microblade production. It consists of a nearly pure lithic workshop residue: 12 biface fragments, 4 flake cores, and 60 microblades or microblade fragments, many of which were refitted to form a single microblade core. Additionally, a very large number (over 19,000) of obsidian detritus flakes) were recovered from eleven 1x1 m excavation units.

This component was found underneath the volcanic tephra layer, which places its minimum age at 4630 BP. A radiocarbon date of 4870 +- 120 BP (SFU 129) is associated with it. This gives not only the probable age of the oldest cultural occupation at this site, but also the oldest date associated with any cultural remains in the Edziza region.

The sample analysed consisted of 13 artifacts, all chosen from amongst the formed tools. Most consisted of biface or flake tool fragments. One of the microblades refitted to form the core was also analysed, which gave information on the obsidian type for a number of other microblades and the original core.

c. HhTq-1 (EP58)

This site is located on the Arctic Plateau at an elevation of 5085' (1540 m), among a complex of esker ridges at the upper end of More Creek.

It is one of the most isolated sites, the area being otherwise barren of cultural remains. It is interpreted by Fladmark as representative of a single brief occupation, probably a short-term caribou-hunting camp. Environmental considerations suggest that the site was created during warm periods of the Hypsithermal, prior to 4000 B.P. (Fladmark 1982:152).

This was a surface scatter site, with no buried component or dateable material in association with the artifacts. The artifact assemblage was diverse, consisting of 24 obsidian flakes, one long and relatively thick collaterally flaked projectile point, 2 scrapers, 2 bifaces, 2 retouched flake tools, one flake core fragment, 2 microblade core remnants, and 14 microblades (Fladmark 1982:151-152).

From this assemblage, six artifacts, including the projectile point, two microblades, a microblade core, and two flake tools, were analysed.

Hypotheses on possible local obsidian procurement strategies

HiTp-1 House 1. Since this is a high-intensity lithic workshop located very near prime obsidian source areas (on "Goat" Mtn., and in the "Fan Creek" talus deposit) it is presumed that high-quality obsidian was deliberately sought out and brought to this site for reduction. If the "Goat Mtn." source was being exploited, then Edziza 3 should be the sole obsidian flow represented here. Similarly, if the "Fan Creek" talus deposit was sought, then all artifacts should be made of type 2 obsidian, since that is the only type present in the "Fan Creek" deposit. If such was not the case, then a more generalized and diffuse exploitation pattern is indicated. A high percentage of Edziza 8 obsidian (and small quantities of types 2 and 7) would indicate that the slide in Destall Pass was exploited; similarly, high percentages of Edziza 3 and Edziza 6 (and small quantities of types 7 and 8) would indicate that the obsidian was collected from the outwash gravels of Artifact Creek. Presence of the obsidian flows represented in the gravels of Destall Pass and Artifact Creek is unlikely, as these deposits are small in quantity, and are composed of poor quality obsidian. The presence of these flows, despite the fact that this obsidian would necessarily be of inferior quality, or the presence of type 2 obsidian, would indicate that the people who left behind the enormous amount of obsidian detritus at House 1 preferred to collect the raw material at low-elevation easily accessible locations. The climatic conditions prevailing around 3000 BP were those of the Neoglacial (Fladmark 1982), and access to the high-altitude obsidian outcrops on "Goat" Mtn. during that period may have been seasonally restricted to such an extent that exploitation of low elevation source areas was necessary.

HiTp-1 Area 2. A greater number of obsidian flows is postulated for this assemblage. The diversity of artifact classes and the fact that this is a campsite suggests that the tools found in this component were not all manufactured at the same time, thus a variety of source materials is more likely. The climate during 4000 BP was probably milder than the Neoglacial conditions of 3000 BP, and so higher-altitude obsidian outcrops would have been more accessible. This would include Edziza 3 and 2 on "Goat" Mtn. and its flanks. Edziza 2 at the base of "Fan" Creek would be the nearest low-elevation source of good quality obsidian clasts. Further away, flows 1, 4, 5, 9, and 10 would also likely have been as accessible as they are today. In spite of the accessibility of these flows, the site location in Artifact valley suggests that the frequency of Edziza 3 obsidian should be higher than any other. Association with a projectile point diagnostic of a coastal group raises the possibility that some of the obsidian tools need not be indigenous to Edziza. Some may have been manufactured on the coast from one of the Alaskan or Yukon obsidian sources, and may have been brought into the site by coastal people along with other tools made of non-local lithic material.

**HiTp-63 Component 1.** The presence and diversity of raw material types in the lithic artifacts not made of obsidian, suggests that a number of obsidian types may also be present in the artifacts from this component. Since this is a possible campsite component, a variety of obsidian types is likely, as the same arguments apply here as in the Area 2 component of HiTp-1 above.

**HiTp-63 Component 2.** This is a lithic workshop component, and so it is most likely that only the Edziza obsidian sources will be represented in the artifacts analyzed. Since it is located in Bourgeaux valley, the nearest naturally available obsidian is of type 2, and is located in the scatters in Raspberry Pass. The principle of least effort would suggest that the artifacts in this component are made of the Edziza 2 obsidian obtainable in Raspberry Pass. This obsidian, however, is not of useable quality. The nearest source of useable quality obsidian is in the moraine at the head of "Point Creek", which is composed of obsidian of type 3. The concentrated remnants of microblade production also suggest that this type was exploited here, since microblade production requires a particularly good quality of raw material. Also, the obsidian from which the microblades were made is visually suggestive of Edziza 3: it is black and glassy, and clearly transparent with a greenish tinge in transmitted light. The other obsidian types found at Mount Edziza which show this green tinge are at best translucent, and often almost completely opaque.

HhTq-1. This site was chosen for analysis because of its unique position and artifact assemblage within the Mount Edziza Volcanic Complex. Because of its isolated position it is impossible to guess where the obsidian was procured. The people may have traveled from the north along Mess Creek, down the west side of the Complex, in which case they may have collected their raw material at Cocoa Crater or Coffee Crater. In this case the obsidian flows 1, 2, and 4 would be expected in the assemblage. Alternatively, they may have traveled down the east side of the Complex, and collected their obsidian in Artifact Creek (the most easily accessible source area), and in upper Artifact valley. The presence of obsidian flows 2, 3, 6, 7, or 8 would confirm this route. Should all artifacts be made of Edziza 3 obsidian, a direct route over the high plateau areas to the "Goat" Mtn. source would be indicated.

## The Chemical Analysis of Five Artifact Assemblages

Sample preparation was limited to washing all artifacts under deionized water. The analysis was performed using the same instrumental setup of Section 1.

It was determined in Section 1 that only the elements Fe, Rb, Y, Zr, and Nb were significant in chemical flow discrimination, and the relative intensity of these peaks was well defined at even the shortest analysis times (Fig. 3). Since the purpose of this analysis was to assign each artifact to one of the 10 obsidian flows and not to establish precise concentrations for all elements in each flow, the artifacts were analysed for 5 minutes only. All 169 artifacts were analyzed non-destructively with the exception of 3 very large cores or flakes, from which a small flake was detached for analysis.

It is important to note that of the ten natural Edziza obsidian flows, a positive identification of flows 3, 4, 5, 9, and 10 can be made by visual examination of their spectra (Fig. 4). However, the Armadillo Formation flows 1, 2, 6, 7, and 8 cannot be reliably distinguished from each other on the basis of their spectra. During analysis most of the spectra collected were identified by inspection as representative of the Edziza 3 obsidian flow. The remainder of the spectra appeared to represent the five Armadillo flows (1, 2, 6, 7, and 8). None of the 169 artifact spectra examined were characteristic of flows 4, 5, 9, or 10.

The precise obsidian source identification of the artifacts whose spectra could not be positively identified by inspection was made analytically. Approximately half of the artifacts identified on the basis of their spectra as made of Edziza 3 obsidian were also analysed, to confirm that the flow identifications made visually were not in error. The analyses involved peak extraction, normalization, and comparison with normalized element values obtained for source flows 1, 2, 3, 6, 7, and 8.

Inspection of the A-coefficients separating the relevant natural Edziza obsidian flows suggested that the most efficient way to attribute the artifacts to the obsidian source flows was on the basis of the element ratios Fe/Zr, Rb/Zr, and Nb/Zr. Rather than submitting the data to the lengthy process of peak extraction through the GAMANAL computer program as in Section 1, the peak areas corresponding to the K-alpha emission lines of Fe, Rb, Zr, and Nb were extracted using the internal peak extraction routine of the ND66 multichannel analyser. However, as this was a departure from the procedure followed for the establishment of the semi-quantitative element values for each flow in Section 1, it was felt that direct comparison of these results with the values for the ten Edziza flows presented in Table 3 would not be valid. This is unfortunately one of the shortcomings of the semi-quantitative method, and so a more cautious approach was indicated. Three source pebbles from each of the chemical types 1, 2, 3, 6, 7, and 8 were analysed with the artifacts, and their Fe, Rb, Zr, and Nb peaks were extracted using the ND66 multichannel analyser's peak extraction routine. The Fe, Rb, and Nb values were normalized to Zr, and the average values were computed from the three pebbles in each flow for these element/Zr ratios. The results of all artifact analyses were then compared to the source flow element/Zr ratios obtained in this manner, rather than directly to the results obtained in Section 1.

## Artifact Analysis Results

The results of the analysis are presented in Table 8 and in Figure 11. Detailed results of the analysis of the 53 formed tools are presented in Appendix F. Briefly, the findings are as follows:

1. The 169 artifacts were identified as made from obsidian flows 2, 3, and 6. Flow 3 was predominant, and it made up 83% of the sample. Flow 2 made up the remaining 17%. Flow 6 was identified in only one artifact.

2. All artifacts from the two-component sites HiTp-1 and HiTp-63 were made from the obsidian flows 2 and 3. These two flows were identified both in the obsidian detritus flakes from HiTp-1, and in the formed tools sampled from each of the four components represented by the two sites. No other obsidian flows were represented in these artifacts.

3. Among the formed tools, there was no significant difference in flow frequencies between the two components within each of the two-component sites (HiTp-1, HiTp-63). However, there was a difference between sites: flow 2 was twice as common in HiTp-63 (14.5%) as in HiTp-1 (6.5%).

4. In HiTp-1 House 1 (the workshop component), flow 2 was much more frequent among the debitage (about 20%) than among the biface preforms (5%). There was considerable variation in the flow frequencies between levels. For example, flow 2 represented 38% of the level 2 sample, but only 12% of the level 4 sample.

5. The large collaterally flaked biface from HhTq-1 was of the flow 6. The only location where obsidian from this flow is found is in the outwash gravels of Artifact Creek (locality 3). The remaining 5 artifacts, including the microblades, were made of Euziza 3 obsidian.

## TABLE 8

## Obsidian Artifact Source Analysis Summary

### a. Debitage

| HiTp-1 House 1<br>(N22-23 E18-19 SE)<br>Lithic Workshop | N* | Edziza #2 | Edziza #3 | Edziza #6 |
|---|---|---|---|---|
| Level 2 | 16 | 6 (37.5%) | 10 (63.5%) | |
| Level 3 | 15 | 3 (20%) | 12 (80%) | |
| Level 4 | 50 | 6 (12%) | 44 (88%) | |
| Level 5 | 30 | 8 (27%) | 22 (73%) | |
| Subtotal | 111 | 23 (21%) | 88 (79%) | |

### b. Formed Tools

| | | | | | |
|---|---|---|---|---|---|
| HiTp-1 | House 1 Lithic Workshop | 20 | 1 (5%) | 19 (95%) | |
| | Area 2 Campsite | 12 | 1 (8%) | 11 (92%) | |
| HiTp-63 | Component 1 Campsite | 7 | 1 (14%) | 6 (86%) | |
| | Component 2 Lithic Workshop | 13 | 2 (15%) | 11 (85%) | |
| HhTq-1 | Hunting Camp | 6 | | 5 | 1 |
| | Subtotal | 58 | 5 (9%) | 52 (90%) | 1 (2%) |
| | TOTAL | 169 | 28 (16.6%) | 140 (82.8%) | 1 (0.6%) |

*N represents a 1% sample of Levels 2, 4, and 5, and a 5% sample of Level 3 in the debitage.

Figure 11: Results of the obsidian artifact source analysis.

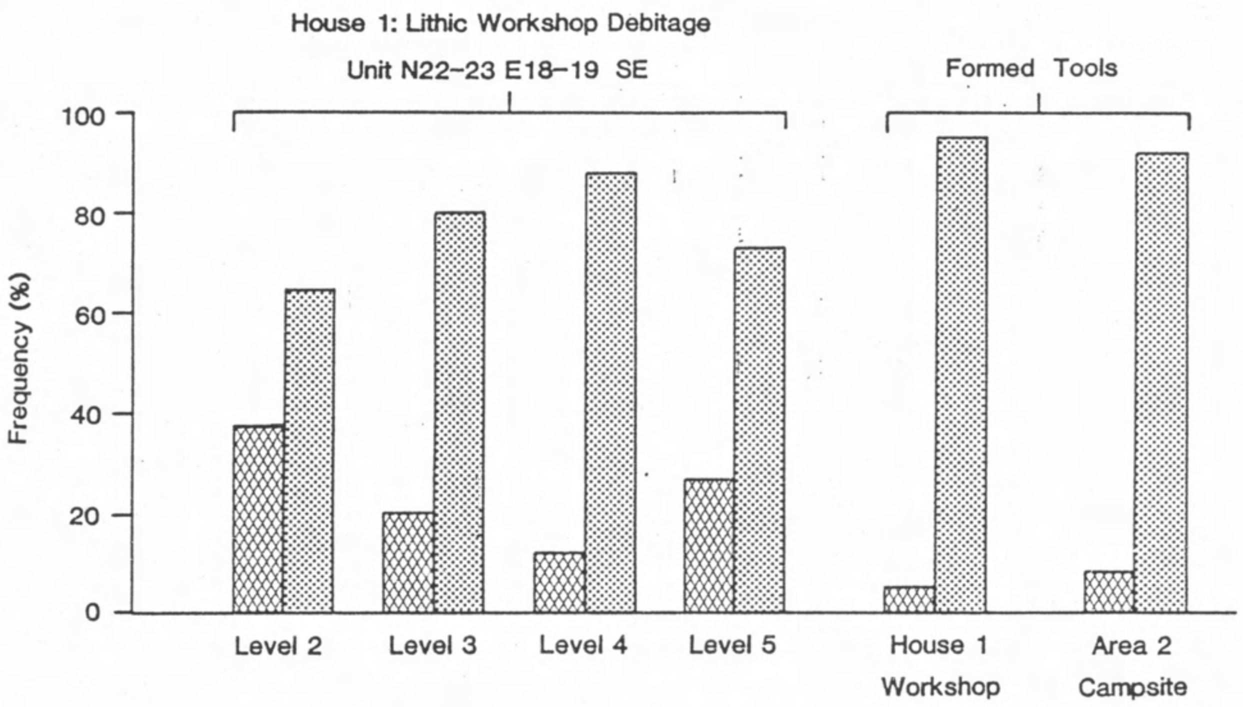
**LEGEND:**

▩ Edziza #2

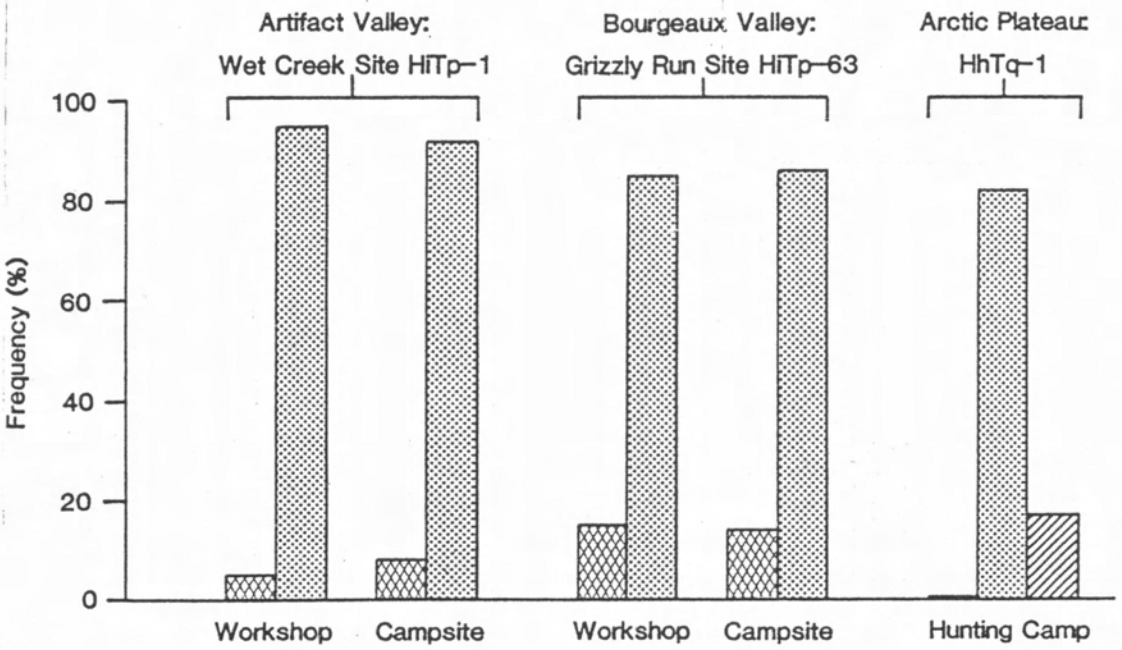
░ Edziza #3

▨ Edziza #6

A: Obsidian type frequencies in artifacts of the Wet Creek Site (HiTp-1)



B: Obsidian type frequencies in the formed tools of HiTp-1, HiTp-63, and HhTq-1.



## Discussion

It was surprising to find that among the five artifact assemblages examined, essentially only two obsidian flows were represented: Edziza 2 and 3. Edziza 3 was predominant in all assemblages. It made up between 64% and 95% of each assemblage analysed.

The obsidian sources nearest to the Grizzly Run site are the scattered clasts naturally present in Raspberry Pass (represented by flow 2 only), and the obsidian in the gravel slide in Destall Pass (composed of obsidian from flows 8, 2, and 7). None of the material found in these gravels is of useable quality, however. The nearest and most accessible obsidian of flakeable quality is found in the moraine at the head of "Point Creek", which contains obsidian of type 3. The obsidian source nearest to the Wet Creek site is in the outwash gravels of Artifact Creek (locality 3), which is made up of obsidian from flows 3, 6, 7, and 8, but it too is not of sufficient quantity or quality to be used in tool manufacture. The nearest useable sources are found in the talus at the base of "Fan Creek", which is made up of type 2 obsidian, and in Artifact Valley Moraine, composed of type 3 obsidian. As none of the four assemblages from the two sites in Artifact and Bourgeaux valleys reflect the obsidian flow frequencies corresponding to one of the source localities of good quality obsidian nearest to each site, the possibility of obsidian exploitation by the "principle of least effort" has to be firmly rejected.

Judging by the consistently high frequencies of flow 3 in each assemblage, it seems evident that the source areas preferentially exploited were those where this flow is predominant. On the other hand, since none of the assemblages were made up exclusively of Edziza 3 obsidian, but all included small quantities of obsidian from flow 2, it would seem that the single-flow sources of Edziza 3 obsidian were not necessarily always sought out. This includes the high-elevation sources on top of "Goat" Mtn. and on Obsidian Ridge, and the two low-elevation sources of Point Valley Moraine and Artifact Valley Moraine.

The presence of small quantities of type 2 obsidian in both sites is indicative of an exploitation strategy of source areas where types 2 and 3 are mixed through natural erosive processes. The geological samples taken from sites on Kitsu Plateau and on Swarm Ridge (localities 1.01 and 1.26) indicate that the outcrops of flow 2 are found within an elevation range of 5900-6200' (1790-1880 m). It would thus appear that raw material procurement from the flanks of "Goat" Mtn. at or below these elevations would result in some amounts of obsidian from flow 2 as well as obsidian from flow 3, being included in the sample. Obsidian procurement from these areas was probably preferred to the exploitation of valley bottom sources, because the rock fragments found nearer the outcrops were larger and less weathered than those found at lower elevations.

An alternative explanation for the presence of types 2 and 3 in the obsidian artifacts of the two sites under consideration is that the type frequencies reflect the exploitation of only the two low-elevation type 3 sources (Artifact Valley Moraine and "Point" Valley Moraine) and the type 2 source at the base of "Fan Creek". Because the frequenc~~ies~~y of type 2 obsidian in these artifacts is so low, however, despite the fact that the "Fan Creek" deposit is readily accessible and of good quality, this is an unlikely situation.

The extensive and concentrated source areas on top of "Goat" Mtn. were most likely also exploited, since it is highly improbable that people collecting obsidian from the flanks of the mountain would not have known of the high-quality obsidian to be obtained only 500-800' further up. However, it is possible that conditions during the cooler periods of the Neoglacial, or simply the snow cover of the spring or fall seasons, may have made the highest areas inaccessible.

The slightly different frequencies of flow 2 in the formed artifacts from the two multi-component sites are most likely caused by the exploitation of slightly different source areas surrounding "Goat" Mtn. Geological information (J.Souther, pers. comm.) indicates that the Armadillo Formation of which flow 2 is a part, ends in the general area of Artifact valley. Thus the outcrops of flow 2 in the walls of Artifact valley should be thinner, and the resultant number of eroded clasts slightly lower, than the outcrops of this flow to the north of "Goat" Mtn. The people who left behind the assemblages at the Grizzly Run site most probably approached the mountain from the north, perhaps via "Point" Creek, whereas the people who created the assemblages at the Wet Creek site would have approached it from the southeast up Artifact valley, or through Destall Pass. The consistency of flow frequencies in the different assemblages within each site, even though these assemblages are not coeval, suggests that these frequencies are indeed caused by slight differences in natural flow distributions in different areas of "Goat" Mtn. This also suggests that the approach routes from Bourgeaux valley and Artifact valley to "Goat" Mtn. were slightly different, and probably led to specific source areas.

The hypothesis that a diverse assemblage representative of a camp occupation should contain a wider diversity of obsidian types than a lithic tool production workshop was not borne out, in spite of the fact that they do contain diverse assemblages of other rock types. There was essentially no difference in obsidian flow frequencies between the campsite and the lithic workshop component of the Grizzly Run site, and a similar lack of difference between the campsite and the lithic workshop component at the Wet Creek site.

The hypothesis that obsidian detritus sampled from the lithic workshop component of the Wet Creek site should represent a more complete sample of obsidian flows than does the sample of biface preforms from this component was not confirmed. Obsidian from flows 2 and 3 only is found in both the detritus sample and in the biface preforms. There are, however, significant differences in the frequencies of each flow observed in the detritus as compared to the preforms. Flow 2 is found in only 5% of the biface preforms, but it represents 21% of the detritus sample. The higher frequency of flow 2 in the detritus may be due to the inferior industrial quality of this stone, and a greater tendency for it to fragment during early stages of the lithic reduction process, which led to the abandonment of the piece worked before the stage of a recognizable biface preform was reached. On the other hand, a completely different explanation is also possible if one assumes that the flow frequencies in the detritus reflect the true proportions of the flows in the obsidian worked and in all resultant biface preforms. Since the bifaces left at the workshop were those which were not successfully completed, and those analysed show a greater proportion of type 3, this may indicate a greater rate of success with the production of useable biface preforms out of obsidian from flow 2.

Flow frequency differences were observed in the obsidian detritus flakes sampled from the four stratigraphic levels of the Wet Creek site's workshop component. Since these are arbitrary excavation levels, the differences between them are useful as indicators of overall trends only. These differences may be suggestive of certain procurement strategies. The lowest level sampled (level 5) contains a high frequency (27%) of flow 2, but this drops dramatically to only 12% in level 4. This suggests that some superior-quality obsidian was brought down to the workshop while the lithic reduction work was in progress. The frequency of obsidian from flow 2 increases gradually in subsequent levels, and is highest (37.5%) in the uppermost level sampled (level 2). Perhaps obsidian from flow 3 was deliberately selected during the manufacturing process on the basis of some of its visual attributes: glass clarity and purity, interesting colour variants, or the lack of textural graininess. As this prime quality obsidian was being depleted during the course of biface production, the workmen turned increasingly to the slightly coarser grades of black obsidian still available, rather than returning to "Goat" Mtn. for a fresh supply. All ten Mount Edziza obsidian flows, including flows 2 and 3, are predominantly of this grade, and it is impossible to select a specific obsidian flow from among this slightly coarse black variety. The frequency of flow 2 obsidian in the uppermost level (37.5%) is nearly two times that flow's frequency in the level immediately below (20%). Such a strong distinction is suggestive of a later reoccupation of the workshop depression.

The presence of obsidian #6 in the artifact sample from HhTq-1 suggests that the people who created this site procured their raw material from Artifact Valley, and not from Coffee Crater or Cocoa Crater. As noted in the preceeding section, flow 6 is not represented by any geological samples, and its actual source or outcrop location is unknown. Chemical similarity to some of the other flows indicates that flow 6 is a part of the Armadillo Formation, and that its outcrops should occur at a somewhat lower elevation than the outcrops of Edziza flows 2, 7, and 8. Since the artifacts at HhTq-1 are made of obsidian from flows 3 and 6, a possible procurement locality for this obsidian is the outwash gravels of Artifact Creek (locality 3), which contains obsidian clasts from flows 3, 6, 7, and 8. However, the size of the projectile point which is made of the obsidian from flow 6 (minimum 8 cm, distal end missing), the quality of material, and the excellent workmanship evident in its production, all argue that the raw material was probably not from among the mechanically-weakened small pebbles obtainable at locality 3. Thus it is also possible that the people who explored the valley and then created the assemblage at HhTq-1 found the actual outcrop of flow 6 somewhere within Artifact valley, and there they procured a large chunk of the obsidian. The discovery of an outcrop of this flow should be one of the goals of future archaeological and geological explorations of Artifact valley.

### Cultural Interpretations Summary

The results of ED-XRF analysis of 169 obsidian artifacts from three sites in the Mount Edziza Volcanic Complex indicate that the "Goat" Mountain obsidian source was well known and heavily exploited. It appears that the low-elevation obsidian sources located in passes, valley floors and moraines, with the possible exception of the "Fan Creek" deposit, were ignored. Instead, the high-elevation concentrated obsidian scatters located on the flanks of "Goat" Mountain were preferentially sought out for raw obsidian procurement purposes during the period 5000-3000 BP. Depending on the approach route taken, (from the north via Raspberry or Bourgeaux valleys, or from the southwest via Artifact valley) different obsidian concentrations on the mountain were utilized.

There was no evidence for exploitation of the obsidian sources on Big Raven Plateau, north of Raspberry Pass. Artifacts made of obsidian from flows 1 and 4, as well as 5, 9, and 10 would have provided this evidence.

Obsidian flow frequencies in artifacts from an isolated site on the Arctic Plateau confirm that the exploitation of the "Goat" Mtn. source via Artifact valley was the preferred strategy in obsidian procurement within the Mount Edziza Volcanic Complex.

## CONCLUSION

The purpose of this study was to determine how many distinct obsidian flows there are within the Mount Edziza Volcanic Complex of northwestern British Columbia. This Complex forms the largest and the most extensively exploited source of obsidian in the Northwest. The natural volcanic glass naturally available there was intensively quarried and widely traded in prehistoric times as a lithic material resource to adjacent provinces, territories and states. Prior to the commencement of this work, four distinct obsidian flows from the Mount Edziza Volcanic Complex were known.

Using a semi-quantitative energy-dispersive x-ray fluorescence technique, ten distinct obsidian flows were identified within the Mount Edziza Volcanic Complex. Four of these correspond to the Edziza flows previously reported by Nelson, D'Auria and Bennett (1975). Nine of the ten obsidian flows identified in this study were correlated to obsidian outcrop samples from the Armadillo, Spectrum, Ice Peak, and Pyramid formations. Stratigraphic and geochemical information indicate that another flow, Edziza 6, probably forms part of a basal unit of the Armadillo Formation.

The analysis of obsidian samples from a large number of gravel deposits within the Mount Edziza Volcanic Complex gave additional information on the high- and low-elevation secondary distributions of each flow, and the frequencies of each flow in mixed gravel deposits. Five flows (1, 4, 5, 9, and 10) are naturally present only in areas well north of Raspberry Pass. Because these are high-altitude barren and rugged terrains, accessibility to these flows is difficult, and their significance in prehistoric obsidian exploitation of the Complex is thus judged low. The other five obsidian flows (2, 3, 6, 7, and 8) are available in the valleys and passes immediately to the south and north of "Goat" Mountain. Flows 2, 3, 7, and 8 are also available either on "Goat" Mtn. and its flanks, or at high elevations in the surrounding landscape. The obsidian flow of high quality which is most easily accessible in large quantities is Edziza 3. This flow is predominant in all samples from "Goat" Mountain, Obsidian Ridge, and in Artifact valley.

The chemical composition of the ten obsidian flows was determined by wavelength-dispersive x-ray fluorescence. This analysis yielded ten major element concentrations (in %) and 17 trace element concentrations (in ppm) for each flow. This extensive data set enabled the Mount Edziza obsidian flows to be compared to the basalt-comendite rock series of the Mount Edziza Volcanic Complex, and to several other major obsidian sources of the world. These comparisons indicate that the Mount Edziza obsidians show an unusually wide range in their total Fe content, which varies from 1.2% to 10.7%, and very wide concentration ranges for Ti, Al, Mn, and several of the trace elements. Characteristic in all ten flows are very low Ba and Sr contents, and high enrichment in the trace elements Rb, Y, Zn, Zr, and Nb, and the rare earth elements Ce, Nd, and La. Trace element values for some Edziza flows in many cases reach or exceed the values reported for both the Mount Edziza basalt comendite series, and the obsidian sources with which they were compared.

Comparative information indicates that most of the Mount Edziza obsidian flows may be classified as peralkaline volcanic rocks. The chemical composition of flows 1, 2, 6, 7, and 8 is pantelleritic (flow 6 being transitional to a pantelleritic trachyte), while flows 3, 4, and 5 are only mildly peralkaline, and are classified as comendites. The chemistry of these eight flows is similar to some of the obsidian flows from the East African Rift Valley and to the Mayor Island obsidian source of New Zealand. The chemistry of flows 9 and 10, however, is interpreted here as sub-alkaline; they are similar to the obsidian source from Glass Mountain, Mono County, California.

A study of 169 artifacts sampled from five components of three sites in the Mount Edziza Volcanic Complex, indicates that only those deposits which contain obsidian clasts from flows 2 and 3 were extensively exploited. Two such deposits were identified in the study of natural gravel scatters, both of which are found on the flanks of "Goat" Mtn. This suggests a preference by prehistoric people for exploiting the prime obsidian deposits found on "Goat" Mtn., and an unwillingness on their part to use the widely scattered poorer-quality obsidian gravel deposits found at low elevations in Artifact and Raspberry valleys, in Artifact and "Point" valley moraines, and at some other minor but easily accessible locations.

The absence in the sites of those obsidian types present solely in the rugged regions north of Raspberry Pass ( flows 1, 4, 5, 9, 10) suggests that people of the middle prehistoric period (5000 - 2000 BP) avoided the more environmentally hostile regions. They confined their exploitation to the easily accessible major valleys of Bourgeaux and Artifact Creek, and to the gentler environment of the Arctic Plateau south of these valleys.

# APPENDICES

# APPENDIX A: Study Material Provenience

| Rock Number | Source Location |
|---|---|
| Geological samples | Geological Survey Transect Number, 1965-1981 |
| 1.01 | SE0504-73 |
| 1.02 | IGC-72 |
| 1.03,1.28 | SE1303C-73 |
| 1.04 | SE1303D-73 |
| 1.05 | ML4111a-65 |
| 1.06 | SE0104B-72 |
| 1.07 | SE45VG-65 |
| 1.09 | SE5214-65 |
| 1.10,1.25 | SE1306-72 |
| 1.11 | SE2902a-66 |
| 1.12 | SE4a |
| 1.13 | SE10D-56 (one pebble) |
| 1.14 | SE3115-66 |
| 1.15,1.27 | SE2309a-66 |
| 1.16 | SE0101-73 |
| 1.17,1.36,1.37 | SE1806B-70 |
| 1.18 | SE226B-81 |
| 1.19 | SE0603A-72 |
| 1.20 | SE0604-72 |
| 1.21 | SE18-3B |
| 1.22 | ML4111-65 |
| 1.23 | SE0606-72 |
| 1.24 | SE0602A-72 |
| 1.26 | SF0912a-72 |
| 1.29 | SE0104B-73 |
| 1.30 | SE4617-65 |
| 1.31 | SE14-8A |
| 1.32 | SE2813B-67 |
| 1.33 | SE0812D-68 |
| 1.34 | SE709A-72 |
| 1.35 | ML1208A-65 |
| 1.38 | SE2202A-76 |
| Archaeological samples, collected 1977 and 1981 | |
| 2.01-2.20 | Gravel slide on the west side of Destall Pass |
| 3.01-3.24 | Outwash gravels in Artifact Creek between "Wet" and "Fan" creeks |
| 6.01-6.06 | Near 1977 camp, Artifact Valley |
| 7.01-7.07 | Source areas west of the 1977 camp in Artifact Valley |
| 9.01-9.11 | Slide, west end of Raspberry Pass |
| 12.01-12.03 | Peak north of the 1977 camp in Artifact Valley |
| 16.01-16.13 | East Coffee Crater |
| 17.01-17.09 | West Coffee Crater |
| 18.01-18.08 | "Point" Valley Moraine |
| 19.01-19.05 | Talus slope at the base of "Fan" Creek |
| 20.01-20.05 | General scatters in Raspberry Pass |
| 21.01-21.04 | Obsidian Ridge overlooking Stewbomb Creek |
| 22.01-22.15 | Artifact Valley Moraine |
| 23.01-23.05 | Ridge between Raspberry and Artifact valleys |

# APPENDIX B

## AN APPLICATION OF ESCA ANALYSIS TO THE STUDY OF TWO MOUNT EDZIZA OBSIDIAN FLOWS

The purpose of this work was to determine whether ESCA (electron spectroscopy for chemical analysis) could be applied to distinguish between related obsidian flows, to compare these ESCA results to those obtained using XRF (x-ray fluorescence), and to determine what advantages there are in using ESCA instead of XRF for obsidian studies.

The material chosen for this study consists of obsidian pebbles from two flows found within the Mount Edziza Volcanic Complex in northern B.C. The two flows in question are separated geographically by several kilometres (see Figure 2 in text). They are known as Edziza #1, one of several flows associated with the Armadillo Formation, and Edziza #3, associated with the relatively young Spectrum Formation. The Edziza #1 samples come from the east flanks of Coffee Crater, while the Edziza #3 samples come from three locations in the Artifact Creek valley area: "Goat Mountain" (quotation marks indicate informal name given this landmark), Artifact valley moraine, and Obsidian Ridge. All these samples were collected by K. Fladmark and his crew during a 6-week archaeological reconnaissance of the Complex in 1981.

Since this was a test case, the obsidian chosen for this work was already known to represent two distinct chemical types. They were first identified by Nelson, D'Auria and Bennett (1975), who detected 13 elements using energy-dispersive x-ray fluorescence (ED-XRF). The semi-quantitative concentrations of three of these elements (Fe, Rb, and Nb, expressed as ratios with respect to Zr) were sufficiently different as to discriminate between the two flows.

The main difference between the ESCA method and XRF is that in ESCA a beam of high-energy electrons rather than high-energy x-rays is used for excitation of the atoms in the sample. ESCA can usually detect the major constituent elements only, ie., those whose concentrations exceed 1%, while XRF is capable of detecting trace elements (in parts per million concentrations). The two methods are similar in that in both cases the characteristic K and L x-rays emitted by the elements in a sample are analyzed.

Because of the specific differences between the particular instruments used in this work, it was noted that the ESCA system has some advantages: 1. it is used in conjunction with a scanning electron microscope, so one could actually see the surface being analyzed; 2. it could detect much lighter elements such as Na, Si, and Cl; 3. the beam of electrons which analyzes the sample could either be focused down to a diameter of 6 μm, or it could be "fanned out" to obtain an averaged reading from a large area; and 4. beam penetration is confined to the top 2 nm from the surface of the sample, which ensures that only the visible features are being analyzed. These points made this system very useful in the detection and chemical analysis of any micro-crystals, phenocrysts, and other deviations from the typical amorphous glassy matrix of obsidian, as well as the chemical effects of very shallow-layer weathering of the glass.

## Instrumentation and Sample Preparation

The ESCA instrument used in this study was a JEOL JSM-35CF scanning electron microscope. Data collection and elemental analysis were done on a Tracor Northern TN4000 multichannel analyzer, in tandem with a dedicated TN2000-TN131 computer system. The samples were washed in distilled water and then electroplated with a thin layer of Au-Pd alloy in order to make them conductive. The plating process was done in a Hummer V ion sputtering instrument, for 5 minutes at 10 mA and 6-8 volts, under a partial vacuum (110 millitorr). This process deposits a 50 nm thick layer of metal on the sample, which can easily be cleaned off with acetone afterwards. The samples were placed on a small Cu-Zn pedestal, inserted into the analysis chamber, and analyzed under vacuum. This process is non-destructive. No grinding or surface polishing is necessary, and so samples of any shape may be analyzed in this manner. An upper limit to the size of a sample is placed by the 2" diameter of the entrance to the analysis chamber. All pieces were analyzed at least twice, on different parts of the surface.

## Results

The ESCA results obtained are semi-quantitative. They are presented in Table 1A. The element values for all the ESCA results presented here (also in Tables 2 and 3) were normalized so that their sum totals 100. These are compared with the actual elemental concentrations (Table 1B, determined by wavelength-dispersive XRF) and with semi-quantitative ED-XRF results (Table 1C), presented in the main body of this thesis. The ED-XRF work was done in the Chemistry Department at Simon Fraser University, while the WD-XRF work was done in the Oceanography Department at the University of British Columbia.

Table 1A shows that it may be possible to distinguish between the two flows on the basis of the relative concentrations of some of the major elements detected. The Al and Fe values have no overlap at one standard deviation, while Ti is present in one flow (#1) and absent in the other (#3). These three elements (Al, Fe, and Ti) are thus on the verge of being able to discriminate between the flows.

A comparison of the ESCA relative concentrations with the absolute element concentrations given in Table 1B indicates that the ESCA data reflect the actual elemental differences between the two flows, although the statistical errors associated with the ESCA results are large. We also note that the discrimination between the flows is achieved on the basis of elements whose absolute concentrations differ by 2% or more, ie. Al and Fe. Also notable is the fact that Ti was not detected at all in Edziza #3, but that it was detected (although not consistently) in Edziza #1. This indicates that a 0.4% Ti concentration is right at the detection limit of the ESCA instrument, while 0.2% Ti is clearly below the detection limit. We are confident that further work could reduce the statistical errors to more acceptable levels, so that statistically significant flow discrimination (no overlap at two standard deviations) can be achieved.

The ESCA data were also compared with semi-quantitative ED-XRF data, presented in Table 1C. The ED-XRF instrument and sample treatment were essentially as described by Nelson, D'Auria and Bennett (1975), with some minor improvements. The XRF data presented here were normalized to the Compton scatter peak. The discrimination between the two flows is better than that achieved with ESCA however, since several elements show no overlap at 2 standard deviations from their means, whereas ESCA was only capable of this discrimination at 1 standard deviation. In addition to the elements quoted, the ED-XRF instrument detected several minor and trace elements (Ca, Zn, Ga, Pb, Sr, Y, and Zr) not able to distinguish between the two flows. It did not, however, detect the low-Z elements Na, Al and Si. Finally, the ED-XRF result was obtained without the need for plating, with comparable data collection periods (10 minutes per sample).

In conclusion, the results of Table 1 suggest that ESCA may be used to discriminate between obsidian flows on the basis of their major elements, if their absolute concentrations differ by 2% or more. However, at this time such discrimination can be achieved faster, with less sample preparation, and with a greater degree of separation using semi-quantitative ED-XRF. However, both of the above methods are faster and simpler than fully quantitative analysis using wavelength-dispersive XRF.

The results obtained here are consistent with the findings of Michels (1982). He applied bulk element analysis in an attempt to differentiate between a number of obsidian source areas within the El Chayal source system in Guatemala. He found that the obsidian source areas could be differentiated successfully 70% of the time. The differentiation of the same source areas, using the same raw material specimens, but based on trace element concentrations, was successful in 97% of cases.

This work thus confirms that, all other things being equal, bulk element analysis is not as effective as trace element analysis in discriminating between closely related flows. However, semi-quantitative bulk element analysis using the ESCA system described here would probably be successful in discriminating between obsidian flows which are not as closely related as those analyzed in this test. For example, the Fe concentrations in two obsidian flows of the Mount Edziza Volcanic Complex can differ by as much as 9.5% by weight (for flows 6 and 10); the Si concentrations by as much as 10.4% (flows 6 and 5); and the Al concentrations by as much as 5% (flows 7 and 10). Semi-quantitative ESCA analysis should have no difficulty in distinguishing these flows from each other. Bulk-element differentiation between non-related sources from vastly different locations (for example, the Edziza obsidians from the Anahim obsidians of central B.C.) should be easily successful as well.

### Other applications for ESCA

Having said all that, two instances where the use of the SEM-ESCA system holds an advantage over XRF were noted.

First, it permits the recognition and examination of weathered surfaces of flakes which appeared surficially unaltered when viewed with the naked eye. The weathering is recognizable through the irregular pitting and surface scratches, clearly visible at 600x magnification, and completely distinct from a fresh surface. It was thus possible to compare the chemical compositions of these weathered surfaces with the unaltered glassy matrix of the same flake (Table 2).

No significant difference in the chemical compositions of these two surfaces were found. This disagreed with the data of Tsong et al (1978) who found a 20% depletion of Na and K within the hydration rind of obsidian. The findings of this study are interpreted as indicating that the observed weathering pattern on the obsidian flake is due to mechanical pitting and scouring, and that chemical alteration had not taken place within the shallow surface layer.

The second test made possible with the SEM-ESCA system which cannot be done using XRF is a check for microscopic inhomogeneities within the obsidian glass. This might be helpful in distinguishing different colour variants of a single obsidian flow, or pieces which differ in graininess or their fracturing properties. Among the several pieces examined, one such instance was found, a small crystal which had formed within an otherwise perfect glassy matrix. Its elemental concentrations differed from that of the surrounding glass (Table 3).

The crystal showed a significantly greater proportion of Al, while its relative Fe concentration was depleted.

## Conclusion

The foregoing results show that ESCA is a very powerful method, and that it has several potential advantages over XRF. However, because of the large experimental uncertainties in the results, some of these advantages could not be realized. However, it is certain that the large errors can be reduced. This error reduction might be achieved mainly through using a defocused electron beam to analyze the glass matrix, to average out "spot differences" in the chemical composition of the glass, and through the analysis of more samples. The ESCA method can be applied successfully to differentiate quickly and non-destructively on a semi-quantitative basis between some of the less closely related flows from a major obsidian source area such as the Mount Edziza Volcanic Complex, and to differentiate between obsidians from unrelated source areas, using the semi-quantitative concentrations in their major elements.

## Table 1

### A: ESCA Relative Concentrations

| | #1 (n=4) x | #1 (n=4) s | #3 (n=13) x | #3 (n=13) s |
|---|---|---|---|---|
| Na | 1.6 | 0.2 | 1.3 | 0.8 |
| Al | 2.7 | 0.3 | 4.2 | 0.8 |
| Si | 60.4 | 1.4 | 64.4 | 5.4 |
| K | 12.1 | 1.7 | 12.2 | 1.6 |
| Ti | 0.4 | 0.4 | n.d. | |
| Fe | 16.5 | 1.2 | 11.0 | 2.4 |
| Rb | 6.6 | 2.1 | 7.0 | 3.4 |
| | ----------- | | ----------- | |
| Total | 100.3 | | 100.1 | |

### B: WD-XRF Absolute Concentrations

| | #1 x | #3 x | (n=10) s |
|---|---|---|---|
| Na (%) | 4.25 | 4.13 | 0.06 |
| Al | 9.09 | 11.10 | 0.11 |
| Si | 76.34 | 76.78 | 0.29 |
| K | 4.24 | 4.52 | 0.02 |
| Ti | 0.39 | 0.18 | 0.01 |
| Fe | 6.00 | 2.99 | 0.03 |
| Rb (ppm) | 106 | 124 | 1 |

### C: ED-XRF Relative Concentrations
(normalized to the Compton scatter peak)

| | #1 x | (n=26) s | #3 x | (n=80) s |
|---|---|---|---|---|
| Na | n.d. | | n.d. | |
| Al | n.d. | | n.d. | |
| Si | n.d. | | n.d. | |
| K | 9.2 | 2.0 | 7.4 | 1.2 |
| Ti | 5.7 | 1.3 | 2.0 | 0.8 |
| Fe | 628.2 | 69.9 | 273.0 | 26.4 |
| Rb | 104.3 | 4.9 | 124.5 | 4.8 |
| Mn | 7.9 | 1.1 | 3.4 | 0.9 |
| Nb | 51.9 | 4.4 | 81.8 | 5.0 |

<u>Notes</u>: n.d. = not detected
x = experimental mean of n analyses
s = one standard deviation from the mean
n = number of analyses

## Table 2

| | Fresh Surface | Weathered Surface |
|---|---|---|
| Na | 1.6 ± 0.2 | 1.4 |
| Al | 4.0 ± 0.1 | 4.3 |
| Si | 63.5 ± 4.9 | 67.1 |
| K | 11.7 ± 0.3 | 11.5 |
| Ti | n.d. | n.d. |
| Fe | 11.5 ± 2.7 | 9.1 |
| Nb | 7.6 ± 2.0 | 6.7 |
| Total | 99.9 | 100.1 |

## Table 3

| | Glass | Crystal |
|---|---|---|
| Na | 1.0 ± 1.0 | 2.8 |
| Al | 4.6 ± 1.1 | 10.1 |
| Si | 67.9 ± 5.6 | 65.5 |
| K | 12.8 ± 2.4 | 15.5 |
| Ti | n.d. | n.d. |
| Fe | 9.2 ± 2.0 | 4.2 |
| Nb | 4.7 ± 2.9 | 2.0 |
| Total | 100.2 | 100.0 |

# APPENDIX C

EDZIZA SOURCE OBSIDIANS: UNCORRECTED RAW PEAK COUNTS OBTAINED FROM THE GAMANAL SPECTRUM-STRIPPING PROGRAM.

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.01 | 768 | 0 | 481 | 815 | 56730 | 2292 | 355 | 367 | 5974 | 0 | 9314 | 94150 | 11570 | 77581 | 95589 |
| 2 | 1.02 | 840 | 310 | 544 | 693 | 59240 | 1765 | 362 | 269 | 4897 | 0 | 7823 | 79630 | 10250 | 81741 | 99482 |
| 3 | 1.03 | 641 | 0 | 0 | 311 | 24750 | 1320 | 424 | 339 | 7471 | 0 | 8311 | 80690 | 11830 | 75361 | 97322 |
| 4 | 1.04 | 634 | 0 | 287 | 365 | 28670 | 1482 | 346 | 288 | 8533 | 0 | 9525 | 101400 | 13710 | 83893 | 110470 |
| 5 | 1.05 | 892 | 0 | 217 | 274 | 26140 | 1243 | 303 | 218 | 9831 | 403 | 11300 | 64110 | 16230 | 87792 | 114267 |
| 6 | 1.06 | 773 | 0 | 263 | 331 | 27350 | 1398 | 271 | 298 | 8763 | 0 | 9743 | 90600 | 13630 | 84572 | 110547 |
| 7 | 1.07 | 730 | 0 | 0 | 194 | 24660 | 1217 | 301 | 303 | 9063 | 379 | 10280 | 57820 | 14440 | 82496 | 106525 |
| 8 | 1.09 | 981 | 183 | 150 | 346 | 23770 | 1065 | 281 | 234 | 8116 | 290 | 9147 | 52330 | 13000 | 69631 | 91826 |
| 9 | 1.10 | 662 | 0 | 157 | 384 | 24950 | 1278 | 149 | 297 | 7505 | 0 | 8017 | 78130 | 11500 | 74284 | 95547 |
| 10 | 1.12 | 923 | 0 | 629 | 874 | 70080 | 2071 | 447 | 202 | 5793 | 0 | 9500 | 95500 | 12480 | 97418 | 117680 |
| 11 | 1.13 | 787 | 0 | 0 | 385 | 30100 | 1641 | 442 | 532 | 14700 | 0 | 12840 | 91400 | 18200 | 97521 | 128510 |
| 12 | 1.14 | 1062 | 311 | 244 | 234 | 28440 | 1296 | 285 | 224 | 10030 | 357 | 11550 | 66530 | 16680 | 91990 | 120272 |
| 13 | 1.14 | 706 | 0 | 229 | 296 | 26350 | 1259 | 264 | 197 | 10440 | 335 | 11600 | 66470 | 16910 | 98394 | 132079 |
| 14 | 1.15 | 798 | 251 | 352 | 497 | 47620 | 1826 | 228 | 229 | 4831 | 0 | 7409 | 74670 | 8969 | 46827 | 56756 |
| 15 | 1.16 | 836 | 0 | 246 | 413 | 33510 | 1734 | 468 | 394 | 9990 | 0 | 11040 | 107000 | 15520 | 97959 | 125842 |
| 16 | 1.15 | 1002 | 299 | 543 | 942 | 72900 | 2854 | 331 | 361 | 8132 | 0 | 13780 | 142000 | 17700 | 103453 | 121579 |
| 17 | 1.16 | 1177 | 211 | 200 | 396 | 32640 | 1687 | 404 | 303 | 9331 | 0 | 10070 | 94460 | 13720 | 83396 | 107904 |
| 18 | 1.17 | 567 | 0 | 142 | 311 | 19060 | 1066 | 295 | 114 | 5545 | 0 | 5801 | 55960 | 8100 | 49004 | 63418 |
| 19 | 1.18 | 895 | 87 | 0 | 217 | 21190 | 1499 | 264 | 671 | 17190 | 0 | 13450 | 47450 | 17960 | 84039 | 113995 |
| 20 | 1.17 | 793 | 0 | 254 | 370 | 28410 | 1550 | 386 | 351 | 8233 | 0 | 8435 | 80980 | 11520 | 66439 | 88169 |
| 21 | 1.18 | 769 | 0 | 158 | 176 | 21290 | 1673 | 213 | 728 | 17850 | 0 | 14300 | 50220 | 19440 | 101657 | 136150 |
| 22 | 1.19 | 999 | 0 | 537 | 1207 | 85560 | 3032 | 402 | 323 | 7734 | 141 | 13160 | 131200 | 17210 | 78362 | 93967 |
| 23 | 1.19 | 1042 | 363 | 523 | 885 | 76400 | 2584 | 375 | 338 | 7133 | 0 | 12870 | 129345 | 17692 | 91201 | 107337 |
| 24 | 1.20 | 919 | 0 | 586 | 780 | 74520 | 2438 | 447 | 373 | 6418 | 0 | 11690 | 117400 | 16180 | 90299 | 108404 |
| 25 | 1.21 | 898 | 0 | 164 | 237 | 30110 | 1729 | 0 | 538 | 15050 | 0 | 13720 | 99550 | 19410 | 111785 | 147058 |
| 26 | 1.20 | 872 | 0 | 624 | 1007 | 76810 | 2516 | 337 | 396 | 6976 | 0 | 12300 | 125300 | 17050 | 102076 | 120411 |
| 27 | 1.21 | 911 | 0 | 179 | 369 | 30980 | 1694 | 414 | 496 | 14100 | 0 | 11610 | 81730 | 15540 | 72930 | 99153 |
| 28 | 1.22 | 779 | 0 | 182 | 387 | 29790 | 1584 | 530 | 134 | 11370 | 537 | 12930 | 73970 | 18390 | 104854 | 137397 |
| 29 | 1.23 | 886 | 0 | 376 | 1295 | 92520 | 4307 | 283 | 718 | 11800 | 290 | 22500 | 254400 | 35720 | 92432 | 105102 |
| 30 | 1.22 | 1096 | 0 | 353 | 364 | 37660 | 1789 | 514 | 304 | 14120 | 633 | 15950 | 91260 | 22830 | 120007 | 158622 |
| 31 | 1.23 | 1114 | 0 | 443 | 1228 | 95060 | 4187 | 193 | 769 | 12270 | 477 | 25090 | 262700 | 33820 | 97878 | 110160 |
| 32 | 1.24 | 907 | 0 | 489 | 1148 | 87650 | 3314 | 535 | 541 | 9209 | 0 | 16570 | 171900 | 22950 | 102976 | 119156 |
| 33 | 1.25 | 973 | 0 | 307 | 437 | 35380 | 1874 | 321 | 419 | 10980 | 0 | 11940 | 115600 | 17290 | 107402 | 140200 |
| 34 | 1.24 | 1146 | 321 | 319 | 1106 | 88040 | 3295 | 417 | 401 | 8874 | 0 | 16640 | 169700 | 22650 | 100076 | 114663 |
| 35 | 1.25 | 932 | 0 | 238 | 380 | 35420 | 1819 | 456 | 336 | 10450 | 0 | 11700 | 112400 | 16110 | 104567 | 133981 |
| 36 | 1.26 | 901 | 0 | 527 | 604 | 62960 | 2290 | 482 | 348 | 8025 | 147 | 12010 | 128300 | 15590 | 105806 | 127150 |
| 37 | 1.27 | 963 | 0 | 508 | 776 | 75180 | 2973 | 466 | 463 | 8403 | 0 | 13620 | 138500 | 17320 | 93389 | 111601 |
| 38 | 1.26 | 963 | 0 | 534 | 852 | 65990 | 2339 | 316 | 328 | 7909 | 0 | 12340 | 130400 | 15690 | 98314 | 121108 |
| 39 | 1.27 | 903 | 0 | 471 | 652 | 65030 | 2612 | 384 | 385 | 6964 | 0 | 11500 | 116900 | 14730 | 78342 | 93851 |
| 40 | 1.28 | 840 | 0 | 237 | 462 | 32860 | 1682 | 353 | 275 | 10040 | 0 | 11060 | 104100 | 15390 | 96361 | 125880 |
| 41 | 1.29 | 879 | 174 | 310 | 371 | 32350 | 1684 | 287 | 468 | 10220 | 0 | 11160 | 104200 | 15440 | 101080 | 130208 |
| 42 | 1.28 | 933 | 0 | 197 | 410 | 33820 | 1727 | 278 | 463 | 10500 | 0 | 11400 | 112400 | 16220 | 103347 | 134884 |
| 43 | 1.29 | 668 | 0 | 292 | 302 | 25160 | 1264 | 188 | 302 | 7621 | 0 | 8200 | 76240 | 11190 | 68749 | 91475 |
| 44 | 1.30 | 753 | 0 | 0 | 0 | 13710 | 1379 | 464 | 784 | 26110 | 0 | 16840 | 23260 | 21250 | 107252 | 147760 |
| 45 | 1.31 | 876 | 0 | 165 | 176 | 13740 | 1521 | 429 | 967 | 27140 | 0 | 16960 | 23040 | 21070 | 95881 | 134239 |
| 46 | 1.30 | 957 | 356 | 0 | 0 | 13390 | 1425 | 291 | 968 | 26380 | 0 | 16850 | 22920 | 21110 | 105454 | 146914 |
| 47 | 1.31 | 662 | 0 | 0 | 0 | 13930 | 1555 | 390 | 979 | 28000 | 0 | 17630 | 24430 | 22070 | 109768 | 150621 |
| 48 | 1.32 | 1046 | 243 | 277 | 305 | 30040 | 1408 | 397 | 231 | 10600 | 417 | 11980 | 68410 | 16660 | 88301 | 116571 |
| 49 | 1.33 | 1060 | 251 | 453 | 797 | 63810 | 2196 | 382 | 147 | 6446 | 0 | 10220 | 103400 | 13010 | 84206 | 103924 |
| 50 | 1.32 | 970 | 176 | 249 | 256 | 27640 | 1332 | 414 | 230 | 9657 | 406 | 10560 | 58550 | 14900 | 72185 | 95064 |

EDZIZA SOURCE OBSIDIANS: UNCORRECTED RAW PEAK COUNTS OBTAINED FROM THE GAMANAL SPECTRUM-STRIPPING PROGRAM.

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 1.33 | 1020 | 179 | 526 | 880 | 63250 | 1975 | 298 | 256 | 6587 | 0 | 10340 | 109700 | 13800 | 98420 | 118931 |
| 52 | 1.34 | 648 | 0 | 221 | 326 | 30270 | 1551 | 211 | 371 | 9483 | 0 | 10510 | 101400 | 15090 | 96795 | 126361 |
| 53 | 1.34 | 946 | 160 | 202 | 507 | 33190 | 1495 | 178 | 440 | 10250 | 0 | 11200 | 107300 | 15650 | 96636 | 127310 |
| 54 | 1.35 | 579 | 0 | 0 | 134 | 15300 | 1090 | 320 | 408 | 11890 | 0 | 9429 | 31490 | 12260 | 58798 | 79199 |
| 55 | 1.36 | 1110 | 230 | 208 | 388 | 33260 | 1695 | 391 | 446 | 9820 | 0 | 10100 | 102700 | 16580 | 91646 | 119185 |
| 56 | 1.35 | 606 | 0 | 0 | 184 | 19680 | 1541 | 481 | 614 | 16840 | 0 | 13640 | 47150 | 18320 | 97371 | 132838 |
| 57 | 1.36 | 841 | 0 | 250 | 408 | 33250 | 1718 | 503 | 355 | 9979 | 0 | 11220 | 105300 | 15300 | 95790 | 123290 |
| 58 | 1.37 | 924 | 0 | 273 | 535 | 35350 | 1918 | 234 | 374 | 10660 | 0 | 11790 | 112600 | 16740 | 97024 | 128241 |
| 59 | 1.38 | 751 | 0 | 193 | 416 | 30600 | 1421 | 184 | 444 | 9119 | 0 | 9862 | 95750 | 13920 | 85961 | 112205 |
| 60 | 1.37 | 670 | 96 | 366 | 431 | 32860 | 1730 | 337 | 361 | 10020 | 0 | 10740 | 104700 | 15230 | 98225 | 127142 |
| 61 | 1.38 | 776 | 0 | 186 | 409 | 32270 | 1699 | 358 | 362 | 9024 | 0 | 9962 | 93180 | 13620 | 78487 | 104414 |
| 62 | 1.11 | 716 | 0 | 443 | 577 | 57190 | 1562 | 303 | 164 | 4911 | 0 | 7432 | 74480 | 9610 | 75797 | 92063 |
| 63 | 1.11 | 1038 | 296 | 432 | 824 | 57280 | 1610 | 255 | 156 | 3863 | 0 | 5465 | 53470 | 6471 | 44448 | 54783 |
| 64 | 2.01 | 762 | 0 | 515 | 744 | 64240 | 2161 | 197 | 311 | 5264 | 0 | 9376 | 94900 | 12680 | 71157 | 84019 |
| 65 | 2.02 | 751 | 0 | 394 | 647 | 53430 | 1812 | 363 | 181 | 6750 | 69 | 10190 | 110000 | 13440 | 90429 | 109707 |
| 66 | 2.03 | 722 | 0 | 506 | 816 | 65340 | 2101 | 285 | 265 | 5926 | 0 | 10410 | 104700 | 14610 | 82221 | 97836 |
| 67 | 2.04 | 511 | 0 | 354 | 434 | 39600 | 1301 | 194 | 153 | 3316 | 0 | 5781 | 58940 | 8209 | 42386 | 50481 |
| 68 | 2.04 | 809 | 0 | 440 | 691 | 62700 | 2168 | 413 | 314 | 5612 | 0 | 9495 | 96790 | 13060 | 68742 | 82078 |
| 69 | 2.05 | 820 | 321 | 590 | 734 | 61830 | 2071 | 412 | 321 | 5586 | 0 | 9690 | 97560 | 13820 | 73204 | 88216 |
| 70 | 2.06 | 740 | 0 | 466 | 654 | 58460 | 1947 | 314 | 246 | 5209 | 0 | 9102 | 92160 | 12720 | 67814 | 82244 |
| 71 | 2.07 | 632 | 0 | 349 | 597 | 40270 | 1676 | 230 | 171 | 3317 | 0 | 6091 | 59190 | 7999 | 43885 | 52274 |
| 72 | 2.08 | 621 | 0 | 420 | 581 | 53970 | 1708 | 314 | 226 | 4508 | 0 | 7639 | 76010 | 10420 | 56253 | 67388 |
| 73 | 2.09 | 602 | 0 | 340 | 563 | 48470 | 1609 | 289 | 176 | 3888 | 0 | 6867 | 65960 | 8772 | 47768 | 56728 |
| 74 | 2.10 | 685 | 0 | 269 | 563 | 42810 | 1403 | 215 | 199 | 3758 | 0 | 6616 | 65810 | 9153 | 52237 | 62280 |
| 75 | 2.11 | 587 | 0 | 482 | 714 | 52640 | 1697 | 258 | 227 | 4403 | 0 | 7694 | 75450 | 10250 | 56839 | 65325 |
| 76 | 2.12 | 753 | 0 | 580 | 833 | 65030 | 2103 | 325 | 345 | 5991 | 0 | 10240 | 103300 | 14360 | 80984 | 94847 |
| 77 | 2.13 | 663 | 0 | 424 | 622 | 49420 | 1430 | 0 | 183 | 3996 | 0 | 7028 | 69920 | 9752 | 54612 | 63571 |
| 78 | 2.14 | 508 | 0 | 259 | 821 | 62980 | 2702 | 135 | 531 | 7671 | 0 | 14770 | 156400 | 20700 | 58744 | 63034 |
| 79 | 2.15 | 980 | 278 | 425 | 677 | 52050 | 1746 | 269 | 222 | 4576 | 0 | 7884 | 78730 | 11110 | 62543 | 73054 |
| 80 | 2.16 | 936 | 170 | 512 | 770 | 65550 | 2176 | 314 | 313 | 5867 | 56 | 10210 | 103300 | 14000 | 81479 | 96295 |
| 81 | 2.17 | 730 | 205 | 368 | 648 | 49420 | 1637 | 180 | 263 | 4379 | 0 | 7890 | 78020 | 10720 | 56821 | 67120 |
| 82 | 2.18 | 457 | 0 | 227 | 531 | 41160 | 1865 | 97 | 333 | 5434 | 0 | 10900 | 113000 | 14930 | 46527 | 50158 |
| 83 | 2.18 | 959 | 0 | 417 | 1124 | 90250 | 4154 | 473 | 642 | 10640 | 297 | 20210 | 209100 | 26820 | 67218 | 77489 |
| 84 | 2.19 | 315 | 0 | 275 | 390 | 33730 | 1079 | 227 | 173 | 2822 | 0 | 5249 | 50560 | 6736 | 39406 | 46048 |
| 85 | 2.19 | 783 | 0 | 506 | 852 | 66510 | 2175 | 364 | 320 | 5401 | 0 | 8919 | 87890 | 11830 | 62359 | 76178 |
| 86 | 2.20 | 587 | 151 | 303 | 495 | 42400 | 1367 | 177 | 186 | 3497 | 0 | 6108 | 60560 | 8395 | 44796 | 53669 |
| 87 | 3.01 | 593 | 0 | 169 | 229 | 19440 | 1052 | 0 | 237 | 5742 | 0 | 6263 | 59630 | 8915 | 58205 | 72640 |
| 88 | 3.02 | 1120 | 478 | 1107 | 2380 | 109900 | 1982 | 344 | 227 | 6496 | 0 | 10750 | 114100 | 18860 | 86228 | 91544 |
| 89 | 3.03 | 655 | 0 | 0 | 381 | 30730 | 1578 | 326 | 366 | 9288 | 0 | 10170 | 96690 | 14330 | 85808 | 112370 |
| 90 | 3.04 | 813 | 262 | 795 | 1973 | 94950 | 1976 | 268 | 199 | 5243 | 0 | 8931 | 89410 | 14530 | 66049 | 69339 |
| 91 | 3.05 | 818 | 287 | 610 | 1339 | 64440 | 1163 | 194 | 145 | 3310 | 0 | 5483 | 57880 | 9537 | 43455 | 45925 |
| 92 | 3.05 | 671 | 210 | 670 | 1396 | 67400 | 1153 | 162 | 179 | 3710 | 0 | 5751 | 60140 | 9717 | 40442 | 44529 |
| 93 | 3.06 | 408 | 0 | 121 | 0 | 20620 | 1139 | 276 | 207 | 6682 | 0 | 7418 | 68180 | 9969 | 63540 | 85289 |
| 94 | 3.07 | 951 | 401 | 641 | 2018 | 94330 | 1555 | 280 | 272 | 5221 | 0 | 8517 | 91110 | 14990 | 66787 | 70739 |
| 95 | 3.08 | 907 | 442 | 774 | 1783 | 94450 | 1779 | 375 | 226 | 5342 | 0 | 9047 | 94790 | 15590 | 69576 | 74042 |
| 96 | 3.09 | 667 | 0 | 202 | 382 | 24020 | 1284 | 262 | 224 | 6181 | 0 | 6627 | 62870 | 8820 | 51781 | 67398 |
| 97 | 3.10 | 606 | 0 | 203 | 273 | 20120 | 1024 | 243 | 218 | 5568 | 0 | 6076 | 57600 | 8349 | 53017 | 67847 |
| 98 | 3.11 | 791 | 0 | 211 | 436 | 28300 | 1502 | 353 | 309 | 8113 | 0 | 8870 | 84960 | 12440 | 70225 | 92217 |
| 99 | 3.12 | 860 | 0 | 207 | 439 | 28120 | 1483 | 331 | 327 | 8705 | 0 | 9066 | 86830 | 12890 | 71724 | 96231 |
| 100 | 3.13 | 1055 | 482 | 641 | 1944 | 99820 | 1736 | 339 | 184 | 5890 | 0 | 9433 | 100400 | 16350 | 72117 | 77276 |

EDZIZA SOURCE OBSIDIANS: UNCORRECTED RAW PEAK COUNTS OBTAINED FROM THE GAMANAL SPECTRUM-STRIPPING PROGRAM.

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 3.14 | 787 | 345 | 756 | 1906 | 96740 | 1716 | 279 | 262 | 5444 | 0 | 9010 | 93210 | 15200 | 69054 | 72606 |
| 102 | 3.15 | 805 | 0 | 590 | 867 | 65820 | 2270 | 454 | 259 | 6095 | 0 | 11220 | 110800 | 15550 | 84695 | 98061 |
| 103 | 3.16 | 643 | 279 | 518 | 1318 | 62640 | 1132 | 204 | 131 | 3358 | 0 | 5205 | 54600 | 8890 | 38830 | 41306 |
| 104 | 3.17 | 454 | 0 | 178 | 253 | 16770 | 924 | 194 | 156 | 4424 | 0 | 4959 | 47850 | 6902 | 42104 | 54836 |
| 105 | 3.18 | 750 | 0 | 246 | 238 | 22440 | 1213 | 234 | 251 | 6953 | 0 | 6843 | 66070 | 9601 | 59432 | 77113 |
| 106 | 3.19 | 813 | 0 | 426 | 1047 | 78260 | 3618 | 387 | 601 | 9642 | 207 | 19390 | 201100 | 25640 | 68139 | 77970 |
| 107 | 3.20 | 680 | 0 | 233 | 397 | 26250 | 1426 | 292 | 286 | 7315 | 0 | 7980 | 77790 | 11270 | 66401 | 86556 |
| 108 | 3.21 | 1171 | 510 | 1066 | 2206 | 112800 | 1920 | 246 | 212 | 6399 | 0 | 10280 | 110400 | 17690 | 82879 | 85779 |
| 109 | 3.22 | 1027 | 401 | 795 | 2098 | 102800 | 1826 | 234 | 292 | 5995 | 0 | 9706 | 104400 | 17270 | 73958 | 79445 |
| 110 | 3.23 | 807 | 0 | 235 | 377 | 27790 | 1437 | 287 | 341 | 7180 | 0 | 7626 | 68900 | 9918 | 53138 | 70319 |
| 111 | 3.23 | 760 | 0 | 286 | 398 | 31880 | 1601 | 239 | 385 | 9306 | 0 | 10100 | 97700 | 14300 | 86797 | 112591 |
| 112 | 3.24 | 752 | 0 | 185 | 457 | 29950 | 1417 | 259 | 216 | 9018 | 0 | 9551 | 91690 | 13510 | 77423 | 101307 |
| 113 | 6.01 | 600 | 0 | 294 | 331 | 32750 | 1724 | 418 | 356 | 10390 | 0 | 10790 | 106600 | 15500 | 93427 | 123737 |
| 114 | 6.02 | 699 | 0 | 283 | 392 | 33590 | 1811 | 582 | 477 | 10750 | 0 | 11410 | 109800 | 15940 | 104373 | 133360 |
| 115 | 6.03 | 880 | 0 | 350 | 365 | 34110 | 1679 | 327 | 423 | 9923 | 0 | 10600 | 104900 | 15110 | 94654 | 122866 |
| 116 | 6.04 | 831 | 0 | 271 | 448 | 32410 | 1769 | 396 | 385 | 10060 | 0 | 11200 | 108800 | 15820 | 102215 | 130942 |
| 117 | 6.05 | 705 | 0 | 325 | 374 | 32400 | 1960 | 405 | 331 | 9993 | 0 | 10810 | 104700 | 15140 | 94883 | 122330 |
| 118 | 6.06 | 857 | 0 | 551 | 752 | 65880 | 2113 | 337 | 279 | 6414 | 71 | 10380 | 106000 | 13420 | 79101 | 96071 |
| 119 | 7.01 | 836 | 0 | 259 | 351 | 31570 | 1627 | 176 | 366 | 9322 | 0 | 10170 | 98200 | 14210 | 86184 | 112277 |
| 120 | 7.02 | 760 | 0 | 297 | 334 | 29740 | 2078 | 264 | 339 | 8939 | 0 | 9632 | 91020 | 12630 | 76329 | 100650 |
| 121 | 7.03 | 751 | 0 | 208 | 321 | 27340 | 1324 | 221 | 359 | 8428 | 0 | 9272 | 89100 | 12840 | 82448 | 106736 |
| 122 | 7.04 | 701 | 0 | 190 | 323 | 21300 | 1097 | 170 | 216 | 6271 | 0 | 6708 | 62620 | 9182 | 53522 | 70287 |
| 123 | 7.05 | 885 | 0 | 176 | 321 | 30940 | 1698 | 396 | 425 | 9718 | 0 | 10890 | 101500 | 15060 | 98779 | 126963 |
| 124 | 7.06 | 722 | 0 | 0 | 0 | 26950 | 1468 | 237 | 330 | 8817 | 0 | 9614 | 90360 | 13570 | 83989 | 112132 |
| 125 | 7.07 | 897 | 0 | 220 | 437 | 31410 | 1711 | 391 | 479 | 10190 | 0 | 10990 | 102700 | 15260 | 97859 | 126705 |
| 126 | 9.01 | 958 | 268 | 530 | 791 | 59220 | 2005 | 382 | 316 | 6392 | 0 | 9738 | 102100 | 12350 | 92433 | 113468 |
| 127 | 9.02 | 866 | 0 | 508 | 871 | 62240 | 2154 | 523 | 110 | 6544 | 0 | 9957 | 103000 | 13030 | 90827 | 109750 |
| 128 | 9.03 | 1007 | 197 | 520 | 707 | 62590 | 2120 | 376 | 246 | 6263 | 0 | 9914 | 104800 | 13150 | 96676 | 115898 |
| 129 | 9.04 | 735 | 0 | 562 | 656 | 60030 | 1965 | 181 | 254 | 6360 | 0 | 10000 | 105800 | 13120 | 98325 | 118027 |
| 130 | 9.05 | 1009 | 0 | 488 | 726 | 63510 | 2063 | 434 | 0 | 6405 | 0 | 10260 | 106000 | 13570 | 97906 | 116294 |
| 131 | 9.06 | 788 | 0 | 572 | 800 | 61670 | 2279 | 428 | 249 | 6218 | 0 | 9848 | 101800 | 12520 | 89896 | 108980 |
| 132 | 9.07 | 824 | 0 | 543 | 671 | 60130 | 2052 | 320 | 149 | 6336 | 0 | 9853 | 102900 | 12710 | 91065 | 111761 |
| 133 | 9.08 | 1176 | 237 | 508 | 809 | 62220 | 2066 | 436 | 185 | 6259 | 0 | 9875 | 101100 | 12730 | 84667 | 104112 |
| 134 | 9.09 | 1148 | 153 | 528 | 654 | 66500 | 2178 | 317 | 228 | 6658 | 0 | 10320 | 112000 | 15140 | 99757 | 120673 |
| 135 | 9.10 | 971 | 0 | 535 | 873 | 66100 | 2173 | 473 | 321 | 6812 | 0 | 10820 | 113400 | 14070 | 102318 | 122989 |
| 136 | 9.11 | 898 | 0 | 572 | 832 | 66460 | 2128 | 219 | 155 | 6552 | 0 | 10460 | 107200 | 13030 | 91701 | 110588 |
| 137 | 12.01 | 884 | 0 | 333 | 348 | 29690 | 1609 | 247 | 277 | 8912 | 0 | 9188 | 94930 | 14970 | 90050 | 113718 |
| 138 | 12.02 | 948 | 232 | 367 | 541 | 48150 | 1708 | 265 | 228 | 5545 | 0 | 8186 | 86670 | 10340 | 62036 | 76668 |
| 139 | 12.02 | 1049 | 220 | 492 | 735 | 57000 | 1908 | 260 | 117 | 6875 | 0 | 10190 | 108000 | 13080 | 81963 | 101825 |
| 140 | 12.03 | 559 | 0 | 355 | 495 | 43030 | 1559 | 345 | 194 | 5347 | 0 | 8353 | 88110 | 10590 | 70801 | 87260 |
| 141 | 16.01 | 733 | 0 | 449 | 845 | 55220 | 1420 | 0 | 0 | 4777 | 114 | 7640 | 77550 | 10030 | 85387 | 104177 |
| 142 | 16.02 | 909 | 0 | 541 | 706 | 59560 | 1826 | 320 | 234 | 4659 | 0 | 7690 | 77240 | 9627 | 74805 | 92038 |
| 143 | 16.03 | 906 | 132 | 573 | 827 | 59570 | 1663 | 253 | 197 | 4876 | 130 | 7468 | 72660 | 9014 | 72915 | 88903 |
| 144 | 16.04 | 978 | 0 | 837 | 844 | 74030 | 2255 | 381 | 152 | 6397 | 0 | 10250 | 103000 | 12790 | 111997 | 134990 |
| 145 | 16.06 | 931 | 109 | 691 | 776 | 65520 | 1813 | 376 | 118 | 5303 | 0 | 8191 | 80620 | 10000 | 74495 | 92740 |
| 146 | 16.07 | 826 | 0 | 836 | 889 | 72330 | 1994 | 254 | 190 | 6147 | 0 | 9874 | 100300 | 13050 | 106349 | 128962 |
| 147 | 16.08 | 774 | 0 | 512 | 799 | 55830 | 1651 | 320 | 136 | 4656 | 0 | 7057 | 70620 | 8997 | 66618 | 82537 |
| 148 | 16.09 | 794 | 0 | 557 | 828 | 63720 | 1855 | 384 | 128 | 5161 | 0 | 8464 | 82810 | 10910 | 79351 | 98735 |
| 149 | 16.10 | 1111 | 326 | 512 | 765 | 58340 | 1751 | 261 | 174 | 5146 | 0 | 8217 | 80930 | 10190 | 79635 | 99462 |
| 150 | 16.11 | 923 | 0 | 684 | 819 | 65460 | 1806 | 346 | 122 | 5223 | 0 | 7905 | 77540 | 9667 | 65401 | 83579 |
| 151 | 16.11 | 935 | 170 | 575 | 823 | 65060 | 1875 | 341 | 235 | 5447 | 0 | 8642 | 89740 | 11570 | 88515 | 109023 |
| 152 | 16.12 | 808 | 69 | 558 | 856 | 63550 | 1699 | 362 | 180 | 5534 | 0 | 8846 | 87850 | 11490 | 92891 | 114517 |
| 153 | 16.13 | 1002 | 0 | 633 | 930 | 76210 | 2160 | 266 | 226 | 6549 | 0 | 10440 | 102200 | 13070 | 101767 | 123852 |
| 154 | 17.01 | 750 | 0 | 478 | 665 | 55310 | 1666 | 386 | 109 | 4431 | 0 | 7237 | 69710 | 9125 | 71993 | 87049 |
| 155 | 17.02 | 1169 | 284 | 994 | 896 | 78210 | 2265 | 477 | 211 | 5795 | 0 | 9619 | 92630 | 11590 | 88917 | 106753 |

EDZIZA SOURCE OBSIDIANS: UNCORRECTED RAW PEAK COUNTS OBTAINED FROM THE GAMANAL SPECTRUM-STRIPPING PROGRAM.

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156 | 17.03 | 1034 | 0 | 606 | 994 | 74280 | 2074 | 349 | 316 | 6237 | 0 | 10240 | 103300 | 13410 | 112117 | 133229 |
| 157 | 17.04 | 1336 | 308 | 645 | 917 | 68640 | 2076 | 357 | 247 | 5308 | 0 | 8161 | 78620 | 9849 | 69650 | 85006 |
| 158 | 17.04 | 1074 | 246 | 411 | 760 | 60760 | 1773 | 328 | 165 | 4918 | 0 | 7598 | 77200 | 9808 | 75513 | 92633 |
| 159 | 17.05 | 1020 | 0 | 635 | 1039 | 74580 | 2262 | 520 | 291 | 6113 | 0 | 9729 | 99560 | 12380 | 109260 | 128135 |
| 160 | 17.06 | 1309 | 252 | 650 | 966 | 70080 | 1.03 | 413 | 171 | 5922 | 0 | 9286 | 92740 | 12020 | 95017 | 115789 |
| 161 | 17.07 | 1055 | 297 | 590 | 800 | 63910 | 1944 | 369 | 256 | 5240 | 0 | 8274 | 81930 | 10190 | 82637 | 100227 |
| 162 | 17.08 | 987 | 0 | 495 | 799 | 64750 | 1883 | 399 | 0 | 5315 | 0 | 8395 | 83810 | 10750 | 84574 | 103465 |
| 163 | 17.09 | 912 | 0 | 402 | 745 | 63130 | 1947 | 364 | 303 | 5508 | 0 | 8812 | 88210 | 11450 | 93633 | 112772 |
| 164 | 18.01 | 1034 | 0 | 237 | 515 | 33410 | 1673 | 383 | 417 | 10170 | 0 | 11290 | 109700 | 15740 | 102740 | 133283 |
| 165 | 18.02 | 870 | 0 | 266 | 433 | 33450 | 1676 | 279 | 319 | 9897 | 0 | 11090 | 105700 | 15410 | 101052 | 129909 |
| 166 | 18.03 | 927 | 0 | 287 | 130 | 34730 | 1705 | 191 | 337 | 10750 | 0 | 12090 | 114200 | 16540 | 101723 | 135611 |
| 167 | 18.04 | 807 | 0 | 230 | 488 | 33500 | 1708 | 344 | 481 | 9917 | 0 | 11280 | 109400 | 16100 | 94483 | 128797 |
| 168 | 18.05 | 796 | 0 | 192 | 425 | 33390 | 1653 | 334 | 409 | 9890 | 0 | 11080 | 106200 | 15880 | 99480 | 128187 |
| 169 | 18.06 | 812 | 0 | 377 | 376 | 31920 | 1669 | 364 | 405 | 10180 | 0 | 10860 | 107100 | 15880 | 99572 | 131084 |
| 170 | 18.07 | 941 | 0 | 212 | 374 | 32350 | 1871 | 546 | 392 | 9458 | 0 | 10220 | 95620 | 13880 | 75884 | 105015 |
| 171 | 18.08 | 947 | 0 | 215 | 430 | 34160 | 1658 | 386 | 416 | 9611 | 156 | 10730 | 101600 | 14800 | 94196 | 121253 |
| 172 | 19.01 | 999 | 0 | 433 | 699 | 63610 | 2389 | 508 | 325 | 8001 | 0 | 12530 | 133000 | 15700 | 117470 | 138154 |
| 173 | 19.02 | 861 | 0 | 583 | 756 | 64040 | 2166 | 314 | 164 | 8348 | 0 | 12300 | 134300 | 15850 | 103967 | 128026 |
| 174 | 19.03 | 1187 | 407 | 438 | 761 | 62800 | 2243 | 393 | 441 | 7678 | 0 | 11690 | 125700 | 15060 | 102402 | 125176 |
| 175 | 19.04 | 912 | 0 | 431 | 739 | 54550 | 1985 | 331 | 285 | 6506 | 0 | 10360 | 109600 | 13160 | 89490 | 110505 |
| 176 | 19.05 | 1150 | 280 | 530 | 672 | 62960 | 2293 | 427 | 335 | 7689 | 0 | 12040 | 129200 | 15730 | 101685 | 125199 |
| 177 | 20.01 | 773 | 0 | 613 | 970 | 69640 | 2306 | 398 | 341 | 7199 | 0 | 11170 | 115900 | 14290 | 100460 | 122842 |
| 178 | 20.02 | 835 | 0 | 578 | 829 | 69200 | 2276 | 421 | 347 | 7137 | 0 | 11260 | 116500 | 14390 | 103590 | 123947 |
| 179 | 20.03 | 999 | 0 | 600 | 832 | 67460 | 2204 | 402 | 0 | 6846 | 0 | 10990 | 113800 | 14450 | 106937 | 126850 |
| 180 | 20.04 | 796 | 0 | 385 | 649 | 53610 | 1749 | 413 | 281 | 5202 | 0 | 8039 | 79620 | 9723 | 61537 | 75750 |
| 181 | 20.04 | 704 | 0 | 341 | 594 | 44020 | 1370 | 0 | 125 | 4505 | 0 | 6804 | 69630 | 8671 | 60062 | 75695 |
| 182 | 20.05 | 870 | 0 | 477 | 681 | 56570 | 1678 | 271 | 243 | 5654 | 146 | 9079 | 92320 | 11580 | 76652 | 95522 |
| 183 | 21.01 | 1166 | 158 | 343 | 211 | 32730 | 1639 | 293 | 376 | 10340 | 0 | 11380 | 105400 | 15790 | 101276 | 130203 |
| 184 | 21.02 | 859 | 0 | 296 | 372 | 31360 | 1686 | 334 | 388 | 9491 | 0 | 10240 | 96990 | 13920 | 82921 | 110201 |
| 185 | 21.03 | 927 | 0 | 231 | 454 | 32400 | 1640 | 222 | 346 | 10030 | 0 | 11000 | 105000 | 15360 | 94249 | 124324 |
| 186 | 21.04 | 843 | 0 | 266 | 381 | 32040 | 1701 | 383 | 285 | 9476 | 0 | 10280 | 93470 | 14420 | 93763 | 125715 |
| 187 | 22.01 | 929 | 0 | 198 | 607 | 35680 | 1870 | 377 | 344 | 10810 | 0 | 11840 | 114100 | 16650 | 99747 | 130767 |
| 188 | 22.02 | 809 | 0 | 348 | 325 | 36110 | 1728 | 192 | 394 | 10700 | 0 | 11700 | 110100 | 16040 | 99153 | 128077 |
| 189 | 22.03 | 1029 | 0 | 269 | 338 | 36890 | 1814 | 418 | 614 | 11430 | 0 | 12520 | 122000 | 17450 | 114202 | 147052 |
| 190 | 22.04 | 1066 | 0 | 243 | 338 | 35810 | 1822 | 371 | 392 | 10630 | 0 | 11610 | 115000 | 16820 | 102225 | 133160 |
| 191 | 22.05 | 972 | 230 | 357 | 482 | 38610 | 2036 | 531 | 461 | 11720 | 0 | 12740 | 122900 | 17790 | 103698 | 137467 |
| 192 | 22.06 | 867 | 0 | 428 | 368 | 35090 | 1802 | 416 | 338 | 10680 | 147 | 11570 | 111300 | 16200 | 95588 | 127970 |
| 193 | 22.07 | 573 | 0 | 0 | 255 | 26670 | 1494 | 311 | 214 | 8233 | 0 | 8780 | 82070 | 11820 | 70663 | 93106 |
| 194 | 22.08 | 852 | 130 | 154 | 451 | 29470 | 1571 | 393 | 262 | 8866 | 83 | 9430 | 90680 | 12980 | 80071 | 105938 |
| 195 | 22.09 | 983 | 0 | 269 | 539 | 39030 | 2106 | 526 | 486 | 10840 | 0 | 11460 | 110700 | 15640 | 88421 | 119353 |
| 196 | 22.10 | 668 | 0 | 247 | 239 | 26920 | 1380 | 264 | 290 | 8070 | 0 | 8765 | 81990 | 11860 | 71803 | 95095 |
| 197 | 22.11 | 1413 | 269 | 222 | 426 | 39270 | 1812 | 539 | 472 | 11690 | 0 | 12450 | 121900 | 18020 | 111545 | 143604 |
| 198 | 22.12 | 930 | 0 | 371 | 490 | 36630 | 1996 | 450 | 480 | 11440 | 0 | 12160 | 116800 | 16750 | 103454 | 136338 |
| 199 | 22.13 | 1156 | 253 | 269 | 522 | 36410 | 1950 | 374 | 526 | 11610 | 228 | 12640 | 122400 | 18070 | 111115 | 146701 |
| 200 | 22.14 | 898 | 0 | 0 | 502 | 37440 | 1909 | 438 | 418 | 11410 | 0 | 12700 | 122400 | 17470 | 112136 | 146830 |
| 201 | 22.15 | 1137 | 0 | 214 | 502 | 36420 | 1954 | 417 | 485 | 11180 | 0 | 12480 | 122600 | 17940 | 119154 | 151337 |
| 202 | 23.01 | 1000 | 0 | 267 | 493 | 34470 | 1736 | 358 | 378 | 10790 | 0 | 11840 | 111800 | 16560 | 100104 | 132627 |
| 203 | 23.02 | 1057 | 0 | 0 | 545 | 37660 | 2251 | 486 | 357 | 11000 | 0 | 12310 | 120700 | 17270 | 113178 | 144052 |
| 204 | 23.03 | 891 | 0 | 224 | 453 | 36640 | 2130 | 667 | 454 | 11530 | 0 | 12120 | 116200 | 17030 | 108813 | 141284 |
| 205 | 23.04 | 940 | 0 | 233 | 428 | 35790 | 1870 | 448 | 340 | 10590 | 0 | 11940 | 113600 | 16660 | 108245 | 139856 |
| 206 | 23.05 | 984 | 0 | 313 | 460 | 37310 | 2001 | 540 | 440 | 10910 | 0 | 11750 | 116300 | 17000 | 104695 | 136927 |

# APPENDIX D

## EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE COMPTON PEAK (PK/COMP * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton Pk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.01 | 8.03 | 0 | 5.03 | 8.53 | 593.48 | 23.98 | 3.71 | 3.84 | 62.50 | 0 | 86.84 | 984.95 | 121.04 | 811.61 | 95589 |
| 2 | 1.02 | 8.44 | 3.12 | 5.47 | 6.97 | 595.48 | 17.74 | 3.64 | 2.70 | 49.22 | 0 | 70.29 | 800.45 | 103.03 | 821.67 | 99482 |
| 3 | 1.03 | 6.59 | 0 | 0 | 3.20 | 254.31 | 13.56 | 4.36 | 3.48 | 76.77 | 0 | 72.39 | 829.10 | 121.56 | 774.35 | 97322 |
| 4 | 1.04 | 5.74 | 0 | 2.60 | 3.30 | 259.53 | 13.42 | 3.13 | 2.61 | 77.24 | 0 | 73.13 | 917.90 | 124.11 | 759.42 | 110470 |
| 5 | 1.05 | 7.81 | 0 | 1.90 | 2.40 | 228.76 | 10.88 | 2.65 | 1.91 | 86.04 | 3.53 | 84.31 | 561.05 | 142.04 | 768.31 | 114267 |
| 6 | 1.06 | 6.99 | 0 | 2.38 | 2.99 | 247.41 | 12.65 | 2.45 | 2.70 | 79.27 | 0 | 74.70 | 819.56 | 123.30 | 765.03 | 110547 |
| 7 | 1.07 | 6.85 | 0 | 0 | 1.82 | 231.49 | 11.42 | 2.23 | 2.84 | 85.08 | 3.56 | 82.08 | 542.78 | 135.56 | 774.43 | 106525 |
| 8 | 1.09 | 10.68 | 1.99 | 1.63 | 3.77 | 258.86 | 11.60 | 3.06 | 2.55 | 88.38 | 3.16 | 84.63 | 569.88 | 141.57 | 758.29 | 91826 |
| 9 | 1.10 | 6.93 | 0 | 1.64 | 4.02 | 261.13 | 13.38 | 1.56 | 3.11 | 78.55 | 0 | 70.59 | 817.71 | 120.36 | 777.46 | 95547 |
| 10 | 1.12 | 7.84 | 0 | 5.35 | 7.43 | 595.51 | 17.60 | 3.80 | 1.72 | 49.23 | 0 | 72.38 | 811.52 | 106.05 | 827.82 | 117680 |
| 11 | 1.13 | 6.12 | 0 | 0 | 3.00 | 234.22 | 12.77 | 3.44 | 4.14 | 114.39 | 0 | 80.53 | 711.23 | 141.62 | 758.86 | 128510 |
| 12 | 1.14 | 8.83 | 2.59 | 2.03 | 1.95 | 236.46 | 10.78 | 2.37 | 1.86 | 83.39 | 2.97 | 81.90 | 553.16 | 138.69 | 764.85 | 120272 |
| 13 | 1.14 | 5.35 | 0 | 1.73 | 2.24 | 199.50 | 9.53 | 2.00 | 1.49 | 79.04 | 2.54 | 74.43 | 503.26 | 128.03 | 744.96 | 132079 |
| 14 | 1.15 | 14.06 | 4.42 | 6.20 | 8.76 | 839.03 | 32.17 | 4.02 | 4.03 | 85.12 | 0 | 116.11 | 1315.63 | 158.03 | 825.23 | 56756 |
| 15 | 1.16 | 6.64 | 0 | 1.95 | 3.28 | 266.29 | 13.78 | 3.72 | 3.13 | 79.39 | 0 | 74.27 | 850.27 | 123.33 | 778.43 | 125842 |
| 16 | 1.15 | 8.24 | 2.46 | 4.47 | 7.75 | 599.61 | 23.47 | 2.72 | 2.97 | 66.89 | 0 | 102.00 | 1167.96 | 145.58 | 850.91 | 121579 |
| 17 | 1.16 | 10.91 | 1.96 | 1.85 | 3.67 | 302.49 | 15.63 | 3.74 | 2.81 | 86.48 | 0 | 78.67 | 875.41 | 127.15 | 772.87 | 107904 |
| 18 | 1.17 | 8.94 | 0 | 2.24 | 4.90 | 300.55 | 16.81 | 4.65 | 1.80 | 87.44 | 0 | 76.65 | 882.40 | 127.72 | 772.71 | 63418 |
| 19 | 1.18 | 7.85 | .76 | 0 | 1.90 | 185.89 | 13.15 | 2.32 | 5.89 | 150.80 | 0 | 92.43 | 416.25 | 157.55 | 737.22 | 113995 |
| 20 | 1.17 | 8.99 | 0 | 2.88 | 4.20 | 322.22 | 17.58 | 4.38 | 3.98 | 93.38 | 0 | 79.84 | 918.46 | 130.66 | 753.54 | 88169 |
| 21 | 1.18 | 5.80 | 0 | 1.16 | 1.29 | 156.37 | 12.29 | 1.56 | 5.35 | 131.11 | 0 | 82.81 | 368.86 | 142.78 | 746.65 | 136150 |
| 22 | 1.19 | 10.63 | 0 | 5.71 | 12.84 | 910.53 | 32.27 | 4.28 | 3.44 | 82.31 | 1.50 | 126.10 | 1396.23 | 183.15 | 833.93 | 93967 |
| 23 | 1.19 | 9.71 | 3.38 | 4.87 | 8.25 | 711.78 | 24.07 | 3.49 | 3.15 | 66.45 | 0 | 108.64 | 1205.04 | 164.83 | 849.67 | 107337 |
| 24 | 1.20 | 8.48 | 0 | 5.41 | 7.20 | 687.43 | 22.49 | 4.12 | 3.44 | 59.20 | 0 | 97.80 | 1082.99 | 149.26 | 832.99 | 108404 |
| 25 | 1.21 | 6.11 | 0 | 1.12 | 1.61 | 204.75 | 11.76 | 0 | 3.66 | 102.34 | 0 | 75.95 | 676.94 | 131.99 | 760.14 | 147058 |
| 26 | 1.20 | 7.24 | 0 | 5.18 | 8.36 | 637.90 | 20.90 | 2.80 | 3.29 | 57.93 | 0 | 92.33 | 1040.60 | 141.60 | 847.73 | 120411 |
| 27 | 1.21 | 9.19 | 0 | 1.81 | 3.72 | 312.45 | 17.08 | 4.18 | 5.00 | 142.20 | 0 | 92.99 | 824.28 | 156.73 | 735.53 | 99153 |
| 28 | 1.22 | 5.67 | 0 | 1.32 | 2.82 | 216.82 | 11.53 | 3.86 | .98 | 82.75 | 3.91 | 80.08 | 538.37 | 133.85 | 763.15 | 137397 |
| 29 | 1.23 | 8.43 | 0 | 3.58 | 12.32 | 880.29 | 40.98 | 2.69 | 6.83 | 112.27 | 2.76 | 195.05 | 2420.51 | 339.86 | 879.45 | 105102 |
| 30 | 1.22 | 6.91 | 0 | 2.23 | 2.29 | 237.42 | 11.28 | 3.24 | 1.92 | 89.02 | 3.99 | 85.47 | 575.33 | 143.93 | 756.56 | 158622 |
| 31 | 1.23 | 10.11 | 0 | 4.02 | 11.15 | 862.93 | 38.01 | 1.75 | 6.98 | 111.38 | 4.33 | 208.88 | 2384.71 | 307.01 | 888.51 | 110160 |
| 32 | 1.24 | 7.61 | 0 | 4.10 | 9.63 | 735.59 | 27.81 | 4.49 | 4.54 | 77.29 | 0 | 125.96 | 1442.65 | 192.60 | 864.21 | 119156 |
| 33 | 1.25 | 6.94 | 0 | 2.19 | 3.12 | 252.35 | 13.37 | 2.29 | 2.99 | 78.32 | 0 | 71.89 | 824.54 | 123.32 | 766.06 | 140200 |
| 34 | 1.24 | 9.99 | 2.80 | 2.78 | 9.65 | 767.82 | 28.74 | 3.64 | 3.50 | 77.39 | 0 | 132.00 | 1479.99 | 197.54 | 872.78 | 114663 |
| 35 | 1.25 | 6.96 | 0 | 1.78 | 2.84 | 264.37 | 13.58 | 3.40 | 2.51 | 78.00 | 0 | 74.11 | 838.92 | 120.24 | 780.46 | 133981 |
| 36 | 1.26 | 7.09 | 0 | 4.14 | 4.75 | 495.16 | 18.01 | 3.79 | 2.74 | 63.11 | 1.16 | 83.76 | 1009.04 | 122.61 | 832.14 | 127150 |
| 37 | 1.27 | 8.63 | 0 | 4.55 | 6.95 | 673.65 | 26.64 | 4.18 | 4.15 | 75.30 | 0 | 109.28 | 1241.03 | 155.20 | 836.81 | 111601 |
| 38 | 1.26 | 7.95 | 0 | 4.41 | 7.04 | 544.89 | 19.31 | 2.61 | 2.71 | 65.31 | 0 | 90.82 | 1076.72 | 129.55 | 811.79 | 121108 |
| 39 | 1.27 | 9.62 | 0 | 5.02 | 6.95 | 692.91 | 27.83 | 4.09 | 4.10 | 74.20 | 0 | 109.96 | 1245.59 | 156.95 | 834.75 | 93851 |
| 40 | 1.28 | 6.67 | 0 | 1.88 | 3.67 | 261.04 | 13.36 | 2.80 | 2.18 | 79.76 | 0 | 74.34 | 826.98 | 122.26 | 765.50 | 125880 |
| 41 | 1.29 | 6.75 | 1.34 | 2.38 | 2.85 | 248.45 | 12.93 | 2.20 | 3.59 | 78.49 | 0 | 72.40 | 800.26 | 118.58 | 776.30 | 130208 |
| 42 | 1.28 | 6.92 | 0 | 1.46 | 3.04 | 250.73 | 12.80 | 2.06 | 3.43 | 77.84 | 0 | 71.32 | 833.31 | 120.25 | 766.19 | 134884 |
| 43 | 1.29 | 7.30 | 0 | 3.19 | 3.30 | 275.05 | 13.82 | 2.06 | 3.30 | 83.31 | 0 | 75.52 | 833.45 | 122.33 | 751.56 | 91475 |
| 44 | 1.30 | 5.10 | 0 | 0 | 0 | 92.79 | 9.33 | 3.14 | 5.31 | 176.71 | 0 | 84.02 | 157.42 | 143.81 | 725.85 | 147760 |
| 45 | 1.31 | 6.53 | 0 | 1.23 | 1.31 | 102.35 | 11.33 | 3.20 | 7.20 | 202.18 | 0 | 92.07 | 171.63 | 156.96 | 714.26 | 134239 |
| 46 | 1.30 | 6.51 | 2.42 | 0 | 0 | 91.14 | 9.70 | 1.98 | 6.59 | 179.56 | 0 | 84.26 | 156.01 | 143.69 | 717.79 | 146914 |
| 47 | 1.31 | 4.53 | 0 | 0 | 0 | 92.48 | 10.32 | 2.59 | 6.50 | 185.90 | 0 | 85.54 | 162.20 | 146.53 | 728.77 | 150621 |
| 48 | 1.32 | 8.97 | 2.08 | 2.38 | 2.62 | 257.70 | 12.08 | 3.41 | 1.98 | 90.93 | 3.58 | 87.36 | 586.85 | 142.92 | 757.49 | 116571 |
| 49 | 1.33 | 10.20 | 2.42 | 4.36 | 7.67 | 614.01 | 21.13 | 3.68 | 1.41 | 62.03 | 0 | 87.83 | 994.96 | 125.19 | 810.27 | 103924 |

EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE COMPTON PEAK (PK/COMP * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton Pk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 1.32 | 10.20 | 1.85 | 2.62 | 2.69 | 290.75 | 14.01 | 4.35 | 2.42 | 101.58 | 4.27 | 93.86 | 615.90 | 156.74 | 759.33 | 95064 |
| 51 | 1.33 | 8.58 | 1.51 | 4.42 | 7.40 | 531.82 | 16.61 | 2.51 | 2.15 | 55.39 | 0 | 77.55 | 922.38 | 116.03 | 827.54 | 118931 |
| 52 | 1.34 | 6.71 | 0 | 1.75 | 2.58 | 239.55 | 12.27 | 1.67 | 2.94 | 75.05 | 0 | 70.45 | 802.46 | 119.42 | 766.02 | 126361 |
| 53 | 1.34 | 7.43 | 1.26 | 1.59 | 3.98 | 260.70 | 11.74 | 1.40 | 3.46 | 80.51 | 0 | 74.33 | 842.82 | 122.93 | 759.06 | 127310 |
| 54 | 1.35 | 7.31 | 0 | 0 | 1.69 | 193.18 | 13.76 | 4.04 | 5.15 | 150.13 | 0 | 93.61 | 397.61 | 154.80 | 742.41 | 79199 |
| 55 | 1.36 | 9.31 | 1.93 | 1.75 | 3.26 | 279.06 | 14.22 | 3.28 | 3.74 | 82.39 | 0 | 70.78 | 861.69 | 139.11 | 768.94 | 119185 |
| 56 | 1.35 | 6.07 | 0 | 0 | 1.39 | 148.15 | 11.60 | 3.62 | 4.62 | 126.77 | 0 | 81.19 | 354.94 | 137.91 | 733.01 | 132838 |
| 57 | 1.36 | 6.62 | 0 | 2.03 | 3.31 | 269.69 | 13.93 | 4.12 | 2.88 | 80.94 | 0 | 77.29 | 854.08 | 124.10 | 776.95 | 123290 |
| 58 | 1.37 | 7.21 | 0 | 2.13 | 4.17 | 275.65 | 14.96 | 1.82 | 2.92 | 83.12 | 0 | 77.85 | 878.03 | 130.54 | 756.58 | 128241 |
| 59 | 1.38 | 6.69 | 0 | 1.72 | 3.71 | 272.72 | 12.66 | 1.64 | 3.96 | 81.27 | 0 | 74.12 | 853.35 | 124.06 | 766.11 | 112205 |
| 60 | 1.37 | 6.34 | .76 | 2.88 | 3.39 | 258.45 | 13.61 | 2.65 | 2.84 | 78.81 | 0 | 71.11 | 823.49 | 119.79 | 772.56 | 127142 |
| 61 | 1.36 | 7.43 | 0 | 1.78 | 3.92 | 309.06 | 16.27 | 3.43 | 3.47 | 86.43 | 0 | 80.76 | 892.41 | 130.44 | 751.69 | 104414 |
| 62 | 1.11 | 7.78 | 0 | 4.81 | 6.27 | 621.21 | 16.97 | 3.29 | 1.78 | 53.34 | 0 | 71.69 | 809.01 | 104.39 | 823.32 | 92063 |
| 63 | 1.11 | 16.95 | 5.40 | 7.89 | 15.04 | 1045.58 | 29.39 | 4.65 | 2.85 | 70.51 | 0 | 87.81 | 976.03 | 118.12 | 811.35 | 54783 |
| 64 | 2.01 | 9.07 | 0 | 6.13 | 8.86 | 764.59 | 25.72 | 2.34 | 3.70 | 62.65 | 0 | 100.97 | 1129.51 | 150.92 | 846.92 | 84019 |
| 65 | 2.02 | 6.85 | 0 | 3.59 | 5.90 | 487.02 | 16.52 | 3.31 | 1.65 | 61.53 | .63 | 82.45 | 1002.67 | 122.51 | 824.28 | 109707 |
| 66 | 2.03 | 7.38 | 0 | 5.17 | 8.34 | 667.85 | 21.47 | 2.91 | 2.71 | 60.57 | 0 | 96.14 | 1070.16 | 149.33 | 840.40 | 97836 |
| 67 | 2.04 | 10.12 | 0 | 7.01 | 8.60 | 784.45 | 25.77 | 3.84 | 3.03 | 65.69 | 0 | 103.38 | 1167.57 | 162.62 | 839.64 | 50481 |
| 68 | 2.04 | 9.86 | 0 | 5.36 | 8.42 | 763.91 | 26.41 | 5.03 | 3.83 | 68.37 | 0 | 104.09 | 1179.24 | 159.12 | 837.52 | 82078 |
| 69 | 2.05 | 9.30 | 3.64 | 6.69 | 8.32 | 700.89 | 23.48 | 4.67 | 3.64 | 63.32 | 0 | 99.11 | 1105.92 | 156.66 | 829.83 | 88216 |
| 70 | 2.06 | 9.00 | 0 | 5.67 | 7.95 | 710.81 | 23.67 | 3.82 | 2.99 | 63.34 | 0 | 99.94 | 1120.57 | 154.66 | 824.55 | 82244 |
| 71 | 2.07 | 12.09 | 0 | 6.68 | 11.42 | 770.36 | 32.06 | 4.40 | 3.27 | 63.45 | 0 | 105.77 | 1132.30 | 153.02 | 839.52 | 52274 |
| 72 | 2.08 | 9.22 | 0 | 6.23 | 8.62 | 800.88 | 25.35 | 4.66 | 3.35 | 66.90 | 0 | 102.02 | 1127.95 | 154.63 | 834.76 | 67388 |
| 73 | 2.09 | 10.61 | 0 | 5.99 | 9.92 | 854.43 | 28.36 | 5.09 | 3.10 | 68.54 | 0 | 109.43 | 1162.74 | 154.63 | 842.05 | 56728 |
| 74 | 2.10 | 11.00 | 0 | 4.32 | 9.04 | 687.38 | 22.53 | 3.45 | 3.20 | 60.34 | 0 | 96.00 | 1056.68 | 146.97 | 838.74 | 62280 |
| 75 | 2.11 | 8.99 | 0 | 7.38 | 10.93 | 805.82 | 25.98 | 3.95 | 3.47 | 67.40 | 0 | 106.36 | 1154.99 | 156.91 | 870.10 | 65325 |
| 76 | 2.12 | 7.94 | 0 | 6.12 | 8.78 | 685.63 | 22.17 | 3.43 | 3.64 | 63.16 | 0 | 97.26 | 1089.12 | 151.40 | 853.84 | 94847 |
| 77 | 2.13 | 10.43 | 0 | 6.67 | 9.78 | 777.40 | 22.49 | 0 | 2.88 | 62.86 | 0 | 99.90 | 1099.87 | 153.40 | 859.07 | 63571 |
| 78 | 2.14 | 8.06 | 0 | 4.11 | 13.02 | 999.14 | 42.87 | 2.14 | 8.42 | 121.70 | 0 | 213.69 | 2481.20 | 328.39 | 931.94 | 63034 |
| 79 | 2.15 | 13.41 | 3.81 | 5.82 | 9.27 | 712.49 | 23.90 | 3.68 | 3.04 | 62.64 | 0 | 97.30 | 1077.70 | 152.08 | 856.12 | 73054 |
| 80 | 2.16 | 9.72 | 1.77 | 5.32 | 8.00 | 680.72 | 22.60 | 3.26 | 3.25 | 60.93 | .58 | 95.70 | 1072.75 | 145.39 | 846.14 | 96295 |
| 81 | 2.17 | 10.88 | 3.05 | 5.48 | 9.65 | 736.29 | 24.39 | 2.68 | 3.92 | 65.24 | 0 | 106.49 | 1162.40 | 159.71 | 846.56 | 67120 |
| 82 | 2.18 | 9.11 | 0 | 4.53 | 10.59 | 820.61 | 37.18 | 1.93 | 6.64 | 108.34 | 0 | 198.95 | 2252.88 | 297.66 | 927.61 | 50158 |
| 83 | 2.18 | 12.38 | 0 | 5.38 | 14.51 | 1164.68 | 53.61 | 6.10 | 8.29 | 137.31 | 3.83 | 237.54 | 2698.45 | 346.11 | 867.45 | 77489 |
| 84 | 2.19 | 6.84 | 0 | 5.97 | 8.47 | 732.50 | 23.43 | 4.93 | 3.76 | 61.28 | 0 | 103.60 | 1097.98 | 146.28 | 855.76 | 46048 |
| 85 | 2.19 | 10.28 | 0 | 6.64 | 11.18 | 873.09 | 28.55 | 4.78 | 4.20 | 70.90 | 0 | 105.06 | 1153.75 | 155.29 | 818.60 | 76178 |
| 86 | 2.20 | 10.94 | 2.81 | 5.65 | 9.22 | 790.03 | 25.47 | 3.30 | 3.47 | 65.16 | 0 | 102.76 | 1128.40 | 156.42 | 834.67 | 53669 |
| 87 | 3.01 | 8.16 | 0 | 2.33 | 3.15 | 267.62 | 14.48 | 0 | 3.26 | 79.05 | 0 | 72.82 | 820.90 | 122.73 | 801.28 | 72640 |
| 88 | 3.02 | 12.23 | 5.22 | 12.09 | 26.00 | 1200.52 | 21.65 | 3.76 | 2.48 | 70.96 | 0 | 105.40 | 1246.40 | 206.02 | 941.93 | 91544 |
| 89 | 3.03 | 5.83 | 0 | 0 | 3.39 | 273.47 | 14.04 | 2.90 | 3.26 | 82.66 | 0 | 76.49 | 860.46 | 127.53 | 763.62 | 112370 |
| 90 | 3.04 | 11.73 | 3.78 | 11.47 | 28.45 | 1369.36 | 28.50 | 3.87 | 2.87 | 75.61 | 0 | 115.99 | 1289.46 | 209.55 | 952.55 | 69339 |
| 91 | 3.05 | 17.81 | 6.25 | 13.28 | 29.16 | 1403.16 | 25.32 | 4.22 | 3.16 | 72.07 | 0 | 107.17 | 1260.32 | 207.66 | 946.22 | 45925 |
| 92 | 3.05 | 15.07 | 4.72 | 15.05 | 31.35 | 1513.62 | 25.89 | 3.64 | 4.02 | 83.32 | 0 | 115.03 | 1350.58 | 218.22 | 908.22 | 44529 |
| 93 | 3.06 | 4.78 | 0 | 1.42 | 0 | 241.77 | 13.35 | 3.24 | 2.43 | 78.35 | 0 | 73.70 | 799.40 | 116.88 | 745.00 | 85289 |
| 94 | 3.07 | 13.44 | 5.67 | 9.06 | 28.53 | 1333.49 | 21.98 | 3.96 | 3.85 | 73.81 | 0 | 107.89 | 1287.97 | 211.91 | 944.13 | 70739 |
| 95 | 3.08 | 12.25 | 5.97 | 10.45 | 24.08 | 1275.63 | 24.03 | 5.06 | 3.05 | 72.15 | 0 | 109.96 | 1280.22 | 210.56 | 939.68 | 74042 |
| 96 | 3.09 | 9.90 | 0 | 3.00 | 5.67 | 356.39 | 19.05 | 3.89 | 3.32 | 91.71 | 0 | 82.78 | 932.82 | 130.86 | 768.29 | 67398 |
| 97 | 3.10 | 8.93 | 0 | 2.99 | 4.02 | 296.55 | 15.09 | 3.58 | 3.21 | 82.07 | 0 | 75.64 | 848.97 | 123.06 | 781.42 | 67847 |
| 98 | 3.11 | 8.58 | 0 | 2.29 | 4.73 | 306.88 | 16.29 | 3.83 | 3.35 | 87.98 | 0 | 81.27 | 921.31 | 134.90 | 761.52 | 92217 |
| 99 | 3.12 | 8.94 | 0 | 2.15 | 4.56 | 292.21 | 15.41 | 3.44 | 3.40 | 90.46 | 0 | 78.88 | 902.31 | 133.95 | 745.33 | 96231 |
| 100 | 3.13 | 13.65 | 6.24 | 8.29 | 25.16 | 1291.73 | 22.46 | 4.39 | 2.38 | 76.22 | 0 | 109.15 | 1299.24 | 211.58 | 933.24 | 77276 |

# EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE COMPTON PEAK (PK/COMP * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton Pk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 3.14 | 10.84 | 4.75 | 10.41 | 26.25 | 1332.40 | 23.63 | 3.84 | 3.61 | 74.98 | 0 | 111.39 | 1283.78 | 209.35 | 951.08 | 72606 |
| 102 | 3.15 | 8.21 | 0 | 6.02 | 9.05 | 671.21 | 23.15 | 4.63 | 2.64 | 62.16 | 0 | 103.88 | 1129.91 | 158.57 | 863.70 | 98061 |
| 103 | 3.16 | 15.57 | 6.75 | 12.54 | 31.91 | 1516.49 | 27.41 | 4.94 | 3.17 | 81.30 | 0 | 112.23 | 1321.84 | 215.22 | 940.06 | 41306 |
| 104 | 3.17 | 8.28 | 0 | 3.25 | 4.61 | 305.82 | 16.85 | 3.54 | 2.84 | 80.68 | 0 | 76.76 | 872.60 | 125.87 | 767.82 | 54836 |
| 105 | 3.18 | 9.73 | 0 | 3.19 | 3.09 | 291.00 | 15.73 | 3.03 | 3.25 | 90.17 | 0 | 73.46 | 856.79 | 124.51 | 770.71 | 77113 |
| 106 | 3.19 | 10.43 | 0 | 5.46 | 13.43 | 1003.72 | 46.40 | 4.96 | 7.71 | 123.66 | 2.65 | 227.72 | 2579.20 | 328.84 | 873.91 | 77970 |
| 107 | 3.20 | 7.86 | 0 | 2.69 | 4.59 | 303.27 | 16.47 | 3.37 | 3.30 | 84.51 | 0 | 77.87 | 898.72 | 130.20 | 767.14 | 86556 |
| 108 | 3.21 | 13.65 | 5.95 | 12.43 | 25.72 | 1315.01 | 22.38 | 2.87 | 2.47 | 74.60 | 0 | 107.20 | 1287.03 | 206.23 | 966.19 | 85779 |
| 109 | 3.22 | 12.93 | 5.05 | 10.01 | 26.41 | 1293.98 | 22.98 | 2.95 | 3.68 | 75.46 | 0 | 109.38 | 1314.12 | 217.38 | 930.93 | 79445 |
| 110 | 3.23 | 11.48 | 0 | 3.34 | 5.36 | 395.20 | 20.44 | 4.08 | 4.85 | 102.11 | 0 | 91.14 | 979.82 | 141.04 | 755.67 | 70319 |
| 111 | 3.23 | 6.75 | 0 | 2.54 | 3.53 | 283.15 | 14.22 | 2.12 | 3.42 | 82.65 | 0 | 75.70 | 867.74 | 127.01 | 770.91 | 112591 |
| 112 | 3.24 | 7.42 | 0 | 1.83 | 4.51 | 295.64 | 13.99 | 2.56 | 2.13 | 89.02 | 0 | 79.19 | 905.07 | 133.36 | 764.24 | 101307 |
| 113 | 6.01 | 6.47 | 0 | 2.38 | 2.68 | 264.67 | 13.93 | 3.38 | 2.88 | 83.97 | 0 | 72.97 | 861.50 | 125.27 | 755.04 | 123737 |
| 114 | 6.02 | 6.74 | 0 | 2.12 | 2.94 | 251.87 | 13.58 | 4.36 | 3.58 | 80.61 | 0 | 71.89 | 823.34 | 119.53 | 782.64 | 133360 |
| 115 | 6.03 | 7.16 | 0 | 2.85 | 2.97 | 277.62 | 13.67 | 2.66 | 3.44 | 80.76 | 0 | 74.21 | 853.78 | 122.98 | 770.38 | 122866 |
| 116 | 6.04 | 6.35 | 0 | 2.07 | 3.42 | 247.51 | 13.51 | 3.02 | 2.94 | 76.83 | 0 | 72.51 | 830.90 | 120.82 | 780.61 | 130942 |
| 117 | 6.05 | 5.76 | 0 | 2.66 | 3.06 | 264.86 | 16.02 | 3.31 | 2.71 | 81.69 | 0 | 74.52 | 855.88 | 123.76 | 775.63 | 122330 |
| 118 | 6.06 | 8.92 | 0 | 5.74 | 7.83 | 685.74 | 21.99 | 3.51 | 2.90 | 66.76 | .74 | 96.73 | 1103.35 | 139.69 | 823.36 | 96071 |
| 119 | 7.01 | 7.45 | 0 | 2.31 | 3.13 | 281.18 | 14.49 | 1.57 | 3.26 | 83.03 | 0 | 76.51 | 874.62 | 126.56 | 767.60 | 112277 |
| 120 | 7.02 | 7.55 | 0 | 2.95 | 3.32 | 295.48 | 20.65 | 2.62 | 3.37 | 88.81 | 0 | 80.64 | 904.32 | 125.48 | 758.36 | 100650 |
| 121 | 7.03 | 7.04 | 0 | 1.95 | 3.01 | 256.15 | 12.40 | 2.07 | 3.36 | 78.96 | 0 | 73.48 | 834.77 | 120.30 | 772.45 | 106736 |
| 122 | 7.04 | 9.97 | 0 | 2.70 | 4.60 | 303.04 | 15.61 | 2.42 | 3.07 | 89.22 | 0 | 80.31 | 890.92 | 130.65 | 761.48 | 70287 |
| 123 | 7.05 | 6.97 | 0 | 1.39 | 2.53 | 243.69 | 13.37 | 3.12 | 3.35 | 76.54 | 0 | 72.80 | 799.45 | 118.62 | 778.01 | 126963 |
| 124 | 7.06 | 6.44 | 0 | 0 | 0 | 240.34 | 13.09 | 2.11 | 2.94 | 78.63 | 0 | 72.41 | 805.84 | 121.02 | 749.02 | 112132 |
| 125 | 7.07 | 7.08 | 0 | 1.74 | 3.45 | 247.90 | 13.50 | 3.09 | 3.78 | 80.42 | 0 | 73.11 | 810.54 | 120.44 | 772.34 | 126705 |
| 126 | 9.01 | 8.44 | 2.36 | 4.67 | 6.97 | 521.91 | 17.67 | 3.37 | 2.78 | 56.33 | 0 | 76.27 | 899.81 | 108.84 | 814.62 | 113468 |
| 127 | 9.02 | 7.89 | 0 | 4.63 | 7.94 | 567.11 | 19.63 | 4.77 | 1.00 | 59.63 | 0 | 80.62 | 938.50 | 118.72 | 827.58 | 109750 |
| 128 | 9.03 | 8.69 | 1.70 | 4.49 | 6.10 | 540.04 | 18.29 | 3.24 | 2.12 | 54.04 | 0 | 76.38 | 904.24 | 113.46 | 834.15 | 115898 |
| 129 | 9.04 | 6.23 | 0 | 4.76 | 5.56 | 508.61 | 16.65 | 1.53 | 2.15 | 53.89 | 0 | 75.59 | 896.41 | 111.16 | 833.07 | 118027 |
| 130 | 9.05 | 8.68 | 0 | 4.20 | 6.24 | 546.12 | 17.74 | 3.73 | 0 | 55.08 | 0 | 78.89 | 911.48 | 116.69 | 841.88 | 116294 |
| 131 | 9.06 | 7.23 | 0 | 5.25 | 7.34 | 565.88 | 20.91 | 3.93 | 2.28 | 57.06 | 0 | 80.69 | 934.12 | 114.88 | 824.89 | 108980 |
| 132 | 9.07 | 7.37 | 0 | 4.86 | 6.00 | 538.02 | 18.36 | 2.86 | 1.33 | 56.69 | 0 | 78.55 | 920.71 | 113.72 | 814.82 | 111761 |
| 133 | 9.08 | 11.30 | 2.28 | 4.88 | 7.77 | 597.63 | 19.84 | 4.19 | 1.78 | 60.12 | 0 | 84.66 | 971.07 | 122.27 | 813.23 | 104112 |
| 134 | 9.09 | 9.51 | 1.27 | 4.38 | 5.42 | 551.08 | 18.05 | 2.63 | 1.89 | 55.17 | 0 | 76.17 | 928.13 | 125.46 | 826.67 | 120673 |
| 135 | 9.10 | 7.90 | 0 | 4.35 | 7.10 | 537.45 | 17.67 | 3.85 | 2.61 | 55.39 | 0 | 78.59 | 922.03 | 114.40 | 831.93 | 122989 |
| 136 | 9.11 | 8.12 | 0 | 5.17 | 7.52 | 600.97 | 19.24 | 1.98 | 1.40 | 59.25 | 0 | 84.54 | 969.36 | 117.82 | 829.21 | 110588 |
| 137 | 12.01 | 7.77 | 0 | 2.93 | 3.06 | 261.08 | 14.15 | 2.17 | 2.44 | 78.37 | 0 | 67.51 | 834.78 | 131.64 | 791.87 | 113718 |
| 138 | 12.02 | 12.37 | 3.03 | 4.79 | 7.06 | 628.03 | 22.28 | 3.46 | 2.97 | 72.32 | 0 | 94.51 | 1130.46 | 134.87 | 809.15 | 76668 |
| 139 | 12.02 | 10.30 | 2.16 | 4.83 | 7.22 | 559.78 | 18.74 | 2.55 | 1.15 | 67.52 | 0 | 88.63 | 1060.64 | 128.46 | 804.94 | 101825 |
| 140 | 12.03 | 6.41 | 0 | 4.07 | 5.67 | 493.12 | 17.87 | 3.95 | 2.22 | 61.28 | 0 | 85.34 | 1009.74 | 121.36 | 811.38 | 87260 |
| 141 | 16.01 | 7.04 | 0 | 4.31 | 8.11 | 530.06 | 13.63 | 0 | 0 | 45.85 | 1.09 | 65.56 | 744.41 | 96.28 | 819.63 | 104177 |
| 142 | 16.02 | 9.88 | 0 | 5.88 | 7.67 | 647.12 | 19.84 | 3.48 | 2.54 | 50.62 | 0 | 74.97 | 839.22 | 104.60 | 812.76 | 92038 |
| 143 | 16.03 | 10.19 | 1.48 | 6.45 | 9.30 | 670.06 | 18.71 | 2.85 | 2.22 | 54.85 | 1.46 | 74.71 | 817.30 | 101.39 | 820.16 | 88903 |
| 144 | 16.04 | 7.24 | 0 | 6.20 | 6.25 | 548.41 | 16.70 | 2.82 | 1.13 | 47.39 | 0 | 67.90 | 763.02 | 94.75 | 829.67 | 134990 |
| 145 | 16.06 | 10.04 | 1.18 | 7.45 | 8.37 | 706.49 | 19.55 | 4.05 | 1.27 | 57.18 | 0 | 78.63 | 869.31 | 107.83 | 803.27 | 92740 |
| 146 | 16.07 | 6.40 | 0 | 6.48 | 6.89 | 560.86 | 15.46 | 1.97 | 1.47 | 47.67 | 0 | 68.49 | 777.75 | 101.19 | 824.65 | 128962 |
| 147 | 16.08 | 9.38 | 0 | 6.20 | 9.68 | 676.42 | 20.00 | 3.88 | 1.65 | 56.41 | 0 | 75.94 | 855.62 | 109.01 | 807.13 | 82537 |
| 148 | 16.09 | 8.04 | 0 | 5.64 | 8.39 | 645.36 | 18.79 | 3.89 | 1.30 | 52.27 | 0 | 76.86 | 838.71 | 110.50 | 803.68 | 98735 |
| 149 | 16.10 | 11.17 | 3.28 | 5.15 | 7.69 | 586.56 | 17.60 | 2.62 | 1.75 | 51.74 | 0 | 73.84 | 813.68 | 102.45 | 800.66 | 99462 |
| 150 | 16.11 | 11.04 | 0 | 8.18 | 9.80 | 783.21 | 21.61 | 4.14 | 1.46 | 62.49 | 0 | 83.99 | 927.75 | 115.66 | 782.51 | 83579 |
| 151 | 16.11 | 8.58 | 1.56 | 5.27 | 7.55 | 596.75 | 17.20 | 3.13 | 2.16 | 49.96 | 0 | 70.80 | 823.13 | 106.12 | 811.89 | 109023 |
| 152 | 16.12 | 7.06 | .60 | 4.87 | 7.47 | 554.94 | 14.84 | 3.16 | 1.57 | 48.32 | 0 | 69.06 | 767.14 | 100.33 | 811.15 | 114517 |
| 153 | 16.13 | 8.09 | 0 | 5.11 | 7.51 | 615.33 | 17.44 | 2.15 | 1.82 | 52.88 | 0 | 75.33 | 825.18 | 105.53 | 821.68 | 123852 |
| 154 | 17.01 | 8.62 | 0 | 5.49 | 7.64 | 635.39 | 19.14 | 4.43 | 1.25 | 50.90 | 0 | 74.51 | 800.81 | 104.83 | 827.04 | 87049 |
| 155 | 17.02 | 10.95 | 2.66 | 9.31 | 8.39 | 732.63 | 21.22 | 4.47 | 1.98 | 54.28 | 0 | 80.90 | 867.70 | 108.57 | 832.92 | 106753 |

## EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE COMPTON PEAK (PK/COMP * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Compton Pk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156 | 17.03 | 7.76 | 0 | 4.55 | 7.46 | 557.54 | 15.57 | 2.62 | 2.37 | 46.81 | 0 | 68.93 | 775.36 | 100.65 | 841.54 | 133229 |
| 157 | 17.04 | 15.72 | 3.62 | 7.59 | 10.79 | 807.47 | 24.42 | 4.20 | 2.91 | 63.38 | 0 | 85.26 | 924.88 | 115.86 | 819.35 | 85006 |
| 158 | 17.04 | 11.59 | 2.66 | 4.44 | 8.20 | 655.92 | 19.14 | 3.54 | 1.78 | 53.09 | 0 | 73.02 | 833.40 | 105.88 | 815.18 | 92633 |
| 159 | 17.05 | 7.96 | 0 | 4.96 | 8.11 | 582.04 | 17.65 | 4.06 | 2.27 | 47.71 | 0 | 67.84 | 776.99 | 96.62 | 852.69 | 128135 |
| 160 | 17.06 | 11.31 | 2.18 | 5.61 | 8.34 | 605.24 | 16.44 | 3.57 | 1.48 | 51.14 | 0 | 71.53 | 800.94 | 103.81 | 820.60 | 115789 |
| 161 | 17.07 | 10.53 | 2.96 | 5.89 | 7.98 | 637.65 | 19.40 | 3.68 | 2.55 | 52.28 | 0 | 73.69 | 817.44 | 101.67 | 824.50 | 100227 |
| 162 | 17.08 | 9.54 | 0 | 4.78 | 7.72 | 625.82 | 18.20 | 3.86 | 0 | 51.37 | 0 | 72.43 | 810.03 | 103.90 | 817.42 | 103465 |
| 163 | 17.09 | 8.09 | 0 | 3.56 | 6.61 | 559.80 | 17.26 | 3.23 | 2.69 | 48.84 | 0 | 69.86 | 782.20 | 101.53 | 830.29 | 112772 |
| 164 | 18.01 | 7.76 | 0 | 1.78 | 3.86 | 250.67 | 12.55 | 2.87 | 3.13 | 76.30 | 0 | 71.77 | 823.06 | 118.09 | 770.84 | 133283 |
| 165 | 18.02 | 6.70 | 0 | 2.05 | 3.33 | 257.49 | 12.90 | 2.15 | 2.46 | 76.18 | 0 | 72.45 | 813.65 | 118.62 | 777.87 | 129909 |
| 166 | 18.03 | 6.84 | 0 | 2.12 | .96 | 256.10 | 12.57 | 1.41 | 2.49 | 79.27 | 0 | 75.72 | 842.11 | 121.97 | 750.11 | 135611 |
| 167 | 18.04 | 6.27 | 0 | 1.79 | 3.79 | 260.10 | 13.26 | 2.67 | 3.73 | 77.00 | 0 | 74.53 | 849.40 | 125.00 | 733.58 | 128797 |
| 168 | 18.05 | 6.21 | 0 | 1.50 | 3.32 | 260.48 | 12.90 | 2.61 | 3.19 | 77.15 | 0 | 73.36 | 828.48 | 123.88 | 776.05 | 128187 |
| 169 | 18.06 | 6.19 | 0 | 2.88 | 2.87 | 243.51 | 12.73 | 2.78 | 3.09 | 77.66 | 0 | 69.68 | 817.03 | 121.14 | 759.60 | 131084 |
| 170 | 18.07 | 8.96 | 0 | 2.02 | 3.56 | 308.05 | 17.82 | 5.20 | 3.73 | 90.06 | 0 | 82.05 | 910.54 | 132.17 | 760.69 | 105015 |
| 171 | 18.08 | 7.81 | 0 | 1.77 | 3.55 | 281.72 | 13.67 | 3.18 | 3.43 | 79.26 | 1.29 | 75.06 | 837.92 | 122.06 | 776.86 | 121253 |
| 172 | 19.01 | 7.23 | 0 | 3.13 | 5.06 | 460.43 | 17.29 | 3.68 | 2.35 | 57.91 | 0 | 80.88 | 962.69 | 113.64 | 850.28 | 138154 |
| 173 | 19.02 | 6.73 | 0 | 4.55 | 5.91 | 500.21 | 16.92 | 2.45 | 1.26 | 65.21 | 0 | 85.02 | 1049.01 | 123.80 | 812.08 | 128026 |
| 174 | 19.03 | 9.48 | 3.25 | 3.50 | 6.08 | 501.69 | 17.92 | 3.14 | 3.52 | 61.34 | 0 | 82.99 | 1004.19 | 120.31 | 818.06 | 125176 |
| 175 | 19.04 | 8.25 | 0 | 3.90 | 6.69 | 493.64 | 17.96 | 3.00 | 2.58 | 58.88 | 0 | 83.77 | 991.81 | 119.09 | 809.83 | 110505 |
| 176 | 19.05 | 9.19 | 2.24 | 4.23 | 5.37 | 502.88 | 18.31 | 3.41 | 2.68 | 61.41 | 0 | 85.76 | 1031.96 | 125.64 | 812.19 | 125199 |
| 177 | 20.01 | 6.29 | 0 | 4.99 | 7.90 | 566.91 | 18.77 | 3.24 | 2.78 | 58.60 | 0 | 81.00 | 943.49 | 116.33 | 817.80 | 122842 |
| 178 | 20.02 | 6.74 | 0 | 4.66 | 6.69 | 558.30 | 18.36 | 3.40 | 2.80 | 57.58 | 0 | 81.09 | 939.92 | 116.10 | 835.76 | 123947 |
| 179 | 20.03 | 7.88 | 0 | 4.73 | 6.57 | 531.81 | 17.37 | 3.17 | 0 | 53.97 | 0 | 77.49 | 897.12 | 113.91 | 843.02 | 126850 |
| 180 | 20.04 | 10.51 | 0 | 5.08 | 8.57 | 707.72 | 23.09 | 5.45 | 3.71 | 68.67 | 0 | 94.49 | 1051.09 | 128.36 | 812.37 | 75750 |
| 181 | 20.04 | 9.30 | 0 | 4.50 | 7.85 | 581.54 | 18.10 | 0 | 1.65 | 59.52 | 0 | 79.80 | 919.88 | 114.55 | 793.47 | 75695 |
| 182 | 20.05 | 9.11 | 0 | 4.99 | 7.13 | 592.22 | 17.57 | 2.84 | 2.54 | 59.19 | 1.53 | 85.01 | 966.48 | 121.23 | 802.45 | 95522 |
| 183 | 21.01 | 8.96 | 1.21 | 2.63 | 1.62 | 251.38 | 12.59 | 2.25 | 2.89 | 79.41 | 0 | 73.94 | 809.51 | 121.27 | 777.83 | 130203 |
| 184 | 21.02 | 7.79 | 0 | 2.69 | 3.38 | 284.57 | 15.30 | 3.03 | 3.52 | 86.12 | 0 | 78.32 | 880.12 | 126.31 | 752.45 | 110201 |
| 185 | 21.03 | 7.46 | 0 | 1.86 | 3.65 | 260.61 | 13.19 | 1.79 | 2.78 | 80.68 | 0 | 74.80 | 844.57 | 123.55 | 758.09 | 124324 |
| 186 | 21.04 | 6.71 | 0 | 2.12 | 3.03 | 254.86 | 13.53 | 3.05 | 2.27 | 75.38 | 0 | 69.00 | 743.51 | 114.70 | 745.84 | 125715 |
| 187 | 22.01 | 7.10 | 0 | 1.51 | 4.64 | 272.85 | 14.30 | 2.88 | 2.63 | 82.67 | 0 | 76.53 | 872.54 | 127.33 | 762.78 | 130767 |
| 188 | 22.02 | 6.32 | 0 | 2.72 | 2.54 | 281.94 | 13.49 | 1.50 | 3.08 | 83.54 | 0 | 77.19 | 859.64 | 125.24 | 774.17 | 128077 |
| 189 | 22.03 | 7.00 | 0 | 1.83 | 2.30 | 250.86 | 12.34 | 2.84 | 4.18 | 77.73 | 0 | 71.97 | 829.64 | 118.67 | 776.61 | 147052 |
| 190 | 22.04 | 8.01 | 0 | 1.82 | 2.54 | 268.92 | 13.68 | 2.79 | 2.94 | 79.83 | 0 | 73.66 | 863.62 | 126.31 | 767.69 | 133160 |
| 191 | 22.05 | 7.07 | 1.67 | 2.60 | 3.51 | 280.87 | 14.81 | 3.86 | 3.35 | 85.26 | 0 | 78.23 | 894.03 | 129.41 | 754.35 | 137467 |
| 192 | 22.06 | 6.78 | 0 | 3.34 | 2.88 | 274.20 | 14.08 | 3.25 | 2.64 | 83.46 | 1.15 | 76.27 | 869.74 | 126.59 | 746.96 | 127970 |
| 193 | 22.07 | 6.15 | 0 | 0 | 2.74 | 286.45 | 16.05 | 3.34 | 2.30 | 88.43 | 0 | 79.31 | 881.47 | 126.95 | 758.95 | 93106 |
| 194 | 22.08 | 8.04 | 1.23 | 1.45 | 4.26 | 278.18 | 14.83 | 3.71 | 2.47 | 83.69 | .78 | 74.83 | 855.97 | 122.52 | 755.83 | 105938 |
| 195 | 22.09 | 8.24 | 0 | 2.25 | 4.52 | 327.01 | 17.65 | 4.41 | 4.07 | 90.82 | 0 | 80.62 | 927.50 | 131.04 | 740.84 | 119353 |
| 196 | 22.10 | 7.02 | 0 | 2.60 | 2.51 | 283.09 | 14.51 | 2.78 | 3.05 | 84.86 | 0 | 77.79 | 862.19 | 124.72 | 755.07 | 95095 |
| 197 | 22.11 | 9.84 | 1.87 | 1.55 | 2.97 | 273.46 | 12.62 | 3.75 | 3.29 | 81.40 | 0 | 72.90 | 848.86 | 125.48 | 776.75 | 143604 |
| 198 | 22.12 | 6.82 | 0 | 2.72 | 3.59 | 268.67 | 14.64 | 3.30 | 3.52 | 83.91 | 0 | 74.97 | 856.69 | 122.86 | 758.81 | 136338 |
| 199 | 22.13 | 7.88 | 1.72 | 1.83 | 3.56 | 248.19 | 13.29 | 2.55 | 3.59 | 79.14 | 1.55 | 72.75 | 834.35 | 123.18 | 757.42 | 146701 |
| 200 | 22.14 | 6.12 | 0 | 0 | 3.42 | 254.99 | 13.00 | 2.98 | 2.85 | 77.71 | 0 | 73.32 | 833.62 | 118.98 | 763.71 | 146830 |
| 201 | 22.15 | 7.51 | 0 | 1.41 | 3.32 | 240.65 | 12.91 | 2.76 | 3.20 | 73.87 | 0 | 69.94 | 810.11 | 118.54 | 787.34 | 151337 |
| 202 | 23.01 | 7.54 | 0 | 2.01 | 3.72 | 259.90 | 13.09 | 2.70 | 2.85 | 81.36 | 0 | 75.48 | 842.97 | 124.86 | 754.78 | 132627 |
| 203 | 23.02 | 7.34 | 0 | 0 | 3.78 | 261.43 | 15.63 | 3.37 | 2.48 | 76.36 | 0 | 72.51 | 837.89 | 119.89 | 785.67 | 144052 |
| 204 | 23.03 | 6.31 | 0 | 1.59 | 3.21 | 259.34 | 15.08 | 4.72 | 3.21 | 81.61 | 0 | 71.95 | 822.46 | 120.54 | 770.17 | 141284 |
| 205 | 23.04 | 6.72 | 0 | 1.67 | 3.06 | 255.91 | 13.37 | 3.20 | 2.43 | 75.72 | 0 | 72.54 | 812.26 | 119.12 | 773.97 | 139856 |
| 206 | 23.05 | 7.19 | 0 | 2.29 | 3.36 | 272.48 | 14.61 | 3.94 | 3.21 | 79.68 | 0 | 72.31 | 849.36 | 124.15 | 764.60 | 136927 |

# APPENDIX E

## EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE ZR PEAK (PK/ZR * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Zr peak |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.01 | 8.16 | 0 | 5.11 | 8.66 | 602.55 | 24.34 | 3.77 | 3.90 | 63.45 | 0 | 88.17 | 1000 | 122.89 | 824.01 | 94150 |
| 2 | 1.02 | 10.55 | 3.89 | 6.83 | 8.70 | 743.94 | 22.17 | 4.55 | 3.38 | 61.50 | 0 | 87.82 | 1000 | 128.72 | 1026.51 | 79630 |
| 3 | 1.03 | 7.94 | 0 | 0 | 3.85 | 306.73 | 16.36 | 5.25 | 4.20 | 92.59 | 0 | 87.31 | 1000 | 146.61 | 933.96 | 80690 |
| 4 | 1.04 | 6.25 | 0 | 2.83 | 3.60 | 282.74 | 14.62 | 3.41 | 2.84 | 84.15 | 0 | 79.67 | 1000 | 135.21 | 827.35 | 101400 |
| 5 | 1.05 | 13.91 | 0 | 3.38 | 4.27 | 407.74 | 19.39 | 4.73 | 3.40 | 153.35 | 6.29 | 150.27 | 1000 | 253.16 | 1369.40 | 64110 |
| 6 | 1.06 | 8.53 | 0 | 2.90 | 3.65 | 301.88 | 15.43 | 2.99 | 3.29 | 96.72 | 0 | 91.14 | 1000 | 150.44 | 933.47 | 90600 |
| 7 | 1.07 | 12.63 | 0 | 0 | 3.36 | 426.50 | 21.05 | 5.21 | 5.24 | 156.75 | 6.55 | 151.22 | 1000 | 249.74 | 1426.77 | 57820 |
| 8 | 1.09 | 18.75 | 3.50 | 2.87 | 6.61 | 454.23 | 20.35 | 5.37 | 4.47 | 155.09 | 5.54 | 148.51 | 1000 | 248.42 | 1330.61 | 52230 |
| 9 | 1.10 | 8.47 | 0 | 2.01 | 4.91 | 319.34 | 16.36 | 1.91 | 3.80 | 96.06 | 0 | 86.33 | 1000 | 147.19 | 950.77 | 78130 |
| 10 | 1.12 | 9.66 | 0 | 6.59 | 9.15 | 733.82 | 21.69 | 4.68 | 2.12 | 60.66 | 0 | 89.19 | 1000 | 130.68 | 1020.08 | 95500 |
| 11 | 1.13 | 8.61 | 0 | 0 | 4.21 | 329.32 | 17.95 | 4.84 | 5.82 | 160.83 | 0 | 113.22 | 1000 | 199.12 | 1066.97 | 91400 |
| 12 | 1.14 | 15.96 | 4.67 | 3.67 | 3.52 | 427.48 | 19.48 | 4.28 | 3.37 | 150.76 | 5.37 | 148.05 | 1000 | 250.71 | 1382.68 | 66530 |
| 13 | 1.14 | 10.62 | 0 | 3.45 | 4.45 | 396.42 | 18.94 | 3.97 | 2.96 | 157.06 | 5.04 | 147.89 | 1000 | 254.40 | 1480.28 | 66470 |
| 14 | 1.15 | 10.69 | 3.36 | 4.71 | 6.66 | 637.74 | 24.45 | 3.05 | 3.07 | 64.70 | 0 | 88.26 | 1000 | 120.12 | 627.25 | 74670 |
| 15 | 1.16 | 7.81 | 0 | 2.30 | 3.86 | 313.18 | 16.21 | 4.37 | 3.68 | 93.36 | 0 | 87.35 | 1000 | 145.05 | 915.50 | 107000 |
| 16 | 1.15 | 7.06 | 2.11 | 3.82 | 6.63 | 513.38 | 20.10 | 2.33 | 2.54 | 57.27 | 0 | 87.34 | 1000 | 124.65 | 728.54 | 142000 |
| 17 | 1.16 | 12.46 | 2.23 | 2.12 | 4.19 | 345.54 | 17.86 | 4.28 | 3.21 | 98.78 | 0 | 89.86 | 1000 | 145.25 | 882.87 | 94460 |
| 18 | 1.17 | 10.13 | 0 | 2.54 | 5.56 | 340.60 | 19.05 | 5.27 | 2.04 | 99.09 | 0 | 86.87 | 1000 | 144.75 | 875.70 | 55960 |
| 19 | 1.18 | 18.86 | 1.83 | 0 | 4.57 | 446.58 | 31.59 | 5.56 | 14.14 | 362.28 | 0 | 222.05 | 1000 | 378.50 | 1771.11 | 47450 |
| 20 | 1.17 | 9.79 | 0 | 3.14 | 4.57 | 350.83 | 19.14 | 4.77 | 4.33 | 101.67 | 0 | 86.93 | 1000 | 142.26 | 820.44 | 80980 |
| 21 | 1.18 | 15.71 | 0 | 3.15 | 3.50 | 423.93 | 33.31 | 4.24 | 14.50 | 355.44 | 0 | 224.50 | 1000 | 387.10 | 2024.23 | 50220 |
| 22 | 1.19 | 7.61 | 0 | 4.09 | 9.20 | 652.13 | 23.11 | 3.06 | 2.46 | 58.95 | 1.07 | 90.31 | 1000 | 131.17 | 597.27 | 131200 |
| 23 | 1.19 | 8.06 | 2.81 | 4.04 | 6.84 | 590.67 | 19.98 | 2.90 | 2.61 | 55.15 | 0 | 90.15 | 1000 | 136.78 | 705.10 | 129345 |
| 24 | 1.20 | 7.83 | 0 | 4.99 | 6.64 | 634.75 | 20.77 | 3.81 | 3.18 | 54.67 | 0 | 90.31 | 1000 | 137.82 | 769.16 | 117400 |
| 25 | 1.21 | 9.02 | 0 | 1.65 | 2.38 | 302.46 | 17.37 | 0 | 5.40 | 151.18 | 0 | 112.20 | 1000 | 194.98 | 1122.90 | 99550 |
| 26 | 1.20 | 6.96 | 0 | 4.98 | 8.04 | 613.01 | 20.08 | 2.69 | 3.16 | 55.67 | 0 | 88.73 | 1000 | 136.07 | 814.65 | 125300 |
| 27 | 1.21 | 11.15 | 0 | 2.19 | 4.51 | 379.05 | 20.73 | 5.07 | 6.07 | 172.52 | 0 | 112.81 | 1000 | 190.14 | 892.33 | 81730 |
| 28 | 1.22 | 10.53 | 0 | 2.46 | 5.23 | 402.73 | 21.41 | 7.17 | 1.81 | 153.71 | 7.26 | 148.75 | 1000 | 248.61 | 1417.52 | 73970 |
| 29 | 1.23 | 3.48 | 0 | 1.48 | 5.09 | 363.68 | 16.93 | 1.11 | 2.82 | 46.38 | 1.14 | 80.58 | 1000 | 140.41 | 363.33 | 254400 |
| 30 | 1.22 | 12.01 | 0 | 3.87 | 3.99 | 412.67 | 19.60 | 5.63 | 3.33 | 154.72 | 6.94 | 148.55 | 1000 | 250.16 | 1315.00 | 91260 |
| 31 | 1.23 | 4.24 | 0 | 1.69 | 4.67 | 361.86 | 15.94 | .73 | 2.93 | 46.71 | 1.82 | 87.59 | 1000 | 128.74 | 372.58 | 262700 |
| 32 | 1.24 | 5.28 | 0 | 2.84 | 6.68 | 509.89 | 19.28 | 3.11 | 3.15 | 53.57 | 0 | 87.31 | 1000 | 133.51 | 599.05 | 171900 |
| 33 | 1.25 | 8.42 | 0 | 2.66 | 3.78 | 306.06 | 16.21 | 2.78 | 3.62 | 94.98 | 0 | 87.19 | 1000 | 149.57 | 929.08 | 115600 |
| 34 | 1.24 | 6.75 | 1.89 | 1.88 | 6.52 | 518.80 | 19.42 | 2.46 | 2.36 | 52.29 | 0 | 89.19 | 1000 | 133.47 | 589.72 | 169700 |
| 35 | 1.25 | 8.29 | 0 | 2.12 | 3.38 | 315.12 | 16.18 | 4.06 | 2.99 | 92.97 | 0 | 88.33 | 1000 | 143.33 | 930.31 | 112400 |
| 36 | 1.26 | 7.02 | 0 | 4.11 | 4.71 | 490.72 | 17.85 | 3.76 | 2.71 | 62.55 | 1.15 | 83.01 | 1000 | 121.51 | 824.68 | 128300 |
| 37 | 1.27 | 6.95 | 0 | 3.67 | 5.60 | 542.82 | 21.47 | 3.36 | 3.34 | 60.67 | 0 | 88.06 | 1000 | 125.05 | 674.29 | 138500 |
| 38 | 1.26 | 7.38 | 0 | 4.10 | 6.53 | 506.06 | 17.94 | 2.42 | 2.52 | 60.65 | 0 | 84.35 | 1000 | 120.32 | 753.94 | 130400 |
| 39 | 1.27 | 7.72 | 0 | 4.03 | 5.58 | 556.29 | 22.34 | 3.28 | 3.29 | 59.57 | 0 | 88.28 | 1000 | 126.01 | 670.16 | 116900 |
| 40 | 1.28 | 8.07 | 0 | 2.28 | 4.44 | 315.66 | 16.16 | 3.39 | 2.64 | 96.45 | 0 | 89.90 | 1000 | 147.84 | 925.66 | 104100 |
| 41 | 1.29 | 8.44 | 1.67 | 2.98 | 3.56 | 310.46 | 16.16 | 2.75 | 4.49 | 98.08 | 0 | 90.48 | 1000 | 148.18 | 970.06 | 104200 |
| 42 | 1.28 | 8.30 | 0 | 1.75 | 3.65 | 300.89 | 15.36 | 2.47 | 4.12 | 93.42 | 0 | 85.59 | 1000 | 144.31 | 919.46 | 112400 |
| 43 | 1.29 | 8.76 | 0 | 3.83 | 3.96 | 330.01 | 16.58 | 2.47 | 3.96 | 99.96 | 0 | 90.61 | 1000 | 146.77 | 901.74 | 76240 |
| 44 | 1.30 | 32.37 | 0 | 0 | 0 | 589.42 | 59.29 | 19.95 | 33.71 | 1122.53 | 0 | 533.72 | 1000 | 913.59 | 4611.01 | 23260 |
| 45 | 1.31 | 38.02 | 0 | 7.16 | 7.64 | 596.35 | 66.02 | 18.62 | 41.97 | 1177.95 | 0 | 536.45 | 1000 | 914.50 | 4161.50 | 23040 |
| 46 | 1.30 | 41.75 | 15.53 | 0 | 0 | 584.21 | 62.17 | 12.70 | 42.23 | 1150.96 | 0 | 540.08 | 1000 | 921.03 | 4600.96 | 22920 |
| 47 | 1.31 | 27.92 | 0 | 0 | 0 | 570.20 | 63.65 | 15.96 | 40.07 | 1146.13 | 0 | 527.38 | 1000 | 903.40 | 4493.16 | 24430 |
| 48 | 1.32 | 15.29 | 3.55 | 4.05 | 4.46 | 439.12 | 20.58 | 5.80 | 3.38 | 154.95 | 6.10 | 148.86 | 1000 | 243.53 | 1290.76 | 68410 |
| 49 | 1.33 | 10.25 | 2.43 | 4.38 | 7.71 | 617.12 | 21.24 | 3.69 | 1.42 | 62.34 | 0 | 88.27 | 1000 | 125.82 | 814.37 | 103400 |
| 50 | 1.32 | 16.57 | 3.01 | 4.25 | 4.37 | 472.08 | 22.75 | 7.07 | 3.93 | 164.94 | 6.93 | 152.40 | 1000 | 254.48 | 1232.88 | 58550 |

## EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE ZR PEAK (PK/ZR * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Zr peak |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 1.33 | 9.30 | 1.63 | 4.79 | 8.02 | 576.57 | 18.00 | 2.72 | 2.33 | 60.05 | 0 | 84.08 | 1000 | 125.80 | 897.17 | 109700 |
| 52 | 1.34 | 8.36 | 0 | 2.18 | 3.21 | 298.52 | 15.30 | 2.08 | 3.66 | 93.52 | 0 | 87.80 | 1000 | 148.82 | 954.59 | 101400 |
| 53 | 1.34 | 8.82 | 1.49 | 1.88 | 4.73 | 309.32 | 13.93 | 1.66 | 4.10 | 95.53 | 0 | 88.19 | 1000 | 145.85 | 900.62 | 107300 |
| 54 | 1.35 | 18.39 | 0 | 0 | 4.26 | 485.87 | 34.61 | 10.16 | 12.96 | 377.58 | 0 | 235.43 | 1000 | 389.33 | 1867.20 | 31490 |
| 55 | 1.36 | 10.81 | 2.24 | 2.03 | 3.78 | 323.86 | 16.50 | 3.81 | 4.34 | 95.62 | 0 | 82.14 | 1000 | 161.44 | 892.37 | 102700 |
| 56 | 1.35 | 17.09 | 0 | 0 | 3.90 | 417.39 | 32.68 | 10.20 | 13.02 | 357.16 | 0 | 228.75 | 1000 | 388.55 | 2065.13 | 47150 |
| 57 | 1.36 | 7.99 | 0 | 2.37 | 3.87 | 315.76 | 16.32 | 4.82 | 3.37 | 94.77 | 0 | 90.49 | 1000 | 145.30 | 909.69 | 105300 |
| 58 | 1.37 | 8.21 | 0 | 2.42 | 4.75 | 313.94 | 17.03 | 2.08 | 3.32 | 94.67 | 0 | 88.66 | 1000 | 148.67 | 861.67 | 112600 |
| 59 | 1.38 | 7.64 | 0 | 2.02 | 4.34 | 319.58 | 14.84 | 1.92 | 4.64 | 95.24 | 0 | 86.85 | 1000 | 145.38 | 897.77 | 95750 |
| 60 | 1.37 | 8.31 | .92 | 3.50 | 4.12 | 313.85 | 16.52 | 3.22 | 3.45 | 95.70 | 0 | 86.36 | 1000 | 145.46 | 938.16 | 104700 |
| 61 | 1.38 | 6.33 | 0 | 2.00 | 4.39 | 346.32 | 18.23 | 3.84 | 3.88 | 96.84 | 0 | 90.50 | 1000 | 146.17 | 842.32 | 93180 |
| 62 | 1.11 | 9.61 | 0 | 5.95 | 7.75 | 767.86 | 20.97 | 4.07 | 2.20 | 65.94 | 0 | 88.61 | 1000 | 129.03 | 1017.68 | 74480 |
| 63 | 1.11 | 19.41 | 5.54 | 8.08 | 15.41 | 1071.25 | 30.11 | 4.77 | 2.92 | 72.25 | 0 | 89.96 | 1000 | 121.02 | 831.27 | 53470 |
| 64 | 2.01 | 8.03 | 0 | 5.43 | 7.84 | 676.92 | 22.77 | 2.08 | 3.28 | 55.47 | 0 | 89.40 | 1000 | 133.61 | 749.81 | 94900 |
| 65 | 2.02 | 6.83 | 0 | 3.58 | 5.88 | 485.73 | 16.47 | 3.30 | 1.65 | 61.36 | .63 | 82.24 | 1000 | 122.18 | 822.08 | 110000 |
| 66 | 2.03 | 6.90 | 0 | 4.83 | 7.79 | 624.07 | 20.07 | 2.72 | 2.53 | 56.60 | 0 | 89.83 | 1000 | 139.54 | 785.30 | 104700 |
| 67 | 2.04 | 8.67 | 0 | 6.01 | 7.36 | 671.87 | 22.07 | 3.29 | 2.60 | 56.26 | 0 | 88.55 | 1000 | 139.28 | 719.14 | 58940 |
| 68 | 2.04 | 8.36 | 0 | 4.55 | 7.14 | 647.79 | 22.40 | 4.27 | 3.24 | 57.98 | 0 | 88.27 | 1000 | 134.93 | 710.22 | 96790 |
| 69 | 2.05 | 8.41 | 3.29 | 6.05 | 7.52 | 633.76 | 21.23 | 4.22 | 3.29 | 57.26 | 0 | 89.62 | 1000 | 141.66 | 750.35 | 97560 |
| 70 | 2.06 | 8.03 | 0 | 5.06 | 7.10 | 634.33 | 21.13 | 3.41 | 2.67 | 56.52 | 0 | 89.18 | 1000 | 138.02 | 735.83 | 92160 |
| 71 | 2.07 | 10.68 | 0 | 5.90 | 10.09 | 680.35 | 28.32 | 3.89 | 2.89 | 56.04 | 0 | 93.41 | 1000 | 135.14 | 741.43 | 59190 |
| 72 | 2.08 | 8.17 | 0 | 5.53 | 7.64 | 710.04 | 22.47 | 4.13 | 2.97 | 59.31 | 0 | 90.45 | 1000 | 137.09 | 740.07 | 76010 |
| 73 | 2.09 | 9.13 | 0 | 5.15 | 8.54 | 734.84 | 24.39 | 4.38 | 2.67 | 58.94 | 0 | 94.12 | 1000 | 132.99 | 724.20 | 65960 |
| 74 | 2.10 | 10.41 | 0 | 4.09 | 8.55 | 650.51 | 21.32 | 3.27 | 3.02 | 57.10 | 0 | 90.85 | 1000 | 139.08 | 793.75 | 65810 |
| 75 | 2.11 | 7.78 | 0 | 6.39 | 9.46 | 697.68 | 22.49 | 3.42 | 3.01 | 58.36 | 0 | 92.08 | 1000 | 135.85 | 753.33 | 75450 |
| 76 | 2.12 | 7.29 | 0 | 5.61 | 8.06 | 629.53 | 20.36 | 3.15 | 3.34 | 58.00 | 0 | 89.30 | 1000 | 139.01 | 783.97 | 103300 |
| 77 | 2.13 | 9.48 | 0 | 6.06 | 8.90 | 706.81 | 20.45 | 0 | 2.62 | 57.15 | 0 | 90.83 | 1000 | 139.47 | 781.06 | 69920 |
| 78 | 2.14 | 3.25 | 0 | 1.66 | 5.25 | 402.69 | 17.28 | .86 | 3.40 | 49.05 | 0 | 86.12 | 1000 | 132.35 | 375.60 | 156400 |
| 79 | 2.15 | 12.45 | 3.53 | 5.40 | 8.60 | 661.12 | 22.18 | 3.42 | 2.82 | 58.12 | 0 | 90.29 | 1000 | 141.12 | 794.40 | 78730 |
| 80 | 2.16 | 9.06 | 1.65 | 4.96 | 7.45 | 634.56 | 21.06 | 3.04 | 3.03 | 56.80 | .54 | 89.21 | 1000 | 135.53 | 788.76 | 103300 |
| 81 | 2.17 | 9.36 | 2.63 | 4.72 | 8.31 | 633.43 | 20.98 | 2.31 | 3.37 | 56.13 | 0 | 91.61 | 1000 | 137.40 | 728.29 | 78020 |
| 82 | 2.18 | 4.04 | 0 | 2.01 | 4.70 | 364.25 | 16.50 | .86 | 2.95 | 48.09 | 0 | 88.31 | 1000 | 132.12 | 411.74 | 113000 |
| 83 | 2.18 | 4.59 | 0 | 1.99 | 5.38 | 431.61 | 19.87 | 2.26 | 3.07 | 50.88 | 1.42 | 88.03 | 1000 | 128.26 | 321.46 | 209100 |
| 84 | 2.19 | 6.23 | 0 | 5.44 | 7.71 | 667.13 | 21.34 | 4.49 | 3.42 | 55.81 | 0 | 94.36 | 1000 | 133.23 | 779.39 | 50560 |
| 85 | 2.19 | 8.91 | 0 | 5.76 | 9.69 | 756.74 | 24.75 | 4.14 | 3.64 | 61.45 | 0 | 91.06 | 1000 | 134.60 | 709.51 | 87890 |
| 86 | 2.20 | 9.69 | 2.49 | 5.00 | 8.17 | 700.13 | 22.57 | 2.92 | 3.07 | 57.74 | 0 | 91.07 | 1000 | 138.62 | 739.70 | 60560 |
| 87 | 3.01 | 9.94 | 0 | 2.83 | 3.84 | 326.01 | 17.64 | 0 | 3.97 | 96.29 | 0 | 88.71 | 1000 | 149.51 | 976.10 | 59630 |
| 88 | 3.02 | 9.82 | 4.19 | 9.70 | 20.86 | 963.19 | 17.37 | 3.01 | 1.99 | 56.93 | 0 | 84.57 | 1000 | 165.29 | 755.72 | 114100 |
| 89 | 3.03 | 6.77 | 0 | 0 | 3.94 | 317.82 | 16.32 | 3.37 | 3.79 | 96.06 | 0 | 88.90 | 1000 | 148.21 | 887.45 | 96690 |
| 90 | 3.04 | 9.09 | 2.93 | 8.89 | 22.07 | 1061.96 | 22.10 | 3.00 | 2.23 | 58.64 | 0 | 89.95 | 1000 | 162.51 | 738.72 | 89410 |
| 91 | 3.05 | 14.13 | 4.96 | 10.54 | 23.13 | 1113.34 | 20.09 | 3.35 | 2.51 | 57.19 | 0 | 85.04 | 1000 | 164.77 | 750.78 | 57880 |
| 92 | 3.05 | 11.16 | 3.49 | 11.14 | 23.21 | 1120.72 | 19.17 | 2.69 | 2.98 | 61.69 | 0 | 85.17 | 1000 | 161.57 | 672.46 | 60140 |
| 93 | 3.06 | 5.98 | 0 | 1.77 | 0 | 302.43 | 16.71 | 4.05 | 3.04 | 98.01 | 0 | 92.19 | 1000 | 146.22 | 931.94 | 68180 |
| 94 | 3.07 | 10.44 | 4.40 | 7.04 | 22.15 | 1035.34 | 17.07 | 3.07 | 2.99 | 57.30 | 0 | 83.77 | 1000 | 164.53 | 733.04 | 91110 |
| 95 | 3.08 | 9.57 | 4.66 | 8.17 | 18.81 | 996.41 | 18.77 | 3.96 | 2.38 | 56.36 | 0 | 85.89 | 1000 | 164.47 | 734.00 | 94790 |
| 96 | 3.09 | 10.61 | 0 | 3.21 | 6.08 | 382.06 | 20.42 | 4.17 | 3.56 | 98.31 | 0 | 88.74 | 1000 | 140.29 | 823.62 | 62870 |
| 97 | 3.10 | 10.52 | 0 | 3.52 | 4.74 | 349.31 | 17.78 | 4.22 | 3.78 | 96.67 | 0 | 89.10 | 1000 | 144.95 | 920.43 | 57600 |
| 98 | 3.11 | 9.31 | 0 | 2.48 | 5.13 | 333.10 | 17.68 | 4.15 | 3.64 | 95.49 | 0 | 88.22 | 1000 | 146.42 | 826.57 | 84960 |
| 99 | 3.12 | 9.90 | 0 | 2.38 | 5.06 | 323.85 | 17.08 | 3.81 | 3.77 | 100.25 | 0 | 87.42 | 1000 | 148.45 | 826.03 | 86830 |
| 100 | 3.13 | 10.51 | 4.80 | 6.38 | 19.36 | 994.22 | 17.29 | 3.38 | 1.83 | 58.67 | 0 | 84.01 | 1000 | 162.85 | 718.30 | 100400 |

EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE ZR PEAK (PK/ZR * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Zr peak |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 3.14 | 8.44 | 3.70 | 8.11 | 20.45 | 1037.87 | 18.41 | 2.99 | 2.81 | 58.41 | 0 | 86.76 | 1000 | 163.07 | 740.84 | 93210 |
| 102 | 3.15 | 7.27 | 0 | 5.32 | 8.01 | 594.04 | 20.49 | 4.10 | 2.34 | 55.01 | 0 | 91.94 | 1000 | 140.34 | 764.40 | 110800 |
| 103 | 3.16 | 11.78 | 5.11 | 9.49 | 24.14 | 1147.25 | 20.73 | 3.74 | 2.40 | 61.50 | 0 | 84.91 | 1000 | 162.82 | 711.17 | 54600 |
| 104 | 3.17 | 9.49 | 0 | 3.72 | 5.29 | 350.47 | 19.31 | 4.05 | 3.26 | 92.46 | 0 | 87.97 | 1000 | 144.24 | 879.92 | 47850 |
| 105 | 3.18 | 11.35 | 0 | 3.72 | 3.60 | 339.64 | 18.36 | 3.54 | 3.80 | 105.24 | 0 | 85.73 | 1000 | 145.32 | 899.53 | 66070 |
| 106 | 3.19 | 4.04 | 0 | 2.12 | 5.21 | 389.16 | 17.99 | 1.92 | 2.99 | 47.95 | 1.03 | 88.29 | 1000 | 127.50 | 338.83 | 201100 |
| 107 | 3.20 | 8.74 | 0 | 3.00 | 5.10 | 337.45 | 18.33 | 3.75 | 3.68 | 94.04 | 0 | 86.64 | 1000 | 144.88 | 853.59 | 77790 |
| 108 | 3.21 | 10.61 | 4.62 | 9.66 | 19.98 | 1021.74 | 17.39 | 2.23 | 1.92 | 57.96 | 0 | 83.29 | 1000 | 160.24 | 750.72 | 110400 |
| 109 | 3.22 | 9.84 | 3.84 | 7.61 | 20.10 | 984.67 | 17.49 | 2.24 | 2.80 | 57.42 | 0 | 83.24 | 1000 | 165.42 | 708.41 | 104400 |
| 110 | 3.23 | 11.71 | 0 | 3.41 | 5.47 | 403.34 | 20.86 | 4.17 | 4.95 | 104.21 | 0 | 93.02 | 1000 | 143.95 | 771.23 | 68900 |
| 111 | 3.23 | 7.78 | 0 | 2.93 | 4.07 | 326.31 | 16.39 | 2.45 | 3.94 | 95.25 | 0 | 87.23 | 1000 | 146.37 | 888.40 | 97700 |
| 112 | 3.24 | 8.20 | 0 | 2.02 | 4.98 | 326.64 | 15.45 | 2.82 | 2.36 | 98.35 | 0 | 87.50 | 1000 | 147.34 | 844.40 | 91690 |
| 113 | 6.01 | 7.50 | 0 | 2.76 | 3.11 | 307.22 | 16.17 | 3.92 | 3.34 | 97.47 | 0 | 84.70 | 1000 | 145.40 | 876.43 | 106600 |
| 114 | 6.02 | 8.19 | 0 | 2.58 | 3.57 | 305.92 | 16.49 | 5.30 | 4.34 | 97.91 | 0 | 87.32 | 1000 | 145.17 | 950.57 | 109800 |
| 115 | 6.03 | 8.39 | 0 | 3.34 | 3.48 | 325.17 | 16.01 | 3.12 | 4.03 | 94.59 | 0 | 86.92 | 1000 | 144.04 | 902.33 | 104900 |
| 116 | 6.04 | 7.64 | 0 | 2.49 | 4.12 | 297.89 | 16.26 | 3.64 | 3.54 | 92.46 | 0 | 87.27 | 1000 | 145.40 | 939.48 | 108800 |
| 117 | 6.05 | 6.73 | 0 | 3.10 | 3.57 | 309.46 | 18.72 | 3.87 | 3.16 | 95.44 | 0 | 87.07 | 1000 | 144.60 | 906.24 | 104700 |
| 118 | 6.06 | 8.08 | 0 | 5.20 | 7.09 | 621.51 | 19.93 | 3.18 | 2.63 | 60.51 | .67 | 87.67 | 1000 | 126.60 | 746.24 | 106000 |
| 119 | 7.01 | 8.51 | 0 | 2.64 | 3.57 | 321.49 | 16.57 | 1.79 | 3.73 | 94.93 | 0 | 87.47 | 1000 | 144.70 | 877.64 | 98200 |
| 120 | 7.02 | 8.35 | 0 | 3.26 | 3.67 | 326.74 | 22.83 | 2.90 | 3.72 | 98.21 | 0 | 89.18 | 1000 | 138.76 | 838.60 | 91020 |
| 121 | 7.03 | 8.43 | 0 | 2.33 | 3.60 | 306.85 | 14.86 | 2.48 | 4.03 | 94.59 | 0 | 88.03 | 1000 | 144.11 | 925.34 | 89100 |
| 122 | 7.04 | 11.19 | 0 | 3.03 | 5.16 | 340.15 | 17.52 | 2.71 | 3.45 | 100.14 | 0 | 90.15 | 1000 | 146.65 | 854.71 | 62620 |
| 123 | 7.05 | 8.72 | 0 | 1.73 | 3.16 | 304.83 | 16.73 | 3.90 | 4.19 | 95.74 | 0 | 91.06 | 1000 | 148.37 | 973.19 | 101500 |
| 124 | 7.06 | 7.99 | 0 | 0 | 0 | 298.25 | 16.25 | 2.62 | 3.65 | 97.58 | 0 | 89.86 | 1000 | 150.18 | 929.49 | 90360 |
| 125 | 7.07 | 8.73 | 0 | 2.14 | 4.26 | 305.84 | 16.66 | 3.81 | 4.66 | 99.22 | 0 | 90.19 | 1000 | 148.59 | 952.86 | 102700 |
| 126 | 9.01 | 9.38 | 2.62 | 5.19 | 7.75 | 580.02 | 19.64 | 3.74 | 3.10 | 62.61 | 0 | 84.77 | 1000 | 120.96 | 905.32 | 102100 |
| 127 | 9.02 | 8.41 | 0 | 4.93 | 8.46 | 604.27 | 20.91 | 5.08 | 1.07 | 63.53 | 0 | 85.90 | 1000 | 126.50 | 881.82 | 103000 |
| 128 | 9.03 | 9.61 | 1.88 | 4.96 | 6.75 | 597.23 | 20.23 | 3.59 | 2.35 | 59.76 | 0 | 84.47 | 1000 | 125.48 | 922.48 | 104800 |
| 129 | 9.04 | 6.95 | 0 | 5.31 | 6.20 | 567.39 | 18.57 | 1.71 | 2.40 | 60.11 | 0 | 84.33 | 1000 | 124.01 | 929.35 | 105800 |
| 130 | 9.05 | 9.52 | 0 | 4.60 | 6.85 | 599.15 | 19.46 | 4.09 | 0 | 60.42 | 0 | 86.55 | 1000 | 128.02 | 923.64 | 106000 |
| 131 | 9.06 | 7.74 | 0 | 5.62 | 7.86 | 605.80 | 22.39 | 4.20 | 2.45 | 61.08 | 0 | 86.39 | 1000 | 122.99 | 883.06 | 101800 |
| 132 | 9.07 | 8.01 | 0 | 5.28 | 6.52 | 584.35 | 19.94 | 3.11 | 1.45 | 61.57 | 0 | 85.32 | 1000 | 123.52 | 884.99 | 102900 |
| 133 | 9.08 | 11.63 | 2.34 | 5.02 | 8.00 | 615.43 | 20.44 | 4.31 | 1.83 | 61.91 | 0 | 87.18 | 1000 | 125.91 | 837.46 | 101100 |
| 134 | 9.09 | 10.25 | 1.37 | 4.71 | 5.84 | 593.75 | 19.45 | 2.83 | 2.04 | 59.45 | 0 | 82.07 | 1000 | 135.18 | 890.69 | 112000 |
| 135 | 9.10 | 8.56 | 0 | 4.72 | 7.70 | 582.89 | 19.16 | 4.17 | 2.83 | 60.07 | 0 | 85.23 | 1000 | 124.07 | 902.28 | 113400 |
| 136 | 9.11 | 8.38 | 0 | 5.34 | 7.76 | 619.96 | 19.85 | 2.04 | 1.45 | 61.12 | 0 | 87.21 | 1000 | 121.55 | 855.42 | 107200 |
| 137 | 12.01 | 9.31 | 0 | 3.51 | 3.67 | 312.76 | 16.95 | 2.60 | 2.92 | 93.88 | 0 | 80.87 | 1000 | 157.70 | 948.59 | 94930 |
| 138 | 12.02 | 10.94 | 2.68 | 4.23 | 6.24 | 555.56 | 19.71 | 3.06 | 2.63 | 63.98 | 0 | 83.61 | 1000 | 119.30 | 715.77 | 86670 |
| 139 | 12.02 | 9.71 | 2.04 | 4.56 | 6.81 | 527.78 | 17.67 | 2.41 | 1.08 | 63.66 | 0 | 83.56 | 1000 | 121.11 | 758.92 | 108000 |
| 140 | 12.03 | 6.34 | 0 | 4.03 | 5.62 | 488.37 | 17.69 | 3.92 | 2.20 | 60.69 | 0 | 84.52 | 1000 | 120.19 | 803.55 | 88110 |
| 141 | 16.01 | 9.45 | 0 | 5.79 | 10.90 | 712.06 | 18.31 | 0 | 0 | 61.60 | 1.47 | 88.08 | 1000 | 129.34 | 1101.06 | 77550 |
| 142 | 16.02 | 11.77 | 0 | 7.00 | 9.14 | 771.10 | 23.64 | 4.14 | 3.03 | 60.32 | 0 | 89.34 | 1000 | 124.64 | 968.47 | 77240 |
| 143 | 16.03 | 12.47 | 1.82 | 7.89 | 11.38 | 819.85 | 22.89 | 3.48 | 2.71 | 67.11 | 1.79 | 91.41 | 1000 | 124.06 | 1003.51 | 72660 |
| 144 | 16.04 | 9.50 | 0 | 8.13 | 8.19 | 718.74 | 21.89 | 3.70 | 1.48 | 62.11 | 0 | 88.99 | 1000 | 124.17 | 1087.35 | 103000 |
| 145 | 16.06 | 11.55 | 1.35 | 8.57 | 9.63 | 812.70 | 22.49 | 4.66 | 1.46 | 65.78 | 0 | 90.45 | 1000 | 124.04 | 924.03 | 80620 |
| 146 | 16.07 | 8.24 | 0 | 8.33 | 8.86 | 721.14 | 19.88 | 2.53 | 1.89 | 61.29 | 0 | 88.06 | 1000 | 130.11 | 1060.31 | 100300 |
| 147 | 16.08 | 10.96 | 0 | 7.25 | 11.31 | 790.57 | 23.38 | 4.53 | 1.93 | 65.93 | 0 | 88.75 | 1000 | 127.40 | 943.33 | 70620 |
| 148 | 16.09 | 9.59 | 0 | 6.73 | 10.00 | 769.47 | 22.40 | 4.64 | 1.55 | 62.32 | 0 | 91.65 | 1000 | 131.75 | 958.23 | 82810 |
| 149 | 16.10 | 13.73 | 4.03 | 6.33 | 9.45 | 720.87 | 21.64 | 3.23 | 2.15 | 63.59 | 0 | 90.75 | 1000 | 125.91 | 984.00 | 80930 |
| 150 | 16.11 | 11.90 | 0 | 8.82 | 10.56 | 844.21 | 23.29 | 4.46 | 1.57 | 67.36 | 0 | 90.53 | 1000 | 124.67 | 843.45 | 77540 |
| 151 | 16.11 | 10.42 | 1.89 | 6.41 | 9.17 | 724.98 | 20.89 | 3.80 | 2.62 | 60.70 | 0 | 86.01 | 1000 | 128.93 | 986.35 | 89740 |
| 152 | 16.12 | 9.20 | .79 | 6.35 | 9.74 | 723.39 | 19.34 | 4.12 | 2.05 | 62.99 | 0 | 90.02 | 1000 | 130.79 | 1057.38 | 87850 |
| 153 | 16.13 | 9.80 | 0 | 6.19 | 9.10 | 745.69 | 21.14 | 2.60 | 2.21 | 64.08 | 0 | 91.29 | 1000 | 127.89 | 995.76 | 102200 |

## EDZIZA OBSIDIAN SOURCE DATA NORMALIZED TO THE ZR PEAK (PK/ZR * 10E3)

| Case | Label | K | Ca | Ti | Mn | Fe | Zn | Ga | Pb | Rb | Sr | Y | Zr | Nb | Rayleigh | Zr peak |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 154 | 17.01 | 10.76 | 0 | 6.86 | 9.54 | 793.43 | 23.90 | 5.54 | 1.56 | 63.56 | 0 | 93.04 | 1000 | 130.90 | 1032.75 | 69710 |
| 155 | 17.02 | 12.62 | 3.07 | 10.73 | 9.67 | 844.33 | 24.45 | 5.15 | 2.28 | 62.56 | 0 | 93.24 | 1000 | 125.12 | 959.92 | 92630 |
| 156 | 17.03 | 10.01 | 0 | 5.87 | 9.62 | 719.07 | 20.08 | 3.38 | 3.06 | 60.38 | 0 | 88.89 | 1000 | 129.82 | 1085.35 | 103300 |
| 157 | 17.04 | 16.99 | 3.92 | 8.20 | 11.66 | 873.06 | 26.41 | 4.54 | 3.14 | 68.53 | 0 | 92.19 | 1000 | 125.27 | 885.91 | 78620 |
| 158 | 17.04 | 13.91 | 3.19 | 5.32 | 9.84 | 787.05 | 22.97 | 4.25 | 2.14 | 63.70 | 0 | 87.62 | 1000 | 127.05 | 978.15 | 77200 |
| 159 | 17.05 | 10.25 | 0 | 6.38 | 10.44 | 749.10 | 22.72 | 5.22 | 2.92 | 61.40 | 0 | 87.31 | 1000 | 124.35 | 1097.43 | 99560 |
| 160 | 17.06 | 14.11 | 2.72 | 7.01 | 10.42 | 755.66 | 20.52 | 4.45 | 1.84 | 63.86 | 0 | 89.31 | 1000 | 129.61 | 1024.55 | 92740 |
| 161 | 17.07 | 12.88 | 3.63 | 7.20 | 9.76 | 780.06 | 23.73 | 4.50 | 3.12 | 63.96 | 0 | 90.15 | 1000 | 124.37 | 1008.63 | 81930 |
| 162 | 17.08 | 11.78 | 0 | 5.91 | 9.53 | 772.58 | 22.47 | 4.76 | 0 | 63.42 | 0 | 89.42 | 1000 | 128.27 | 1009.12 | 83810 |
| 163 | 17.09 | 10.34 | 0 | 4.56 | 8.45 | 715.68 | 22.07 | 4.13 | 3.43 | 62.44 | 0 | 89.31 | 1000 | 129.80 | 1061.48 | 88210 |
| 164 | 18.01 | 9.43 | 0 | 2.16 | 4.69 | 304.56 | 15.25 | 3.49 | 3.80 | 92.71 | 0 | 87.20 | 1000 | 143.48 | 936.55 | 109700 |
| 165 | 18.02 | 8.23 | 0 | 2.52 | 4.10 | 316.46 | 15.86 | 2.64 | 3.02 | 93.63 | 0 | 89.05 | 1000 | 145.79 | 956.03 | 105700 |
| 166 | 18.03 | 8.12 | 0 | 2.51 | 1.14 | 304.12 | 14.93 | 1.67 | 2.95 | 94.13 | 0 | 89.91 | 1000 | 144.83 | 890.74 | 114200 |
| 167 | 18.04 | 7.38 | 0 | 2.10 | 4.46 | 306.22 | 15.61 | 3.14 | 4.40 | 90.65 | 0 | 87.74 | 1000 | 147.17 | 863.65 | 109400 |
| 168 | 18.05 | 7.50 | 0 | 1.81 | 4.00 | 314.41 | 15.56 | 3.15 | 3.85 | 93.13 | 0 | 88.55 | 1000 | 149.53 | 936.72 | 106200 |
| 169 | 18.06 | 7.58 | 0 | 3.52 | 3.51 | 298.04 | 15.58 | 3.40 | 3.78 | 95.05 | 0 | 85.29 | 1000 | 148.27 | 929.71 | 107100 |
| 170 | 18.07 | 9.84 | 0 | 2.22 | 3.91 | 338.32 | 19.57 | 5.71 | 4.10 | 98.91 | 0 | 90.12 | 1000 | 145.16 | 835.43 | 95620 |
| 171 | 18.08 | 9.32 | 0 | 2.12 | 4.23 | 336.22 | 16.32 | 3.80 | 4.09 | 94.60 | 1.54 | 89.58 | 1000 | 145.67 | 927.13 | 101600 |
| 172 | 19.01 | 7.51 | 0 | 3.26 | 5.26 | 478.27 | 17.96 | 3.82 | 2.44 | 60.16 | 0 | 84.01 | 1000 | 118.05 | 883.23 | 133000 |
| 173 | 19.02 | 6.41 | 0 | 4.34 | 5.63 | 476.84 | 16.13 | 2.34 | 1.22 | 62.16 | 0 | 81.05 | 1000 | 118.02 | 774.14 | 134300 |
| 174 | 19.03 | 9.44 | 3.24 | 3.48 | 6.05 | 499.60 | 17.84 | 3.13 | 3.51 | 61.08 | 0 | 82.65 | 1000 | 119.81 | 814.65 | 125700 |
| 175 | 19.04 | 8.32 | 0 | 3.93 | 6.74 | 497.72 | 18.11 | 3.02 | 2.60 | 59.36 | 0 | 84.46 | 1000 | 120.07 | 816.51 | 109600 |
| 176 | 19.05 | 8.90 | 2.17 | 4.10 | 5.20 | 487.31 | 17.75 | 3.30 | 2.59 | 59.51 | 0 | 83.10 | 1000 | 121.75 | 787.04 | 129200 |
| 177 | 20.01 | 6.67 | 0 | 5.29 | 8.37 | 600.86 | 19.90 | 3.43 | 2.94 | 62.11 | 0 | 85.85 | 1000 | 123.30 | 866.78 | 115900 |
| 178 | 20.02 | 7.17 | 0 | 4.96 | 7.12 | 593.99 | 19.54 | 3.61 | 2.98 | 61.26 | 0 | 86.27 | 1000 | 123.52 | 889.18 | 116500 |
| 179 | 20.03 | 8.78 | 0 | 5.27 | 7.32 | 592.79 | 19.37 | 3.53 | 0 | 60.16 | 0 | 86.38 | 1000 | 126.98 | 939.69 | 113800 |
| 180 | 20.04 | 10.00 | 0 | 4.84 | 8.15 | 673.32 | 21.97 | 5.19 | 3.53 | 65.34 | 0 | 89.89 | 1000 | 122.12 | 772.88 | 79620 |
| 181 | 20.04 | 10.11 | 0 | 4.90 | 8.53 | 632.20 | 19.68 | 0 | 1.80 | 64.70 | 0 | 86.75 | 1000 | 124.53 | 862.59 | 69630 |
| 182 | 20.05 | 9.42 | 0 | 5.17 | 7.38 | 612.76 | 18.18 | 2.94 | 2.63 | 61.24 | 1.58 | 87.96 | 1000 | 125.43 | 830.29 | 92320 |
| 183 | 21.01 | 11.06 | 1.50 | 3.25 | 2.00 | 310.53 | 15.55 | 2.78 | 3.57 | 98.10 | 0 | 91.34 | 1000 | 149.81 | 960.87 | 105400 |
| 184 | 21.02 | 8.86 | 0 | 3.05 | 3.84 | 323.33 | 17.38 | 3.44 | 4.00 | 97.86 | 0 | 88.99 | 1000 | 143.52 | 854.94 | 96990 |
| 185 | 21.03 | 8.83 | 0 | 2.20 | 4.32 | 308.57 | 15.62 | 2.11 | 3.30 | 95.52 | 0 | 88.57 | 1000 | 146.29 | 897.61 | 105000 |
| 186 | 21.04 | 9.02 | 0 | 2.85 | 4.08 | 342.78 | 18.20 | 4.10 | 3.05 | 101.38 | 0 | 92.80 | 1000 | 154.27 | 1003.13 | 93470 |
| 187 | 22.01 | 8.14 | 0 | 1.74 | 5.32 | 312.71 | 16.39 | 3.30 | 3.01 | 94.74 | 0 | 87.71 | 1000 | 145.92 | 874.21 | 114100 |
| 188 | 22.02 | 7.35 | 0 | 3.16 | 2.95 | 327.97 | 15.69 | 1.74 | 3.58 | 97.18 | 0 | 89.79 | 1000 | 145.69 | 900.57 | 110100 |
| 189 | 22.03 | 8.43 | 0 | 2.20 | 2.77 | 302.38 | 14.87 | 3.43 | 5.03 | 93.69 | 0 | 86.74 | 1000 | 143.03 | 936.08 | 122000 |
| 190 | 22.04 | 9.27 | 0 | 2.11 | 2.94 | 311.39 | 15.84 | 3.23 | 3.41 | 92.43 | 0 | 85.29 | 1000 | 146.26 | 888.91 | 115000 |
| 191 | 22.05 | 7.91 | 1.87 | 2.90 | 3.92 | 314.16 | 16.57 | 4.32 | 3.75 | 95.36 | 0 | 87.50 | 1000 | 144.75 | 843.76 | 122900 |
| 192 | 22.06 | 7.79 | 0 | 3.85 | 3.31 | 315.27 | 16.19 | 3.74 | 3.04 | 95.96 | 1.32 | 87.69 | 1000 | 145.55 | 858.83 | 111300 |
| 193 | 22.07 | 6.98 | 0 | 0 | 3.11 | 324.97 | 18.20 | 3.79 | 2.61 | 100.32 | 0 | 89.98 | 1000 | 144.02 | 861.01 | 82070 |
| 194 | 22.08 | 9.40 | 1.43 | 1.70 | 4.97 | 324.99 | 17.32 | 4.33 | 2.89 | 97.77 | .92 | 87.42 | 1000 | 143.14 | 883.01 | 90680 |
| 195 | 22.09 | 8.88 | 0 | 2.43 | 4.87 | 352.57 | 19.02 | 4.75 | 4.39 | 97.92 | 0 | 86.93 | 1000 | 141.28 | 798.74 | 110700 |
| 196 | 22.10 | 8.15 | 0 | 3.01 | 2.91 | 328.33 | 16.83 | 3.22 | 3.54 | 98.43 | 0 | 90.22 | 1000 | 144.65 | 875.75 | 81990 |
| 197 | 22.11 | 11.59 | 2.21 | 1.82 | 3.49 | 322.15 | 14.86 | 4.42 | 3.87 | 95.90 | 0 | 85.88 | 1000 | 147.83 | 915.05 | 121900 |
| 198 | 22.12 | 7.96 | 0 | 3.18 | 4.20 | 313.61 | 17.09 | 3.85 | 4.11 | 97.95 | 0 | 87.51 | 1000 | 143.41 | 885.74 | 116800 |
| 199 | 22.13 | 9.44 | 2.07 | 2.20 | 4.26 | 297.47 | 15.93 | 3.06 | 4.30 | 94.85 | 1.86 | 87.19 | 1000 | 147.63 | 907.80 | 122400 |
| 200 | 22.14 | 7.34 | 0 | 0 | 4.10 | 305.88 | 15.60 | 3.58 | 3.42 | 93.22 | 0 | 87.96 | 1000 | 142.73 | 916.14 | 122400 |
| 201 | 22.15 | 9.27 | 0 | 1.75 | 4.09 | 297.06 | 15.94 | 3.40 | 3.96 | 91.19 | 0 | 86.34 | 1000 | 146.33 | 971.89 | 122600 |
| 202 | 23.01 | 8.94 | 0 | 2.39 | 4.41 | 308.32 | 15.53 | 3.20 | 3.38 | 96.51 | 0 | 89.54 | 1000 | 148.12 | 895.38 | 111800 |
| 203 | 23.02 | 8.76 | 0 | 0 | 4.52 | 312.01 | 18.65 | 4.03 | 2.96 | 91.14 | 0 | 66.54 | 1000 | 143.08 | 937.68 | 120700 |
| 204 | 23.03 | 7.67 | 0 | 1.93 | 3.90 | 315.32 | 18.33 | 5.74 | 3.91 | 99.23 | 0 | 87.48 | 1000 | 146.56 | 936.43 | 116200 |
| 205 | 23.04 | 8.27 | 0 | 2.05 | 3.77 | 315.05 | 16.46 | 3.94 | 2.99 | 93.22 | 0 | 89.30 | 1000 | 146.65 | 952.86 | 113600 |
| 206 | 23.05 | 8.46 | 0 | 2.69 | 3.96 | 320.81 | 17.21 | 4.64 | 3.78 | 93.81 | 0 | 85.13 | 1000 | 146.17 | 900.21 | 116300 |

## APPENDIX F

### Results of the ED-XRF Analysis of 58 Formed Artifacts from HiTp-1, HiTp-63, and HnTq-1.

| Catalogue Number | Artifact Description | Obsidian Source Flow 2 | 3 | 6 |
|---|---|---|---|---|
| **HiTp-1 House 1 (Lithic Workshop)** | | | | |
| EP1:85 | Biface preform | | x | |
| 96 | Biface preform | | x | |
| 49 | Biface preform | | x | |
| 194 | Biface preform | | x | |
| 81 | Biface preform | | x | |
| 217 | Biface preform | | x | |
| 122 | Biface preform | | x | |
| 28 | Biface preform | | x | |
| 97 | Biface preform | | x | |
| 34 | Biface preform | | x | |
| 119 | Biface preform | | x | |
| 90 | Biface preform | | x | |
| 163 | Biface preform | | x | |
| 162 | Biface preform | | x | |
| 164 | Biface preform | x | | |
| 115 | Biface preform | | x | |
| 220 | Biface preform | | x | |
| 113 | Biface preform | | x | |
| 93 | Biface preform | | x | |
| 121 | Biface preform | | x | |
| **HiTp-1 Area 2 (Campsite Area)** | | | | |
| EP1:199 | Microblade | | x | |
| 198 | Microblade core | | x | |
| 182a | Oval scraper | | x | |
| 182b | Scraper | | x | |
| 202 | Core | | x | |
| 177 | Scraper | | x | |
| 196 | Flake | | x | |
| 229 | Uniface | | x | |
| 197 | Biface fragment, distal end | x | | |
| 176 | Biface, complete | | x | |
| 201 | Biface fragment, proximal end | | x | |
| 172 | Biface fragment | | x | |

| Catalogue Number | Artifact Description | Obsidian Source Flow 2 | 3 | 6 |
|---|---|---|---|---|
| HiTp-63 Component 1 (Campsite/Cache) | | | | |
| EP80:12 | Flake | | x | |
| 105 | Scraper | x | | |
| 102 | Scraper | | x | |
| 14 | Edge fragment | | x | |
| 53 | Core fragment | | x | |
| 65 | Large flake tool | | x | |
| 55 | "battered piece" | | x | |
| HiTp-63 Component 2 (Lithic Workshop) | | | | |
| EP80:29 | Large flake | x | | |
| 29 | Small flake | | x | |
| 86 | Notched piece | | x | |
| 25 | Biface fragment, proximal end | | x | |
| 77 | Flake tool fragment | | x | |
| 41 | Biface fragment | | x | |
| 108 | Biface fragment, proximal end | | x | |
| 25 | Biface fragment | | x | |
| 81 | Scraper fragment | x | | |
| 78 | Flake tool | | x | |
| 44 | Biface fragment | | x | |
| 43 | Large scraper fragment | | x | |
| 74 | Microblade | | x | |
| HhTq-1 Surface Scatter (Campsite) | | | | |
| EP58 | Long, collaterally flaked biface | | | x |
| | Microblade | | x | |
| | Microblade | | x | |
| | Microblade core | | x | |
| | Flake tool | | x | |
| | Flake tool | | x | |
| | Total: | 5 | 52 | 1 |

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