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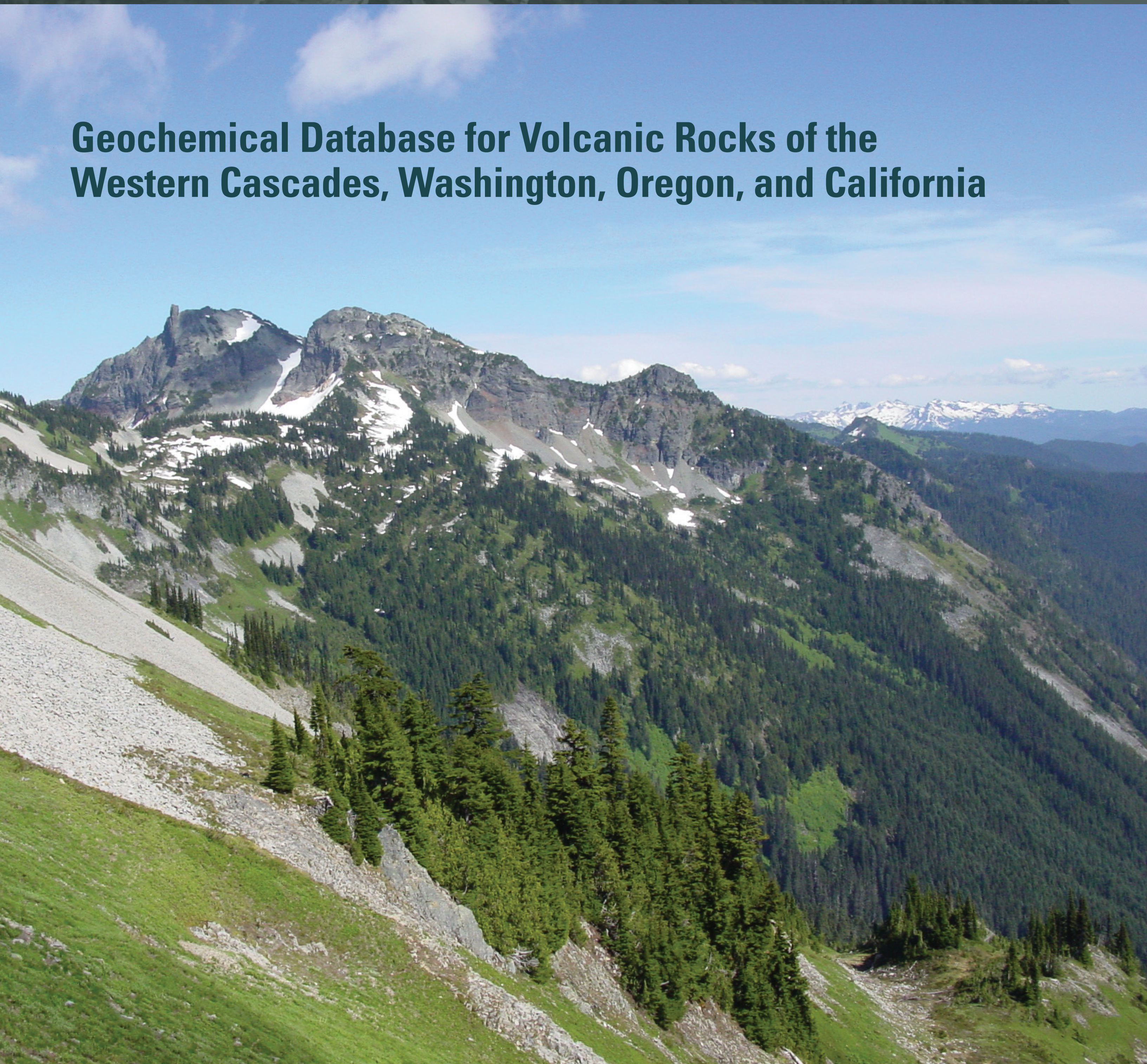
Geochemical Database for Volcanic Rocks of the Western Cascades, Washington, Oregon, and California



Data Series 155

U.S. Department of the Interior
U.S. Geological Survey

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By Edward A. du Bray, David A. John, David R. Sherrod, Russell C. Evarts, Richard M. Conrey, and Jaroslav Lexa

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Introduction

The importance of the Cascade Range magmatic arc in understanding the geologic evolution of western North America is widely recognized, and these arc rocks have been extensively studied. Cenozoic volcanic rocks of the Cascade Range have been traditionally split into two physiographic provinces, the High Cascades and the Western Cascades (fig. 1) (Callaghan, 1933; Thayer, 1937; Peck and others, 1964). Active volcanoes of the modern Cascade magmatic arc form essentially undissected constructional landforms along the crest of the Cascade Range and form the High Cascades. Most of the modern arc rocks, including the prominent north-south chain of stratovolcanoes that extends from Mt. Garibaldi in the north to Lassen Peak in the south, are less than 4 million years old. The High Cascades have been the principal focus of research concerning the petrology and volcano hazards associated with ongoing magmatism in this region. However, these rocks rest on an older volcanic arc in the western part of the Cascade Range. These older rocks, which underlie a broad deeply dissected terrane, form the Western Cascades. Volcanic rocks of the Western Cascades represent the onset of subduction and arc magmatism in the Pacific Northwest, where volcanism has been ongoing for at least 35 m.y. between central Washington and northern California (fig. 1). Although many local studies have been conducted, including a large number of Masters and Doctoral theses completed at the University of Oregon, Oregon State University, Western Washington University, and Portland State University, volcanic rocks of the Western Cascades have not been as thoroughly studied as the products of modern arc volcanism nor has any synthesis of existing data been undertaken since the early interpretive compilations of McBirney (1978), White and McBirney (1978), and Priest (1990). The geochemical database presented here represents the first phase of an effort to synthesize and interpret the geochemistry of Western Cascades volcanic arc rocks.

Previous studies of Western Cascades rocks have been hindered by several factors. First, most of the Western Cascades arc is covered by dense stands of forest and under-story vegetation. Soil and colluvium are well developed and glacial deposits obscure bedrock in some places. Consequently, geologic bedrock exposures are obscured in all but the steepest terrain. Second, zeolite facies burial metamorphism and (or) local propylitic alteration have modified the primary geochemical, mineralogic, and textural characteristics of Western Cascades arc rocks in many places. Finally, the continental magmatic arc environment produced a series of coalescing and mutually overlapping volcanic centers; their intimately intermingled deposits have neither significant lateral persistence nor consistency. The conceptual framework of a continental arc presented by Smith (1993, fig. 3) illustrates the lack of stratigraphic coherency characteristic of deposits of this type. In sum, poor exposure, alteration, and stratigraphic complexity combine to render these rocks difficult to study and interpret. Nevertheless, through studies of small parts of the Western Cascades arc, knowledge and understanding of this arc have been incrementally enhanced. Using the large and synoptic body of information in the present database, it is possible to characterize the primary geochemical attributes of the Western Cascades rocks and begin interpretation of their petrologic, tectonic, and metallogenic significance.

Acknowledgments

We would like to thank several individuals who helped make this effort possible. The staff of the USGS Denver library were critical to the success of this compilation. In particular, the library staff used the interlibrary loan process to obtain many of the geologic reports on which this compilation is based. We thank Joan Luce for her tireless typing; data from many sources were available only in analog form and had to be painstakingly keyboarded. Many geologic researchers gave tirelessly of their time to track down missing bits of information that allow this database to be as complete as it is. These individuals include J.G. Smith, J.M. Curless, A.R. McBirney, C.W. Field, R.A. Duncan, C.M. White, C.G. Barnes, S.R. Munts, B.A. Carkin, S.M. Smith, and E.A. Bestland. Finally, we would like to gratefully acknowledge technical reviews by T.L. Klein and S.D. Ludington that helped

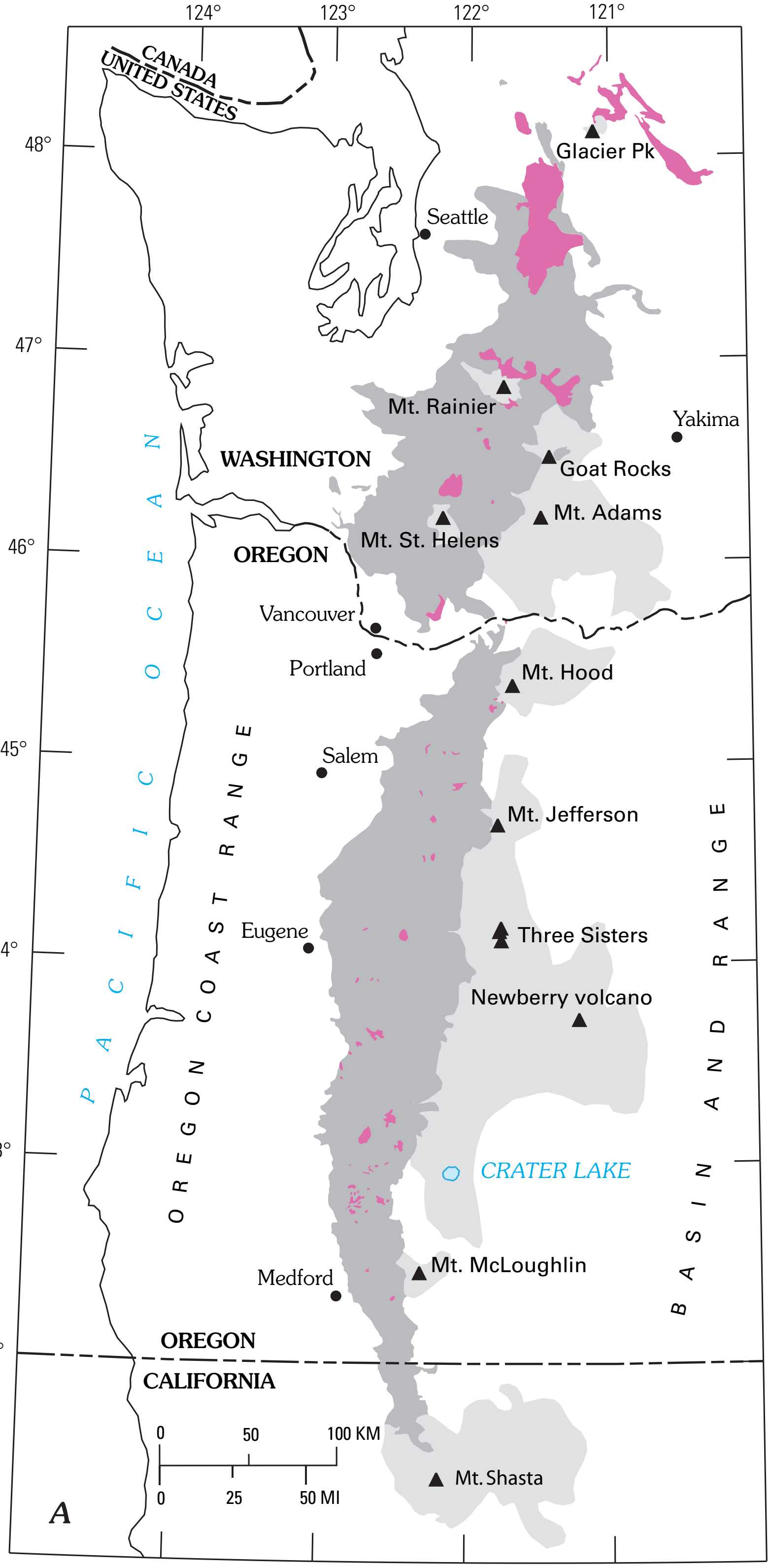

Figure 1 (above and following page). Index map (compiled from Wagner and Saucedo, 1987; Smith, 1993; and Sherrod and Smith, 2000) showing approximate distributions of Western Cascades (dark gray) and High Cascades (light gray) arc rocks. Intrusions colored pink. *A*, Locations of principal Holocene to Pliocene stratovolcanoes of Cascades Mountains shown for reference. *B*, Sample locations for samples included in database, indicated by plus symbols; names of High Cascades volcanoes omitted.

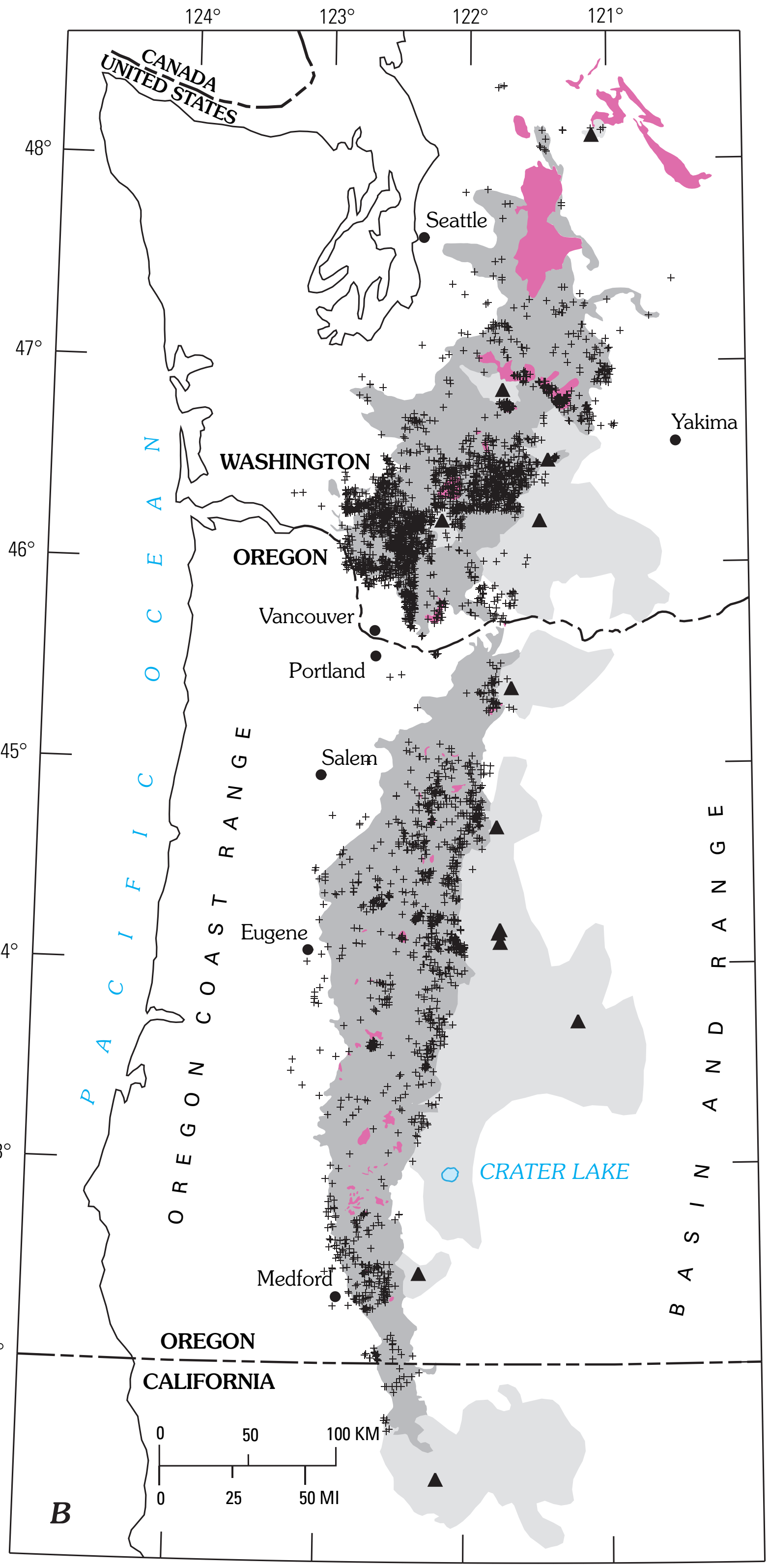

Figure 1. Index map showing approximate distributions of Western Cascades and High Cascades arc rocks—Continued.

improve this report. Work conducted between 1971 and 1972 by Jaroslav Lexa and reported here was carried out at the Center for Volcanology of the University of Oregon under NASA grants in cooperation with Andrew Duncan.

Western Cascades Arc—Geologic Constituents of the Database

There is no consensus definition of what constitutes the Western Cascades magmatic arc. The identity of rocks unequivocally part of this arc, as opposed to those that clearly pre- and post-date the arc, has not been well established. For the purposes of this compilation we used the following criteria:

1. In Oregon and northern California, the Western Cascades arc is composed only of Tertiary volcanic rocks exposed west of the present Cascade Range crest. Middle Tertiary volcanic rocks east of the Cascade crest are considered to represent magmatism related to the Challis volcanic field, back arc magmatism, or magmatism associated with the middle Tertiary geologic evolution of the Basin and Range province. Christiansen and Yeats (1992, fig. 20) suggested that the Western Cascades arc may have reached well south and east of Mt. Lassen, extending into northwest Nevada and nearly as far south as Lake Tahoe on the California-Nevada border. Because the geologic, and particularly tectonic, settings of this presumed Western Cascades arc southeast extension are quite different from those characteristic of the remainder of the Western Cascades arc, this southeast arc extension was not included in our data compilation. In southern Washington, rocks considered constituents of the Western Cascades arc do extend beneath stratovolcanoes of the modern arc and east of the Cascade crest; data for these rocks are included in the database. In Oregon and Washington, volcanic rocks west of the Puget-Willamette Lowland are not considered to be part of the Western Cascades arc; these rocks, widely distributed throughout the Oregon Coast Range, are not considered to be directly related to Western Cascades arc magmatism.

2. Volcanism associated with the Western Cascades arc may have begun as early as 45 Ma and may extend to ages as young as 5 Ma. This broad age range may allow inappropriate inclusion of some pre- and post-Western Cascades samples in the database. At the old end of this age range, earth scientists have struggled to identify (1) volcanic rocks (particularly in central Washington) that are demonstrably associated with the onset of arc magmatism and (2) which rocks may represent magmatism in some other tectonic regime. In many parts of the Cascade Range, no clear discontinuity between magmatism associated with the Western Cascades and High Cascades arcs has been identified. Callaghan (1933) suggested that a pronounced unconformity separates High Cascades from Western Cascades volcanic rocks. Abundant field work has shown since that such an unconformity is not a ubiquitous nor synchronous feature along the length of the Cascade Range. The onset of High Cascades volcanism has been variably denoted as between 10 and 2 Ma. Using local geologic relations and other criteria described here, we have included data for all Cascade Range volcanic rocks presumed older than approximately 5 Ma in the database.

3. Middle Miocene volcanic rocks of the voluminous Columbia River basalt are not related to Western Cascades arc magmatism and are not included in the database.

4. Undissected volcanic rocks that retain primary constructional morphology are considered to be part of the High Cascades.

5. Data for samples of lava flows, pyroclastic deposits, and intrusions were included in the database, whereas data for sedimentary rocks with a volcanic provenance were excluded.

Background information for some samples is incomplete and may be misleading or incorrect, and (or) invalid interpretations may have been made, any of which could cause inappropriate inclusion of data in the database. Every effort has been made to preclude inclusion of inappropriate samples; their number is probably limited and shouldn't have a significant effect on data interpretations.

Data Compilation Methods

Several of us (Sherrod, Conrey, and Evarts) had already begun compilation of whole rock geochemical data for volcanic rocks from various parts of the Cascade Range. These compilations served as a starting point for the effort described here. Copies of original data source materials (subsequently referred to as sources), including published reports and Masters and Doctoral theses, were used to add data to the database. Reference lists contained in sources of data were examined and used to identify additional data sources. In this way, data for about 4,100 samples from 113 sources were identified and incorporated in the database. We believe that this process has probably resulted in identification and incorporation of most of the data that have been produced for samples of Western Cascades rocks. In order for a sample to be included in the database, at least a sample number and major oxide analysis were required. Samples for which only trace element data were available were not included in the database. Additional trace element (for instance, the rare earths) and (or) isotopic data are available for some samples, but because the number of these samples is very small, these data were not included in the database. No effort was made in this compilation to identify altered samples; these evaluations will be made in the subsequent, interpretive phase of this work, and the contents of a derivative database will accordingly reflect this winnowing process. However, users of this database should be wary of samples with SiO_2 abundances greater than 77 percent, initial analytic totals less than 95 percent or greater than 103 percent, Al_2O_3 abundances less than 10 percent or greater than 20 percent, total volatile contents greater than 5 percent, or Na_2O/K_2O ratios less than 1 or greater than about 12; samples with any of these characteristics are apt to be altered and do not preserve primary igneous rock compositions. Data for samples explicitly identified as hydrothermally altered were not included in the database. Data presented in source materials were included in the database, without modification (with the exception of normalization of major oxide data, as described below), and all input subsequently verified.

Data were compiled using Microsoft Excel and can be accessed using software compatible with .xls files. The database release (file, WCascDB.xls) includes several worksheets that are accessed using tabs arrayed along the base of the spreadsheet screen display. The tab labeled "West Cascades database" is the primary data compilation. The tab labeled "db w censored data deleted" is a copy of the primary data compilation in which censored data (data coded as less than some specified value) were deleted prior to calculation of summary statistics and creation of histograms. The database release also includes a tab-delimited, text file version of the database (file, WCascDB.txt).

Data Fields

Data fields presented and described below represent those considered most critical to addressing questions concerning the tectonic, petrologic, and metallogenic evolution of the Western Cascades arc. Data for each of these fields constitute a column, or set of related columns, in the database. Data in these columns can be sorted, queried, and interpreted to address questions concerning the history, development, and implications of the Western Cascades arc. Sample number records are aggregated in blocks of data that share a primary geochemical data source.

Blank cells in the database indicate that no data are available for the corresponding column. Some sources report values of zero for some database fields. These values indicate that an abundance determination was attempted but that the constituent was not detected in the sample. Similarly, some sources present qualified data. In particular, records for some samples include less than (<) symbols. These data indicate that the constituent was detected but that its concentration was unquantifiable beyond the fact that its concentration is less than the indicated value. Actual analytical precision (number of significant figures) associated with each database entry is portrayed by each displayed onscreen value. Data in some cells appear to be more precise than displayed values, but this is a misleading artifact of computational processes (for instance, normalization to 100 percent volatile free), which may have been used to create data cell contents. Precision varies within individual columns in accordance with that associated with analytical determinations produced by specific analytical protocols and reported in individual sources. In most cases, the number of significant figures defined in data sources was retained. However, in some cases, the level of precision implied is implausible given either the analytical protocol or the corresponding analytical state of the art; accordingly, some numeric data contained in the database have been rounded to indicate a plausible level of analytical precision.

field_no

Identifiers for analyzed samples materials were compiled from sources and presented, without modification.

rock_name

In most cases, a lithologic description of analyzed samples was compiled from information contained in sources. Unless otherwise noted, samples are considered to represent lava of the designated composition; an entry of andesite indicates a sample of andesite lava. In some cases, source materials do not specify whether the sample represents lava, a pyroclastic deposit, or some form of intrusion; in these situations, lava is presumed. Many sources classify the composition of intrusions (dikes, sills, stocks, and so forth) using volcanic rock nomenclature. These designations suggest that these shallowly solidified, and therefore, fine-grained rocks were not evaluated by modal analysis and that subsequent name assignment using the nomenclature of Streckeisen (1973) for phaneritic igneous rocks was not possible. The form of intrusion (dike, sill, stock, and so forth) is given where known. All volcanic rock compositional names derived from the source were evaluated and updated as necessary, relative to the volcanic rock total alkalis versus silica nomenclature grid (LeBas and others, 1986). In cases for which the source provides no indication of rock type, an appropriate compositional name was established using composition data and the volcanic rock nomenclature grid; these samples are presumed to represent lava.

long and lat

An effort was made to obtain location data for all samples. Most sources contain some form of location information. Missing sample location data were requested from authors, most of whom were able to provide the missing information. Accordingly, location data are available for all but a very few samples. Location data are of variable quality as a consequence of the manner in which they were initially acquired and subsequently reported. However, location data contained in the database are probably accurate to within at least several hundred meters. Most location data are likely considerably more accurate and in all cases sufficient for regional-scale interpretation.

Some sources provide only very general information concerning sample locations. Fischer (1970) described sample collection sites relative to prominent topographic features. Murphy (1989) associated each sample with a geologic map unit. Power (1984) indicated only that four analyzed samples of the Spirit Lake pluton are from the Margaret porphyry copper prospect. In order to provide information concerning the geologic units represented by these samples and give the samples some geographic context, sample locations were approximated from available information. Fischer's (1970) brief location descriptions were used to estimate sample locations. Locations for Murphy's (1989) samples were assigned values near the center of the geologic units represented by each sample. Locations for Power's (1984) four samples were assigned to a plausible site where a dirt road crosses the altered area coincident with the Margaret porphyry copper prospect. Locations for all of these samples are in italics in the database to denote their approximate nature.

Latitude and longitude data are reported as decimal degrees (relative to the 1927 North American Datum) to four decimal places, which corresponds to a location accuracy of about 10 m on the ground. Many of the sources report sample location in terms of township, range, and section values, usually to the closest 1/16 of a section. Township-range-section data were digitized to obtain decimal degree location, within the appropriate 1/16 section quadrilaterals; digitized points were usually selected to coincide with a road, trail, stream bottom, quarry, or natural cliff, any of which might represent a likely sampling location. Some sources do not include numerical sample location data but do contain sample maps. Location data for these samples were obtained by digitizing sample sites. A very few sources merely describe sample locations. For Western Cascades samples, longitude is reported as a negative value (western hemisphere) and latitude as a positive value (northern hemisphere).

SiO_2n, TiO_2n, Al_2O_3n, FeO*n, MnOn, MgOn, CaOn, Na_2On, K_2On, and P_2O_5n

Sources report whole rock, major oxide data in a variety of formats. In addition, these data were produced by a wide array of analytical procedures, each with its associated analytical precision and accuracy. Compositions for many of the samples included in the database are presented in their sources already normalized to 100 percent volatile free. Some information loss occurs when data are reported solely in this fashion. Compiling analytical methods and associated estimates of precision and accuracy associated with the reported data was beyond the scope of this effort, but in most cases, each of these is documented in the source. The database includes columns for the abundances of SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5. However, because diverse analytical protocols were used to analyze samples, not all sources contain data for each of these constituents.

Several different schemes are possible for reporting iron contents. In addition, reported abundances of ferrous versus ferric iron in these rocks are unlikely to represent magmatic values, because of oxidation during devitrification, zeolite facies metamorphism, and (or) postmagmatic hydrothermal alteration. Consequently, total iron abundances were recalculated as ferrous iron oxide and denoted as FeO*. Interaction with postmagmatic fluids caused compositions of many Western Cascades volcanic rocks to change in other ways as well. In particular, many of these rocks were hydrated (as indicated by secondary clay minerals, sericite, and (or) chlorite), and others were affected by fluids that precipitated calcite. Both processes caused volatile contents of the affected samples to increase, and correspondingly caused relative abundances of all other constituents to decrease. Therefore, to facilitate meaningful oxide abundance comparisons among samples, all analyses were normalized to 100 percent on a volatile-free basis. The resulting data are reported in columns identified by SiO_2n, TiO_2n, Al_2O_3n, FeO*n, MnOn, MgOn, CaOn, Na_2On, K_2On, and P_2O_5n. All data are reported as weight percent.

total_I

One measure of major oxide analytical accuracy is how nearly the sum of the determined constituents approaches 100 percent. Consequently, the database includes a column that reports initial analytical totals as reported by the source. Some sources do not include totals; totals for these samples were computed and added to the database. Initial analytical totals reported in the sources were spot checked for accuracy; discrepancies were noted and corrected in a number of cases. Many sources present abundances for the oxides listed above but include no abundance data for volatile constituents. Initial analytical totals for these samples tend to be several to 5 or 6 percent less than 100 percent. Unfortunately, it's impossible to determine whether these low initial totals result from inaccurate analyses and (or) unreported volatile constituent abundances.

vol_sum

The volatile content of volcanic rocks provides some insight concerning whether abundances of other constituents accurately represent primary magmatic values. Samples with elevated volatile contents, for example greater than 3 weight percent, are apt to have experienced some fluid-mediated, postmagmatic chemical modification.

The use of diverse sample analysis protocols resulted in widely disparate reporting of data for the volatile constituents of Western Cascades volcanic rocks. Volatile constituents whose abundances are commonly determined include LOI (loss on ignition), H_2O+ (bound), H_2O- (nonessential, moisture), CO_2, F, Cl, and SO_3. Of these, most sources contain no halogen abundance data, and data for SO_3 are presented for only a very few samples. Similarly, data for H_2O+, H_2O-, and CO_2 are so rarely and nonsystematically reported that separately compiling these data was not warranted. The best possible measure of the volatile contents of the analyzed samples is therefore total volatile content. For the purposes of the compilation, LOI data contained in source data compilations were defined as total volatile content. Alternatively, if the source includes data for H_2O+, H_2O-, and CO_2 (usually determined as a group), these data were summed to yield total volatile content.

Ba, La, Ce, Rb, Sr, Y, Zr, Nb, Co, Cr, Ni, Sc, V, Ag, Cu, Mo, Pb, Zn, and Au

The sources present data for inconsistent sets of trace elements. Of these, data for Ba, La, Ce, Rb, Sr, Y, Zr, Nb, Co, Cr, Ni, Sc, V, Cu, Pb, Zn, Mo, Ag, and Au were compiled; all data are in parts per million. These constituents are among those for which sources most often contain data and also are considered sufficient to address many petrologic, tectonic, and metallogenic questions.

chem_src

Data for each sample included in the database were compiled from primary data sources, in most cases a single source. For a few samples, data were culled from two or more sources; for example, major oxide data may have been compiled from one source and trace element data from another. Sources of geochemical information include publications of the U.S. Geological Survey, Masters theses, Doctoral dissertations, articles published in journals, and publications of the Oregon Department of Geology and Mineral Industries and the Washington Department of Natural Resources, Division of Geology and Earth Resources. Approximately one fourth of the geochemical information contained in the database is previously unpublished and was obtained by Russell Evarts in support of geologic mapping studies. A smaller amount of unpublished information was informally transmitted to us by earth scientists working in the Cascade Mountains.

Entries in the "chem_src" column of the database are keyed numerically to sources identified below:

1. Swanson (1994)
2. Swanson (1989)
3. Swanson (1991)
4. Swanson (1992)
5. Swanson (1996a)
6. Swanson and others (1997)
7. Swanson (1996b)
8. Swanson (1993)
9. Wiley and Hladky (1991)
10. McCulla (1986)
11. Nicholson (1988)
12. Carkin (1988)
13. Curless (1991)
14. Hagen (1987)
15. White (1980a)
16. Power (1984)
17. Priest and Vogt (1982)
18. Avramenko (1981)
19. Bargar and others (1993)
20. Barnes (1978)
21. Black and others (1987)
22. Buddington and Callaghan (1936)
23. Peck and others (1964)
24. Callaghan (1933)
25. Phillips and others (1986)
26. Wiley and Smith (1993)
27. Dyhrman (1975)
28. Hladky (1993)
29. Olson (1978)
30. Munts (1978)
31. Lux (1981)
32. Hladky (1998a)
33. Rollins (1975)
34. Schaubs (1978)
35. Sherrod (1986)
36. Thayer (1937)
37. Tolan (1982)
38. Verplanck (1985)
39. Berri and Korosec (1983)
40. Millhollen (1991)
41. Wise (1969)
42. Priest and Vogt (1983)
43. Wells and Waters (1935)
44. Storch (1978)
45. Hladky (1996)
46. Wise (1970)
47. Hladky (1992)
48. Hladky (1999)
49. Shepard (1979)
50. Millhollen (1989)
51. Hladky (1994)
52. Schriener (1978)
53. Hladky (1998b)
54. Murray and Kays (2002)
55. Steinborn (1972)
56. White (1980b)
57. Wiley (1993)
58. Black, G.L., Oregon Department of Geology and Mineral Industries, unpublished data, 2005
59. Priest, G.R., Oregon Department of Geology and Mineral Industries, unpublished data, 2005
60. Murphy and Marsh (1993)
61. Madin, I.P., Oregon Department of Geology and Mineral Industries, unpublished data, 2005
62. Cook (2002)
63. Flaherty (1981)
64. Ritchie (1987)
65. Naslund (1977)
66. Schultz (1988)

67. Lowenstern (1986)
68. Felts (1939)
69. Evarts and Ashley (1993a)
70. Evarts and Ashley (1993b)
71. Evarts and Ashley (1993c)
72. Evarts and Ashley (1993d)
73. Evarts and Ashley (1990a)
74. Evarts and Ashley (1990b)
75. Evarts and Ashley (1991)
76. Evarts and Ashley (1992)
77. Evarts (2001)
78. Evarts (2002)
79. Evarts and Bishop (1994)
80. Evarts (2004a)
81. Evarts (2004c)
82. Evarts (2004b)
83. Evarts, R.C., U.S. Geological Survey, unpublished data, 2005
84. U.S. Geological Survey, National Geochemical Database, 2005
85. Priest and others (1988)
86. Swanson (1978)
87. Conrey and Sherrod (1988)
88. Ort and others (1983)
89. Clayton (1983)
90. Schreiber (1981)
91. Schasse (1987b)
92. Hotz (1977)
93. Gard (1968)
94. Tabor and Crowder (1969)
95. Vine (1969)
96. Brown (1979)
97. Korosec (1987b)
98. Korosec (1987a)
99. Phillips (1987a)
100. Phillips (1987b)
101. Schasse (1987a)
102. Fischer (1970)
103. Craig (1981)
104. Burr (1978)
105. Harle (1974)
106. Winters (1984)
107. Bestland (1985)
108. King (1994)
109. du Bray, E.A., U.S. Geological Survey, unpublished data, 2005
110. Murphy (1989)
111. John, D.A., U.S. Geological Survey, unpublished data, 2005
112. Lexa, Jaroslav, Geological Survey of the Slovak Republic, unpublished data, 2005
113. Thompson (1983)

rad_age

The ages of volcanic rocks that constitute the Cascade Range have been of keen interest and a large number of age determinations have been made. Principal contributions to the geochronologic knowledge of Western Cascades volcanic rocks in particular include those of Sutter (1978), Lux (1981), Priest and Vogt (1983), Tabor and others (1984), Verplanck (1985), Phillips and others (1986), and Evarts and others (1987). The compilation of Fiebelkorn and others (1983) is equally useful. Using these and other appropriate sources, all available radiometric age data were compiled for samples included in the database. The database column titled “rad_age” contains the age(s), in millions of years, determined for the associated sample. Multiple geochronologic age determinations have been obtained for a few samples included in the database. These replicate ages are listed in the “rad_age” column, in otherwise blank rows, below the row that contains geochemical data for the associated sample. If the source indicates that one of these ages is a preferred age, it is presented in italics.

uncert

The database column titled “uncert” contains data, in millions of years, for the analytical uncertainties associated with each of the age determinations reported in the “rad_age” column.

age_src

Radiometric age data for samples included in the database, although scarce, were compiled from primary data sources. In most cases, geochemical and geochronologic data were derived from the same source; the age source for each of these samples is numerically keyed to previously identified geochemistry sources. For the relatively small number of samples for which geochemical and geochronologic data have different sources, age sources data are keyed to alpha-coded citations listed below:

A. Keith and others (1985)
B. Sutter (1978)
C. Evans and Brown (1981)
D. Mertzman, S.A., Franklin and Marshall College, unpublished data, 2005
E. Power and others (1981)
F. Evarts and others (1987)

geol_age

Radiometric ages have not been determined for most samples included in the database. In order to enable study of time-space-composition relations among volcanic rocks of the West Cascades, ages of most samples included in the database were estimated. Entries in the geol_age column are in millions of years. In some cases, the radiometric age of samples that are not part of the database, but representative of the same unit as samples that are included in the database, was used to constrain the geologic age. Similarly, many of the sources include diagrams that correlate rock units with absolute age scales. By knowing the geologic map unit represented by individual samples and by interpolating geologic map unit age ranges from correlation of map units diagrams, approximate ages were estimated for many samples. In addition, the geologic ages of another large group of samples were established by comparing individual sample localities to geology shown on the map of volcanic rocks of the Cascade Mountains in Oregon (Sherrod and Smith, 2000). This and a companion map for the Washington Cascade Range (Smith, 1993) denote the spatial and temporal distribution of Tertiary-age volcanic rocks. These rocks are assigned to one of five age intervals: 2–7 Ma, 7–17 Ma, 17–25 Ma, 25–35 Ma, and 35–45 Ma (Smith, 1993; Sherrod and Smith, 2000). The utility and rationale for definition of these particular intervals is described by Sherrod and Smith (2000).

strat_name

Some sources associate either formal or informal stratigraphic nomenclature with samples for which they include geochemical data. These names were compiled in the database field titled "strat_name" in order to facilitate sorting database contents by stratigraphic unit. Entries in this field are shortened from full stratigraphic designation (for instance, Sardine Formation) to entries that denote just the geographic feature included in the full stratigraphic designation (for instance, Sardine). Coding samples by assigned stratigraphic name allows grouping of samples from a particular stratigraphic unit. Grouped in this way, geochemical characteristics of units can be identified and interpreted and comparisons to other similar stratigraphic units can be made. Among the regionally most important stratigraphic designations of this sort are Sardine, Little Butte, Colestin, Goble, Northcraft, Scorpion Mountain, Breitenbush, Roxy, Heppsie, Wasson, Ohanapecosh, Fifes Peak, Stevens Ridge, and Rhododendron. Unfortunately, many data sources do not assign specific formal or informal stratigraphic names; these sources assign samples names that are entirely lithologic, such as basalt, basaltic andesite, or andesite.

Several sources use the same geographic name for more than one rock unit. For instance, Priest and others (1988) used the name Blue River for an andesite unit and for a basalt unit. To distinguish these name assignments in the database, (and) is appended to the Blue River designation for andesite samples, whereas (bas) is appended for the basalt samples. Priest and others (1988) also assigned the name Frissell Point to an andesite and a basalt; (and) is appended to the Frissell Point designation for andesite samples, and (bas) is appended for the basalt samples. Similarly, Cook (2002) used the name Moose Mountain for an andesite and a rhyolite. To distinguish these designations in the database, (and) is appended to the Moose Mountain designation for andesite samples, whereas (rhy) is appended for the rhyolite samples. Finally, Curless (1991) distinguished strata that compose upper and lower parts of the Elk Lake Formation; entries in the strat_name column for these samples are appended by (upper) and (lower) respectively.

Geologists have identified small- to intermediate-size intrusions that form an approximately north-trending array along the Western Cascades (fig. 1). These intrusions, for example the Spirit Lake pluton and the Detroit Dam, Nimrod, and Champion stocks, are especially significant because of their spatial and genetic association with mineral deposits in the Western Cascades. For each sample of an intrusion, the entry in the strat_name column identifies the name of the particular stock represented by that sample. These designations allow analytical data for individual stocks to be sorted and grouped, thereby enabling interpretation of their geochemistry.

Histograms

A series of histograms (fig. 2) is included in order to provide a basic graphical depiction of the compiled data. These histograms portray frequency distributions for the abundances of each geochemical constituent for which data were compiled. In order to prepare each histogram, a table of data abundance classes (bins) versus frequency within each class was computed (table 1). A set of descriptive statistical abundance parameters, including mean and standard deviation, median, minimum, maximum, and count (number of samples for which abundance data for the particular constituent are available), were computed for each database geochemical constituent and are included on the histograms. For the purpose of constructing the histograms and calculating statistics, all censored (less than) values were deleted. The worksheet tab labeled "db w censored data deleted" is a copy of the primary database with all censored data deleted.

References Cited

Avramenko, Walter, 1981, Volcanism and structure in the vicinity of Echo Mountain, central Oregon Cascade Range: Eugene, Oreg., University of Oregon M.S. thesis, 156 p.

Bargar, K.E., Keith, T.E.C., and Beeson, M.H., 1993, Hydrothermal alteration in the Mount Hood area, Oregon: U.S. Geological Survey Bulletin 2054, 70 p.

Barnes, C.G., 1978, The geology of the Mount Bailey area Oregon: Eugene, Oreg., University of Oregon M.S. thesis, 123 p.

Berri, D.A., and Korosec, M.A., 1983, Geological and geothermal investigation of the lower Wind River Valley, southwest Washington, Cascade Range: Washington Department of Natural Resources, Division of Geology and Earth Resources Open-File Report 83-5, scale 1:24,000, 48 p.

Bestland, E.A., 1985, Stratigraphy and sedimentology of the Oligocene Colestin Formation, Siskiyou Pass area, southern Oregon: Eugene, Oreg., University of Oregon M.S. thesis, 150 p.

Black, G.L., Woller, N.M., and Ferns, M.L., 1987, Geologic map of the Crescent Mountain area, Linn County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-47, scale 1:62,500.

Brown, J.C., 1979, Geology and water resources of Klickitat County: Washington Department of Ecology, Water Supply Bulletin 50, 413 p.

Buddington, A.F., and Callaghan, Eugene, 1936, Dioritic intrusive rocks and contact metamorphism in the Cascade Range in Oregon: American Journal of Science, 5th Series, v. 31, p. 421–449.

Burr, C.D., 1978, Paleomagnetism and tectonic significance of the Goble Volcanics of southern Washington: Bellingham, Wash., Western Washington University M.S. thesis, 235 p.

Callaghan, Eugene, 1933, Some features of the volcanic sequence in the Cascade Range in Oregon: American Geophysical Union Transactions, v. 14, p. 243–249.

Carkin, B.A., 1988, The geology and petrology of the Fifes Peak Formation in the Cliffdell area, Central Cascades, Washington: Bellingham, Wash., Western Washington University M.S. thesis, 148 p.

Christiansen, R.L., and Yeats, R.S., 1992, Post-Laramide geology of the U.S. Cordillera region, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen—Conterminous U.S.: Boulder, Colo., Geological Society of America, The Geology of North America, v. G-3, p. 261–406.

Clayton, G.A., 1983, Geology of the White Pass area, south-central Cascade Range, Washington: Seattle, Wash., University of Washington M.S. thesis, 212 p.

Conrey, R.M., and Sherrod, D.R., 1988, Stratigraphy of drill holes and geochemistry of surface rocks, Breitenbush Hot Springs 15-minute quadrangle, Cascade Range, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-88-5, p. 5–29.

Cook, G.W., 2002, Geology and geochemistry of volcanic rocks of the Menagerie Wilderness, Western Cascades: Boise, Idaho, University of Idaho M.S. thesis, 77 p.

Craig, D.E., 1981, The paleomagnetism of a thick middle Tertiary volcanic sequence in northern California: Bellingham, Wash., Western Washington University M.S. thesis, 131 p.

Curless, J.M., 1991, Geology and hydrothermal mineralization in the vicinity of Rocky Top, Marion County, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 108 p.

Dyhrman, R.F., 1975, Geology of the Bagby Hot Springs area, Clackamas and Marion Counties, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 78 p.

Evans, S.H., and Brown, F.H., 1981, Summary of potassium/argon dating—1981: U.S. Department of Energy, Division of Geothermal Energy DE-AC07-80-ID-12079-45, 29 p.

Evarts, R.C., 2001, Geologic map of the Silver Lake quadrangle, Cowlitz County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2371, scale 1:24,000, 37 p.

Evarts, R.C., 2002, Geologic map of the Deer Island quadrangle, Columbia County, Oregon, and Cowlitz County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2392, scale 1:24,000, 33 p.

Evarts, R.C., 2004a, Geologic map of the Ariel quadrangle, Clark and Cowlitz Counties, Washington: U.S. Geological Survey Scientific Investigations Map 2826, scale 1:24,000.

Evarts, R.C., 2004b, Geologic map of the Ridgefield quadrangle, Clark and Cowlitz Counties, Washington: U.S. Geological Survey Scientific Investigations Map 2844, scale 1:24,000.

Evarts, R.C., 2004c, Geologic map of the Woodland quadrangle, Clark and Cowlitz Counties, Washington: U.S. Geological Survey Scientific Investigations Map 2827, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., 1990a, Preliminary geologic map of the Cougar quadrangle, Cowlitz and Clark Counties, Washington: U.S. Geological Survey Open-File Report 90–631, scale 1:24,000, 40 p.

Evarts, R.C., and Ashley, R.P., 1990b, Preliminary geologic map of the Goat Mountain quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 90–632, scale 1:24,000, 47 p.

Evarts, R.C., and Ashley, R.P., 1991, Preliminary geologic map of the Lakeview Peak quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 91–289, scale 1:24,000, 35 p.

Evarts, R.C., and Ashley, R.P., 1992, Preliminary geologic map of the Elk Mountain quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 92–362, scale 1:24,000, 44 p.

Evarts, R.C., and Ashley, R.P., 1993a, Geologic map of the Spirit Lake East quadrangle, Skamania County, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1679, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., 1993b, Geologic map of the Vanson Peak quadrangle, Lewis, Cowlitz, and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1680, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., 1993c, Geologic map of the Spirit Lake West quadrangle, Skamania County, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1681, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., 1993d, Geologic map of the Cowlitz Falls quadrangle, Lewis and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1682, scale 1:24,000.

Evarts, R.C., Ashley, R.P., and Smith, J.G., 1987, Geology of the Mount St. Helens area—Record of discontinuous volcanic and plutonic activity in the Cascade arc of southern Washington: Journal of Geophysical Research, v. 92, no. B10, p. 10,155–10,169.

Evarts, R.C., and Bishop, K.R., 1994, Chemical data for Tertiary volcanic and intrusive rocks of the Spirit Lake 15-minute quadrangle, southern Washington Cascade Range: U.S. Geological Survey Open-File Report 93–686, 24 p.

Felts, W.M., 1939, A granodiorite stock in the Cascade Mountains of south-western Washington: Ohio Journal of Science, v. 39, no. 6, p. 297–316.

Fiebelkorn, R.B., Walker, G.W., MacLeod, N.S., McKee, E.H., and Smith, J.G., 1983, Index to K-Ar age determinations for the state of Oregon: Isochron/West, no. 37, p. 3–60.

Fischer, J.F., 1970, The geology of the White River–Carbon Ridge area, Cedar Lake quadrangle, Cascade Mountains, Washington: Santa Barbara, Calif., University of California Ph.D. dissertation, 200 p.

Flaherty, G.M., 1981, The Western Cascade–High Cascade transition in the McKenzie Bridge area, central Oregon Cascade Range: Eugene, Oreg., University of Oregon M.S. thesis, 178 p.

Gard, L.M., Jr., 1968, Bedrock geology of the Lake Tapps quadrangle, Pierce County, Washington: U.S. Geological Survey Professional Paper 388–B, 33 p.

Hagen, R.A., 1987, The geology and petrology of the Northcraft Formation, Lewis County, Washington: Eugene, Oreg., University of Oregon M.S. thesis, 252 p.

Harle, D.S., 1974, Geology of the Babyshoe Ridge area, southern Cascades, Washington: Corvallis, Oreg., Oregon State University M.S. thesis, 71 p.

Hladky, F.R., 1992, Geology and mineral resources map of the Shady Grove quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-52, scale 1:24,000.

Hladky, F.R., 1993, Geology and mineral resources map of the McLeod quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-80, scale 1:24,000.

Hladky, F.R., 1994, Geology and mineral resources map of the Lakecreek quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-88, scale 1:24,000.

Hladky, F.R., 1996, Geology and mineral resources map of the Grizzly Peak quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-106, scale 1:24,000.

Hladky, F.R., 1998a, Age, chemistry, and origin of capping lava at Upper Table Rock and Lower Table Rock, Jackson County, Oregon: Oregon Geology, v. 60, p. 81–91.

Hladky, F.R., 1998b, Geology and mineral resources map of the Rio Canyon quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-108, scale 1:24,000.

Hladky, F.R., 1999, Geology and mineral resources map of the Brownsboro quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-109, scale 1:24,000.

Hotz, P.E., 1977, Geology of the Yreka quadrangle, Siskiyou County, California: U.S. Geological Survey Bulletin 1436, 72 p.

Keith, T.E.C., Donnelly-Nolan, J.M., Markman, J.L., and Beeson, M.H., 1985, K-Ar ages of volcanic rocks in the Mount Hood area, Oregon: Isochron/West, no. 42, p. 12–16.

King, J.F., 1994, Magmatic evolution and eruptive history of the granitic Bumping Lake pluton, Washington—Source of the Bumping River and Cash Prairie tuffs: Portland, Oreg., Portland State University M.S. thesis, 71 p.

Korosec, M.A., 1987a, Geologic map of the Hood River quadrangle, Washington and Oregon: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-6, scale 1:100,000, 42 p.

Korosec, M.A., 1987b, Geologic map of the Mount Adams quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-5, scale 1:100,000, 41 p.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks using the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.

Lowenstern, J.B., 1986, Petrology, paleomagnetism, and tectonic significance of the lavas of the Colestin Formation, Jackson County, Oregon: Hanover, N.H., Dartmouth College undergraduate thesis, 61 p.

Lux, D.R., 1981, Geochronology, geochemistry, and petrogenesis of basaltic rocks from the Western Cascades, Oregon: Columbus, Ohio, Ohio State University Ph.D. dissertation, 171 p.

McBirney, A.R., 1978, Volcanic evolution of the Cascade Range: Earth and Planetary Science Annual Reviews, v. 6, p. 437–456.

McCulla, M.S., 1986, Geology and metallization of the White River area, King and Pierce Counties, Washington: Corvallis, Oreg., Oregon State University Ph.D. thesis, 213 p.

Millhollen, G.L., 1989, Alkali basalts at Saddleblanket Mountain, central Oregon Cascade Range: Kansas Academy of Science Transactions, v. 92, nos. 1–2, p. 33–42.

Millhollen, G.L., 1991, Welded tuffs of the Winberry Creek area, central Oregon Cascade Range: Oregon Geology, v. 53, no. 4, p. 89–91.

Munts, S.R., 1978, Geology and mineral deposits of the Quartzville mining district, Linn County, Oregon: Eugene, Oreg., University of Oregon M.S. thesis, 212 p.

Murphy, M.T., 1989, The crystallization and transport of intermediate composition magma: Baltimore, Md., Johns Hopkins University Ph.D. dissertation, 154 p.

Murphy, M.T., and Marsh, B.D., 1993, Textures and magmatic evolution of intermediate-composition dome complexes—Evidence from the northern Tatoosh complex, southern Washington Cascades: Journal of Volcanology and Geothermal Research, v. 54, p. 197–220.

Murray, R.B., and Kays, M.A., 2002, Geologic map of Richter Mountain quadrangle, Douglas and Jackson Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-103, scale 1:24,000.

Naslund, H.R., 1977, The geology of the Hyatt Reservoir and Surveyor Mountain quadrangles, Oregon: Eugene, Oreg., University of Oregon M.S. thesis, 126 p.

Nicholson, D.K., 1988, Geology, geochemistry, and mineralization of the Yellowbottom–Boulder Creek area, Linn County, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 186 p.

Olson, J.P., 1978, Geology and mineralization of the North Santiam mining district, Marion County, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 135 p.

Ort, K.M., Tabor, R.W., and Frizzell, V.A., Jr., 1983, Chemical analyses of selected Tertiary and Quaternary volcanic rocks, Cascade Range, Washington: U.S. Geological Survey Open-File Report 83–1, 14 p.

Peck, D.L., Griggs, A.B., Schlicker, H.G., Wells, F.G., and Dole, H.M., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Phillips, W.M., 1987a, Geologic map of the Mount St. Helens quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-4, scale 1:100,000, 63 p.

Phillips, W.M., 1987b, Geologic map of the Vancouver quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-10, scale 1:100,000, 32 p.

Phillips, W.M., Korosec, M.A., Schasse, H.W., Anderson, J.L., and Hagen, R.A., 1986, K-Ar ages of volcanic rocks in southwest Washington: Isochron/West, no. 47, p. 18–24.

Power, S.G., 1984, The "tops" of porphyry copper deposits—Mineralization and plutonism in the Western Cascades, Oregon: Corvallis, Oreg., Oregon State University Ph.D. thesis, 243 p.

Power, S.G., Field, C.W., Armstrong, R.L., and Harakal, J.E., 1981, K-Ar ages of plutonism and mineralization, Western Cascades, Oregon and southern Washington: Isochron/West, no. 31, p. 27–29.

Priest, G.R., 1990, Volcanic and tectonic evolution of the Cascade volcanic arc, central Oregon: Journal of Geophysical Research, v. 95, no. B12, p. 19,583–19,599.

Priest G.R., and Vogt, B.F., 1982, Geology and geothermal resources of the Mount Hood area, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 14, 100 p.

Priest, G.R., and Vogt, B.F., eds., 1983, Geology and geothermal resources of the central Oregon Cascade Range: Oregon Department of Geology and Mineral Industries Special Paper 15, 123 p.

Priest, G.R., Black, G.L., and Woller, N.M., 1988, Geologic map of the McKenzie Bridge quadrangle, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-48, scale 1:62,500.

Ritchie, Beatrice, 1987, Tholeiitic lavas from the western Cascade Range, Oregon: Eugene, Oreg., University of Oregon M.S. thesis, 94 p.

Rollins, Anthony, 1975, Geology of the Bachelor Mountain area, Linn and Marion Counties, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 83 p.

Schasse, H.W., 1987a, Geologic map of the Centralia quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-11, scale 1:100,000, 27 p.

Schasse, H.W., 1987b, Geologic map of the Mount Rainier [1° by 30'] quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 87-16, scale 1:100,000, 46 p.

Schaubs, M.P., 1978, Geology and mineral deposits of the Bohemia mining district, Lane County, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 135 p.

Schreiber, S.A., 1981, Geology of the Nelson Butte area south-central Cascade Range, Washington: Seattle, Wash., University of Washington M.S. thesis, 81 p.

Schriener, A., Jr., 1978, Geology and mineralization of the north part of the Washougal mining district, Skamania County, Washington: Corvallis, Oreg., Oregon State University M.S. thesis, 135 p.

Schultz, J.M., 1988, Mid-Tertiary volcanic rocks of the Timberwolf Mountain area, south-central Cascades, Washington: Bellingham, Wash., Western Washington University M.S. thesis, 145 p.

Shepard, R.J., 1979, Geology and mineralization of the southern Silver Star stock, Washougal Mining District, Skamania County, Washington: Corvallis, Oreg., Oregon State University M.S. thesis, 113 p.

Sherrod, D.R., 1986, Geology, petrology, and volcanic history of a portion of the Cascade Range between latitudes 43°–44° N, central Oregon, U.S.A.: Santa Barbara, Calif., University of California Ph.D. thesis, 320 p.

Sherrod, D.R., and Smith, J.G., 2000, Geologic map of upper Eocene to Holocene volcanic and related rocks of the Cascade Range, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–2569, scale 1:500,000, 17 p.

Smith, J.G., 1993, Geologic map of upper Eocene to Holocene volcanic and related rocks in the Cascade Range, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–2005, scale 1:500,000, 19 p.

Steinborn, T.L., 1972, Trace element geochemistry of several centers in the High Cascades: Eugene, Oreg., University of Oregon M.S. thesis, 115 p.

Storch, S.G.P., 1978, Geology of the Blue River mining district, Linn and Lane Counties, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 70 p.

Streckeisen, A.L., 1973, Plutonic rocks, classification and nomenclature recommended by the IUGS subcommission on the systematics of igneous rocks: Geotimes, v. 18, no. 10, p. 26–30.

Sutter, J.F., 1978, K/Ar ages of Cenozoic volcanic rocks from the Oregon Cascades west of 121°30': Isochron/West, no. 21, p. 15–21.

Swanson, D.A., 1978, Geologic map of the Tieton River area, Yakima County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–968, scale 1:62,500.

Swanson, D.A., 1989, Geologic maps of the French Butte and Greenhorn Buttes quadrangles, Washington: U.S. Geological Survey Open-File Report 89–309, scale 1:24,000, 3 sheets, 25 p.

Swanson, D.A., 1991, Geologic map of the Tower Rock quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 91–314, scale 1:24,000, 26 p.

Swanson, D.A., 1992, Geologic map of the McCoy Peak quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 92–336, scale 1:24,000, 36 p.

Swanson, D.A., 1993, Geologic map of the Blue Lake quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 93–297, scale 1:24,000, 34 p.

Swanson, D.A., 1994, Geologic map of the East Canyon Ridge quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 94–591, scale 1:24,000, 31 p.

Swanson, D.A., 1996a, Geologic map of the Hamilton Buttes quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 96–0016, scale 1:24,000, 29 p.

Swanson, D.A., 1996b, Geologic map of the Packwood Lake quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 96–0704, scale 1:24,000, 25 p.

Swanson, D.A., Moore, R.B., and Banks, N.G., 1997, Geologic map of the Packwood quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 97–0157, scale 1:24,000, 16 p.

Tabor, R.W., and Crowder, D.F., 1969, On batholiths and volcanoes—Intrusion and eruption of Late Cenozoic magmas in the Glacier Peak area, North Cascades, Washington: U.S. Geological Survey Professional Paper 604, 67 p.

Tabor, R.W., Frizzell, V.A., Jr., Vance, J.A., and Naeser, C.W., 1984, Ages and stratigraphy of lower and middle Tertiary sedimentary and volcanic rocks of the central Cascades, Washington—Application to the tectonic history of the Straight Creek fault: Geological Society of America Bulletin, v. 95, p. 26–44.

Thayer, T.P., 1937, Petrology of later Tertiary and Quaternary rocks of the north-central Cascade Mountains in Oregon, with notes on similar rocks in western Nevada: Geological Society of America Bulletin, v. 48, p. 1611–1651.

Thompson, M.E., 1983, Solidification in magmas—Part 1, the magmatic history of the Tatoosh volcanic-plutonic complex, Mount Rainier National Park, part 2, numerical simulation of heat and mass transfer in solidifying magmas: Eugene, Oreg., University of Oregon M.S. thesis, 227 p.

Tolan, T.L., 1982, The stratigraphic relationships of the Columbia River Basalt Group in the lower Columbia River Gorge of Oregon and Washington: Portland, Oreg., Portland State University M.S. thesis, 151 p.

Verplanck, E.P., 1985, Temporal variations in volume and geochemistry of volcanism in the Western Cascades, Oregon: Corvallis, Oreg., Oregon State University M.S. thesis, 107 p.

Vine, J.D., 1969, Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 624, 67 p.

Wagner, D.L., and Saucedo, G.J., compilers, 1987, Geologic map of the Weed quadrangle, California: California Division of Mines and Geology, Map 4A, 4 sheets, scale 1:250,000, 15 p.

Wells, F.G., and Waters, A.C., 1935, Basaltic rocks in the Umpqua Formation: Geological Society of America Bulletin, v. 46, p. 961–972.

White, C.M., 1980a, Geology and geochemistry of volcanic rock in the Detroit area, Western Cascade Range, Oregon: Eugene, Oreg., University of Oregon Ph.D. thesis, 177 p.

White, C.M., 1980b, Geology of the Breitenbush Hot Springs quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 9, 26 p.

White, C.M., and McBirney, A.R., 1978, Some quantitative aspects of orogenic volcanism in the Oregon Cascades, *in* Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 369–388.

Wiley, T.J., 1993, Geology and mineral resources map of the Cleveland Ridge quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-73, scale 1:24,000.

Wiley, T.J., and Hladky, F.R., 1991, Geology and mineral resources map of the Boswell Mountain quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-70, scale 1:24,000.

Wiley, T.J., and Smith, J.G., 1993, Preliminary geologic map of the Medford East, Medford West, Eagle Point, and Sams Valley quadrangles, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-93-13, scale 1:24,000.

Winters, W.J., 1984, Stratigraphy and sedimentology of Paleogene arkosic and volcaniclastic strata, Johnson Creek–Chambers Creek area, Southern Cascade Range, Washington: Portland, Oreg., Portland State University M.S. thesis, 162 p.

Wise, W.S., 1969, Geology and petrology of the Mt. Hood area—A study of High Cascade volcanism: Geological Society of America Bulletin, v. 80, no. 6, p. 969–1006.

Wise, W.S., 1970, Cenozoic volcanism in the Cascade Mountains of southern Washington: Washington Division of Mines and Geology Bulletin 60, 45 p.

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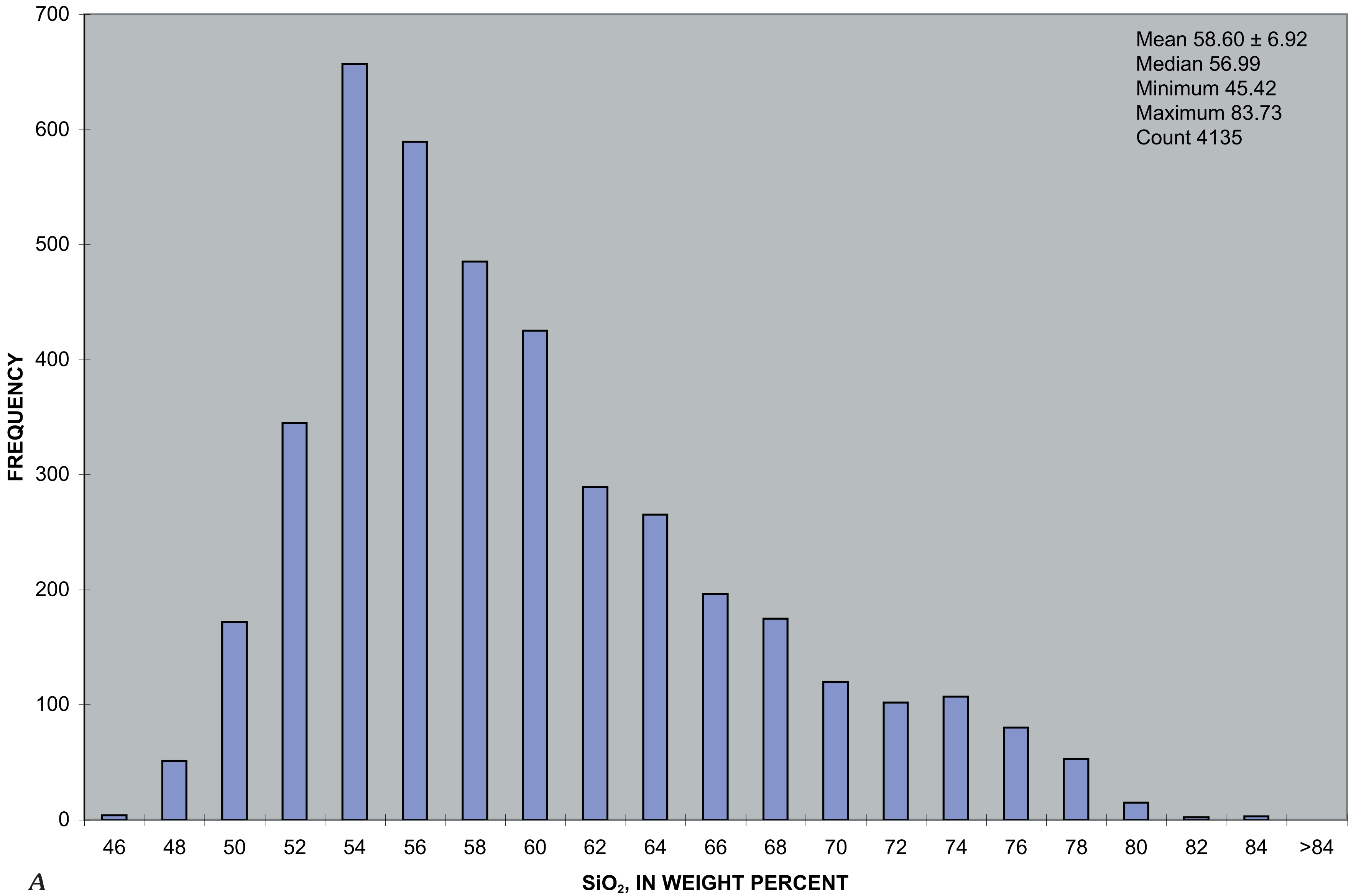
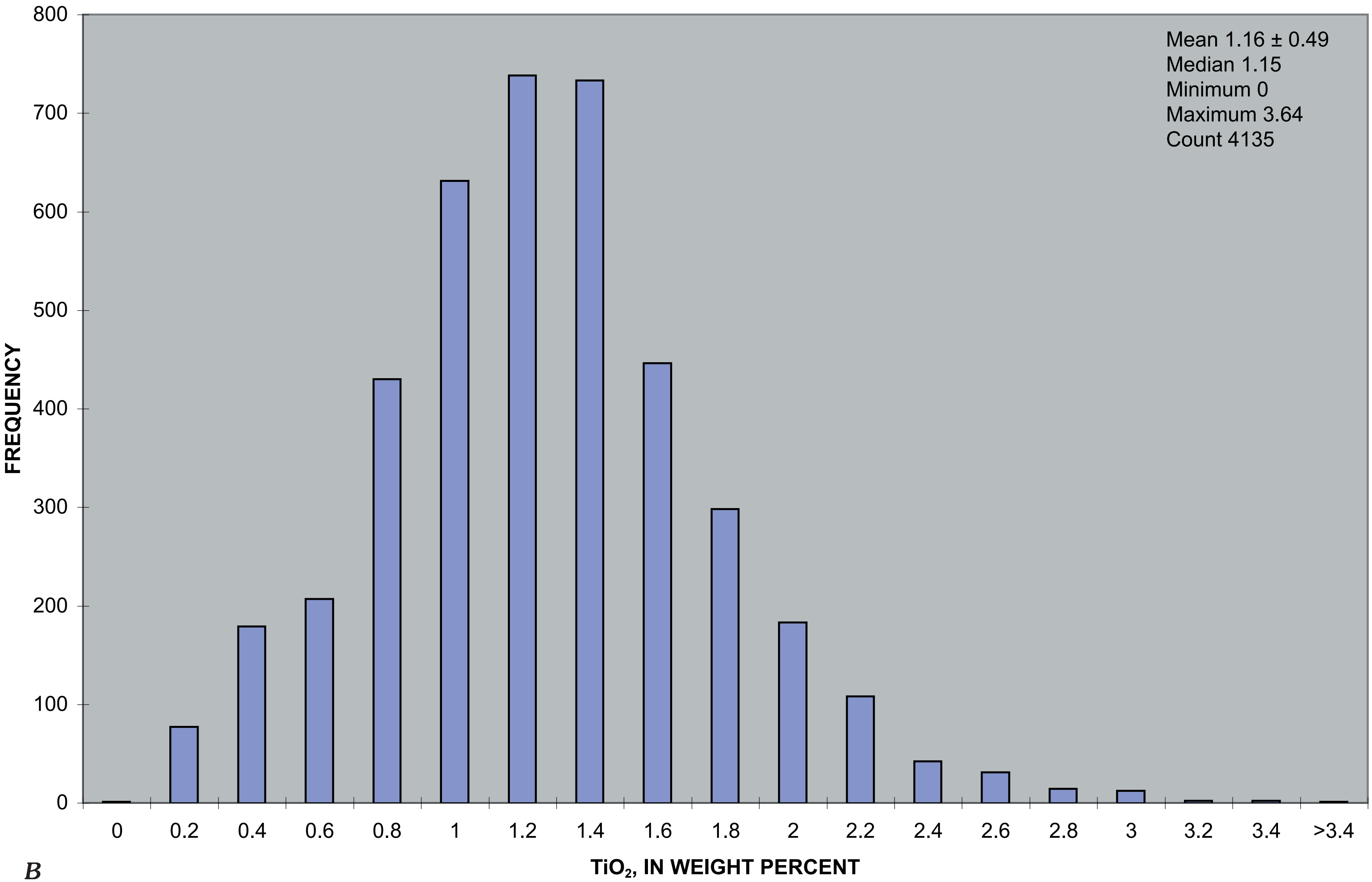
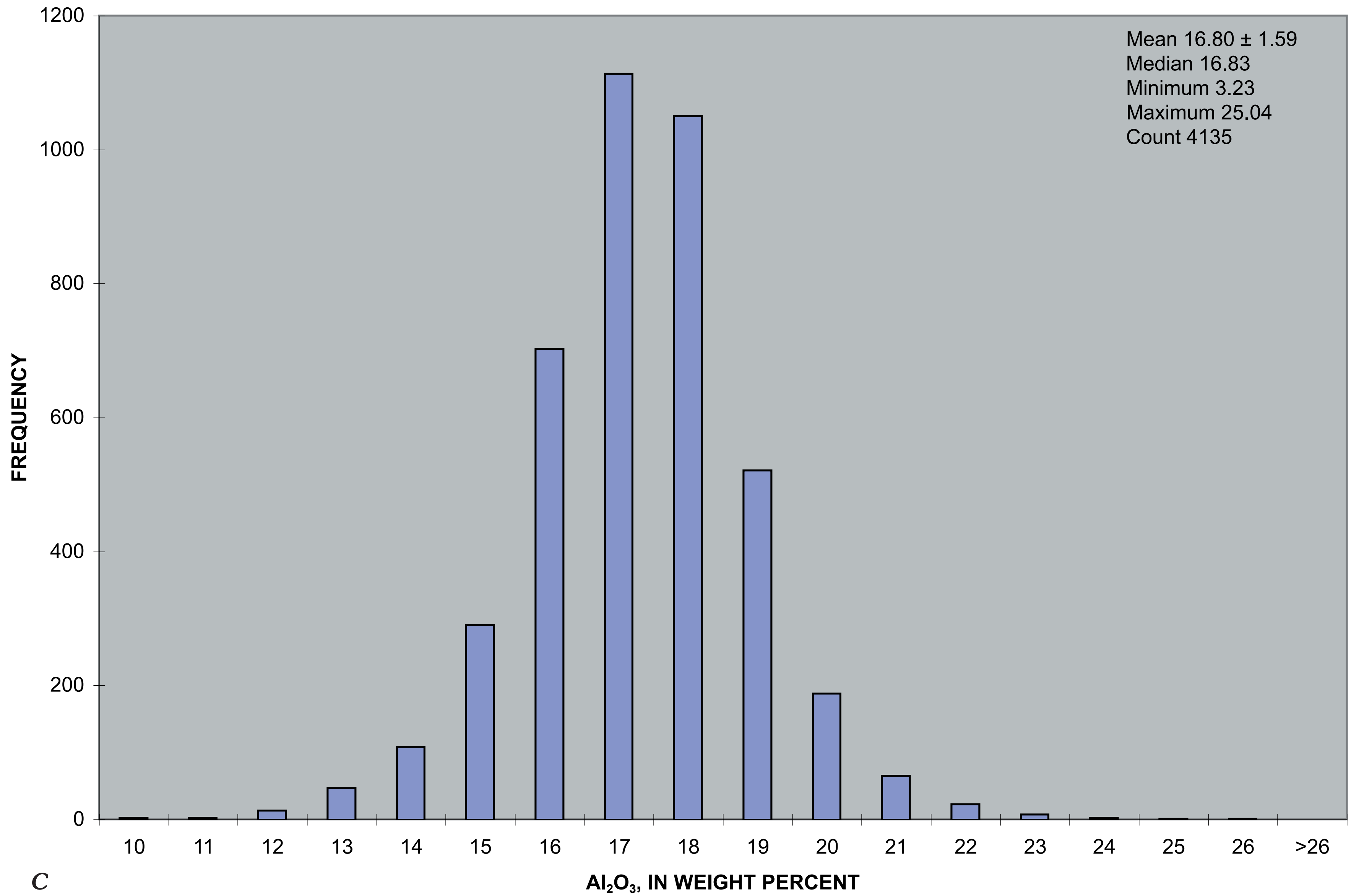


Figure 2 (above and following pages). Frequency distribution histograms showing compositions of Western Cascades igneous rock samples. Height of each histogram bar indicates number of samples whose abundances of indicated component are as much as numeric label beneath bar but greater than value associated with next lower abundance bar (for instance, if two adjacent bars are labeled 90 and 100 and if associated data are reported as whole numbers, the height bar labeled 100 depicts the number of samples with abundances of 91 to 100). Also presented are basic descriptive statistics, including mean and standard deviation, median, minimum, maximum, and count, for each distribution. *A*, SiO_2; *B*, TiO_2; *C*, Al_2O_3; *D*, FeO*; *E*, MnO; *F*, MgO; *G*, CaO; *H*, Na_2O; *I*, K_2O; *J*, P_2O_5; *K*, initial analytical total; *L*, total volatile content; *M*, Ba; *N*, La; *O*, Ce; *P*, Rb; *Q*, Sr; *R*, Y; *S*, Zr; *T*, Nb; *U*, Co; *V*, Cr; *W*, Ni; *X*, Sc; *Y*, V; *Z*, Ag; *AA*, Cu; *BB*, Mo; *CC*, Pb; *DD*, Zn; *EE*, Au.



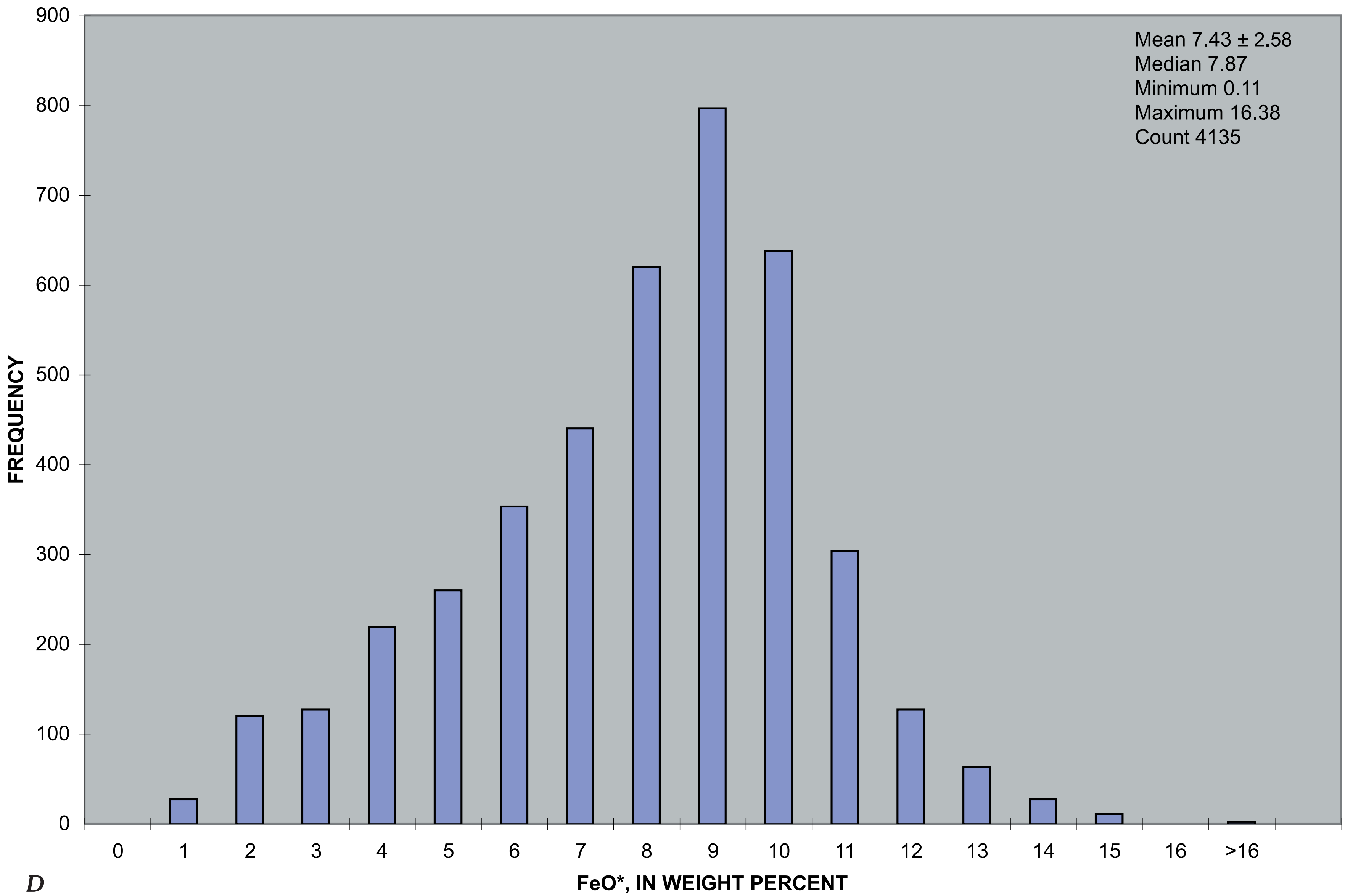
B

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



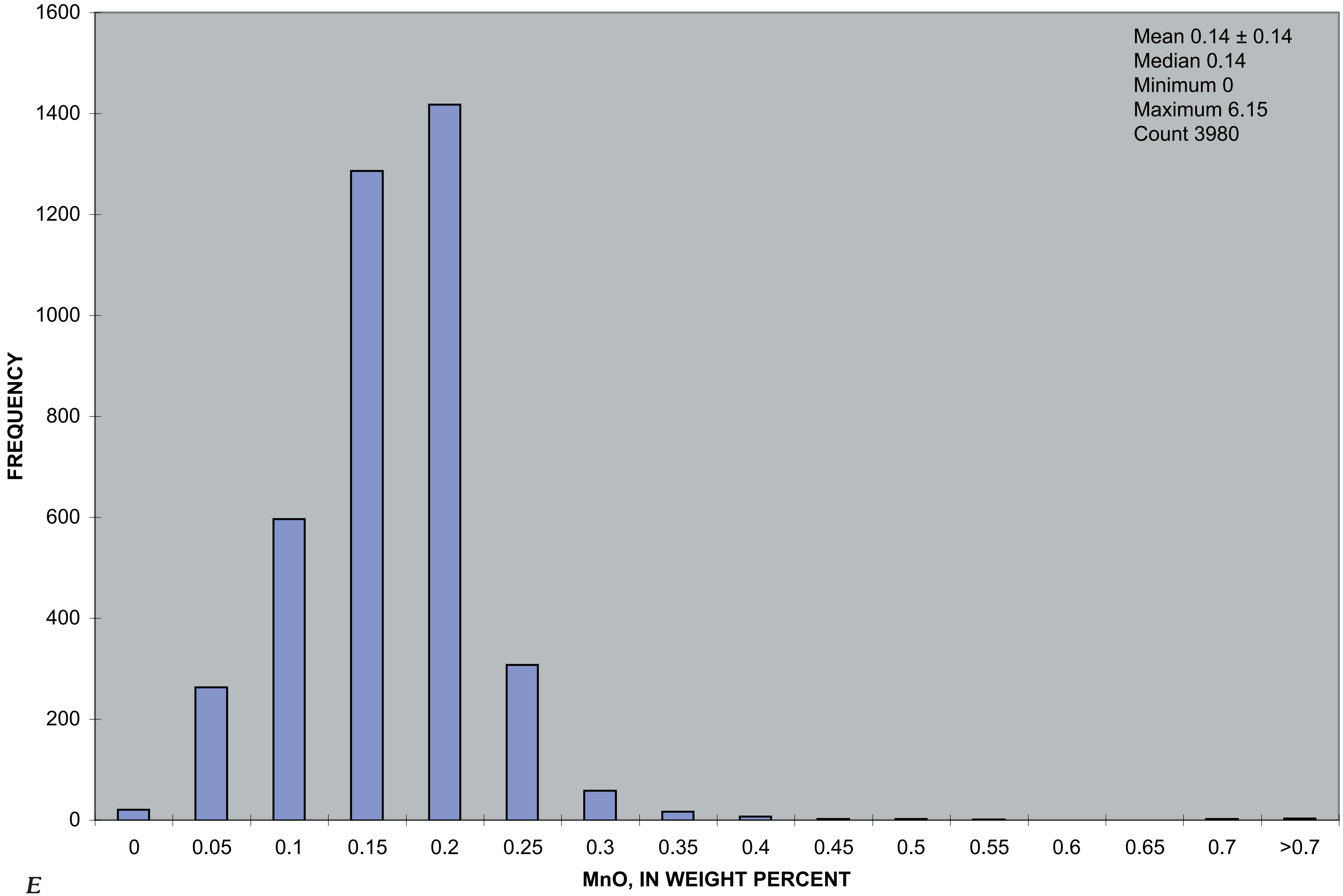
C

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



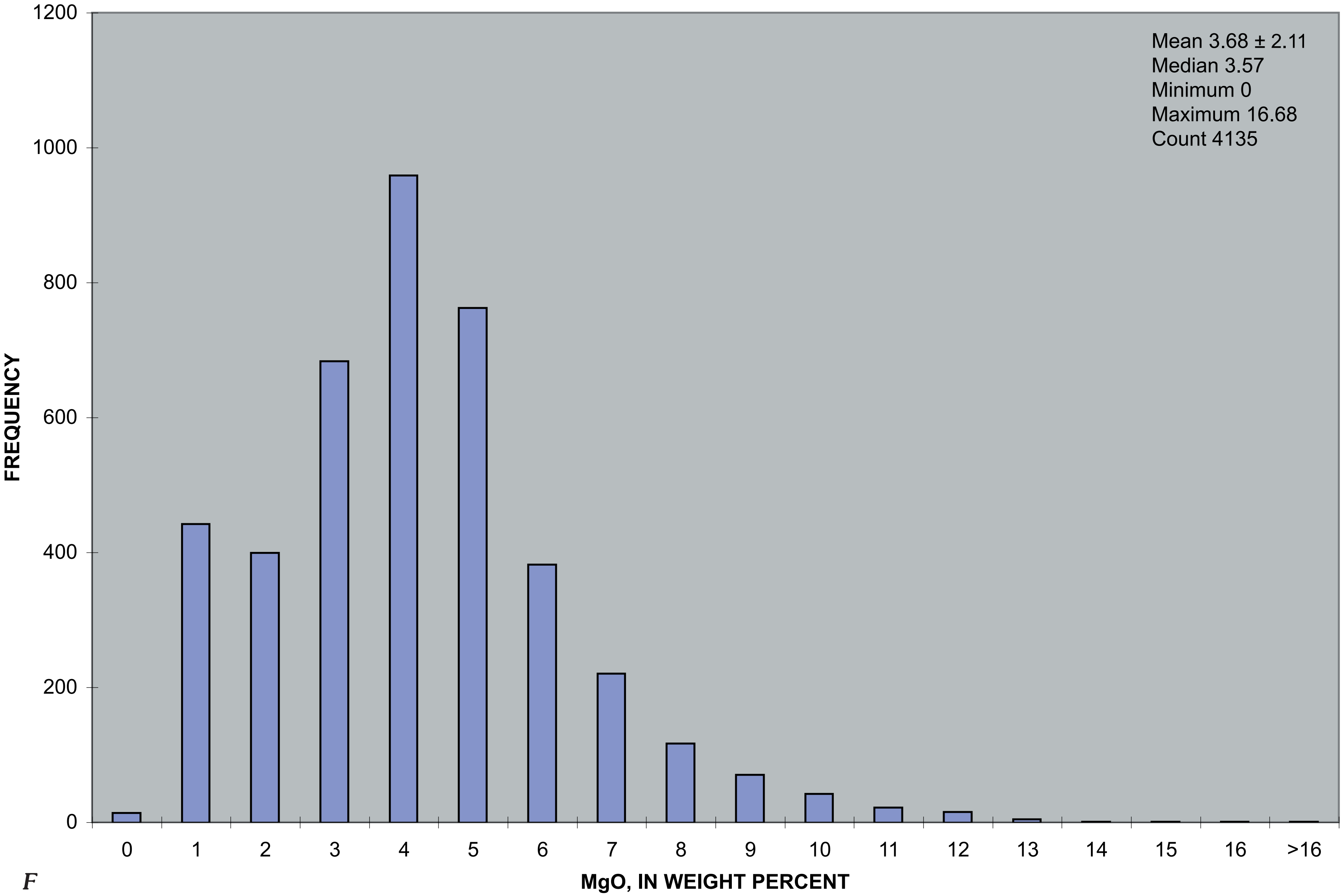
D

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



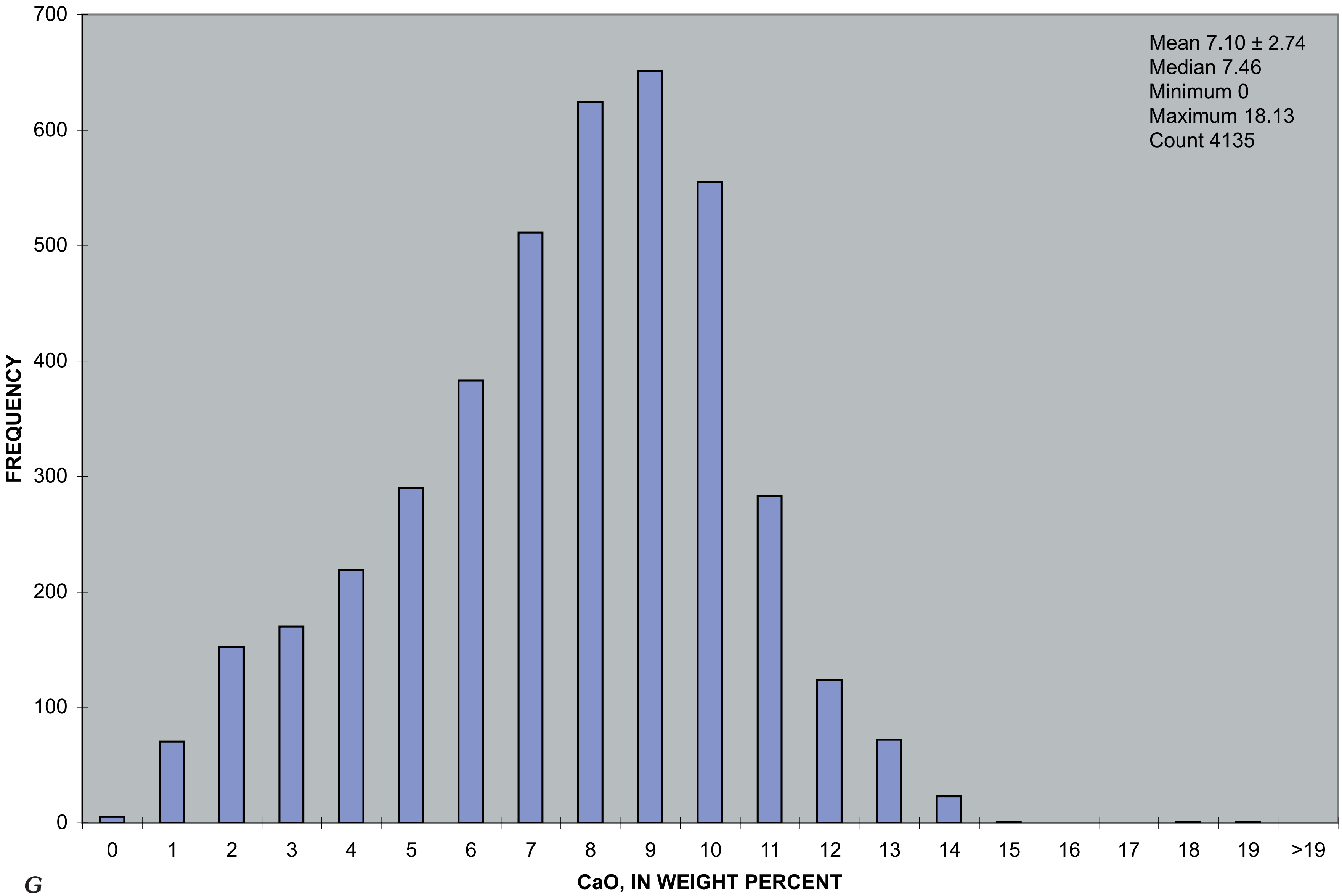
E

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



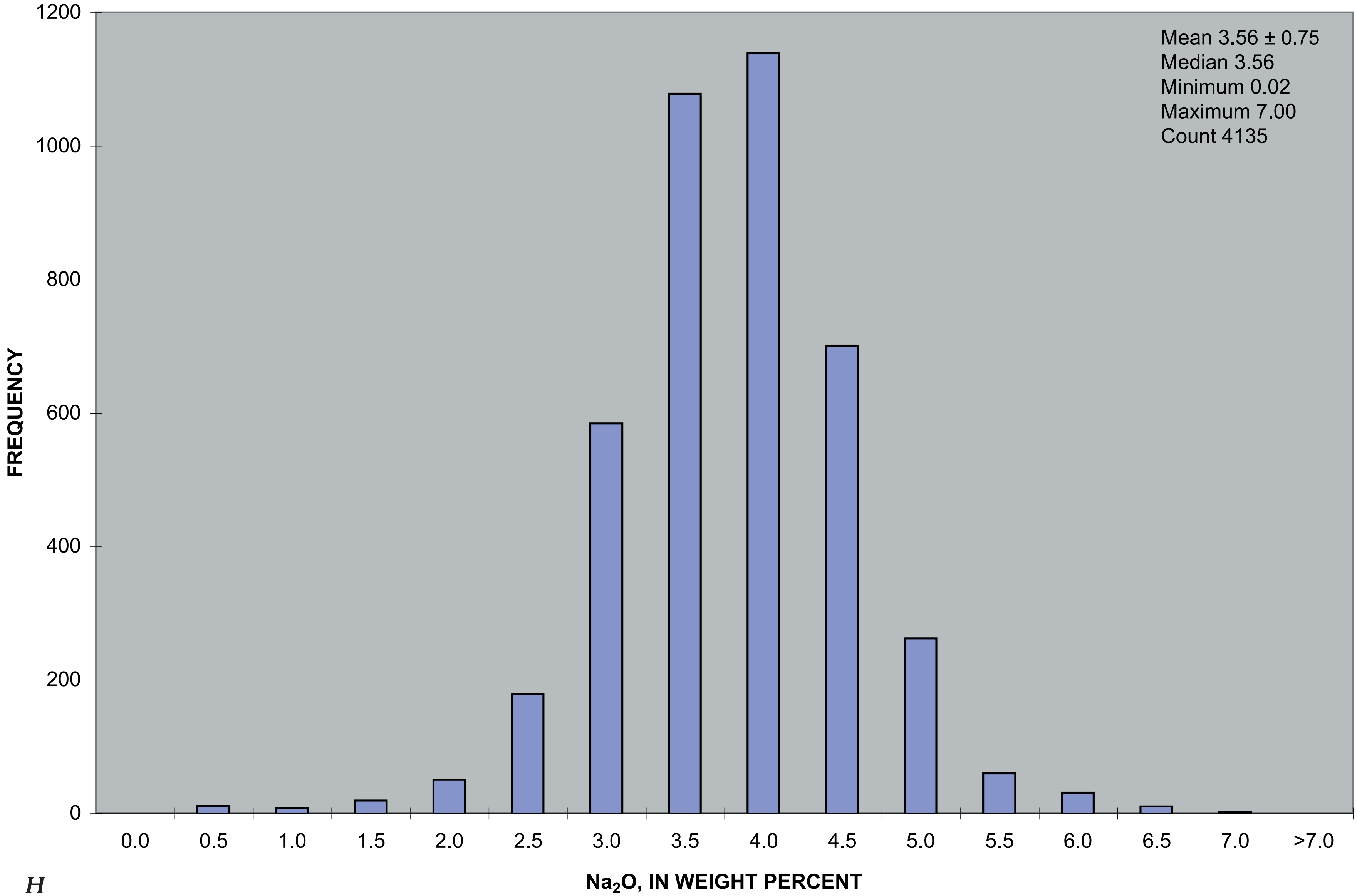
F

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



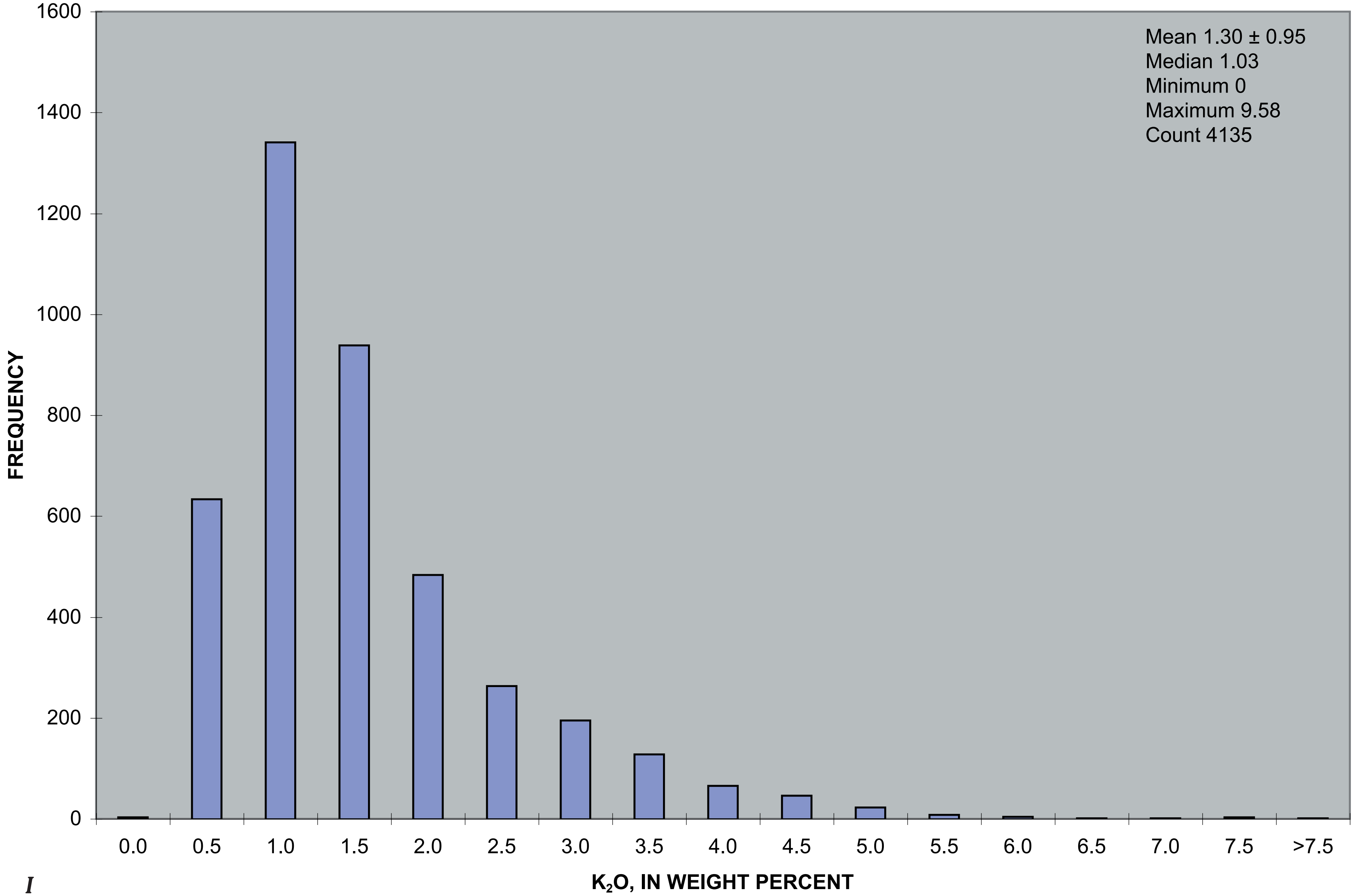
G

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



H

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



I

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

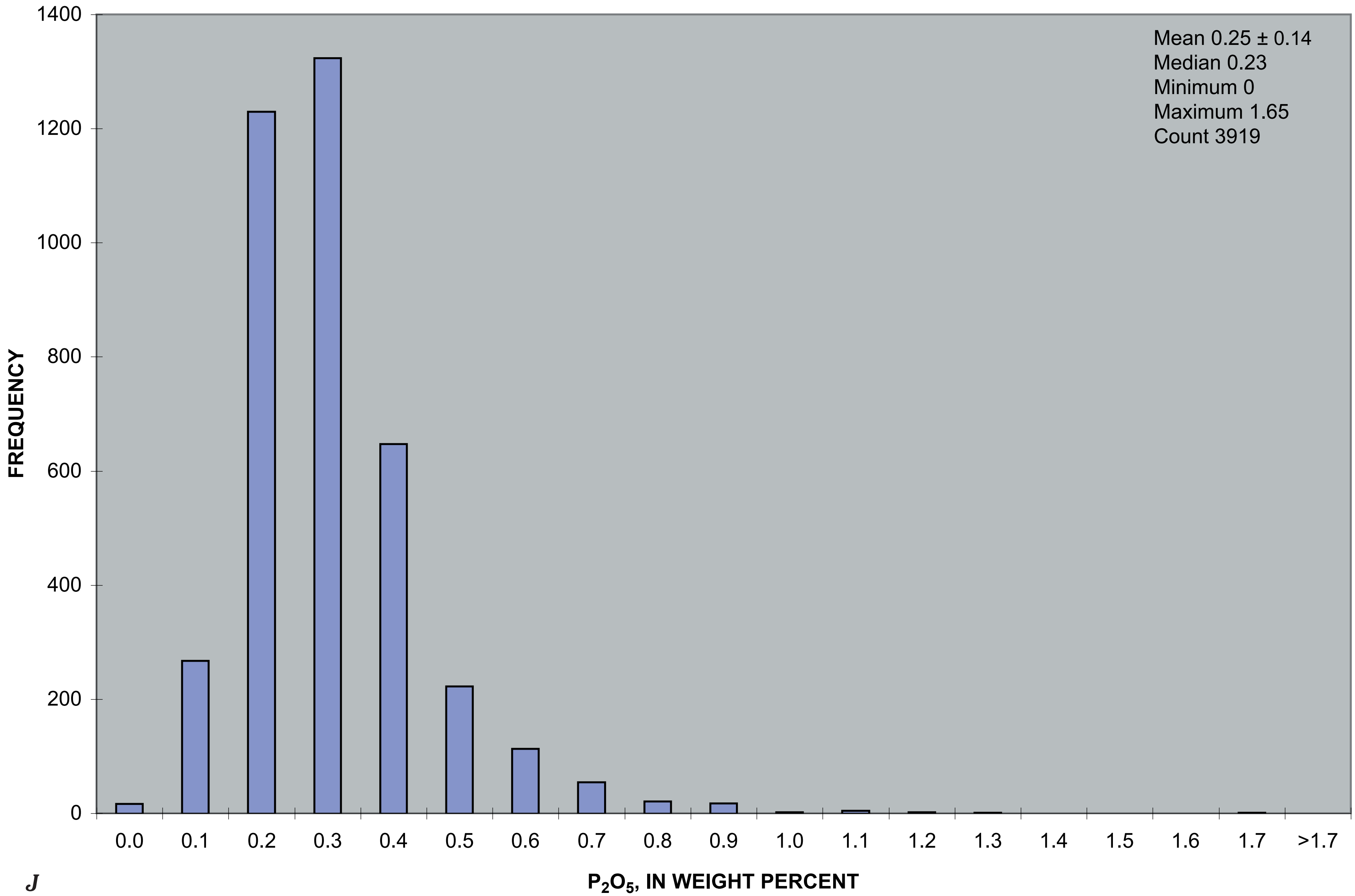


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

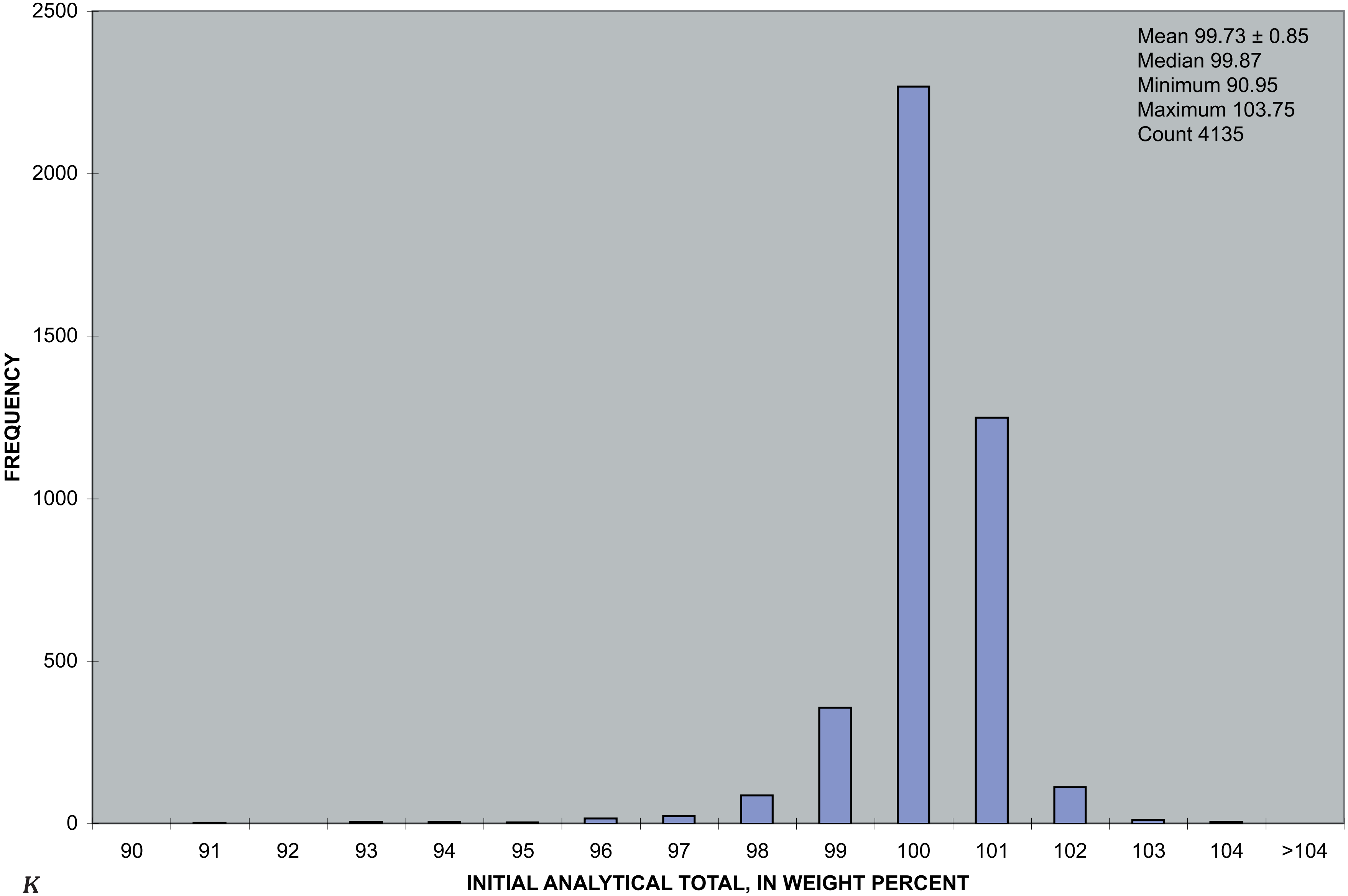
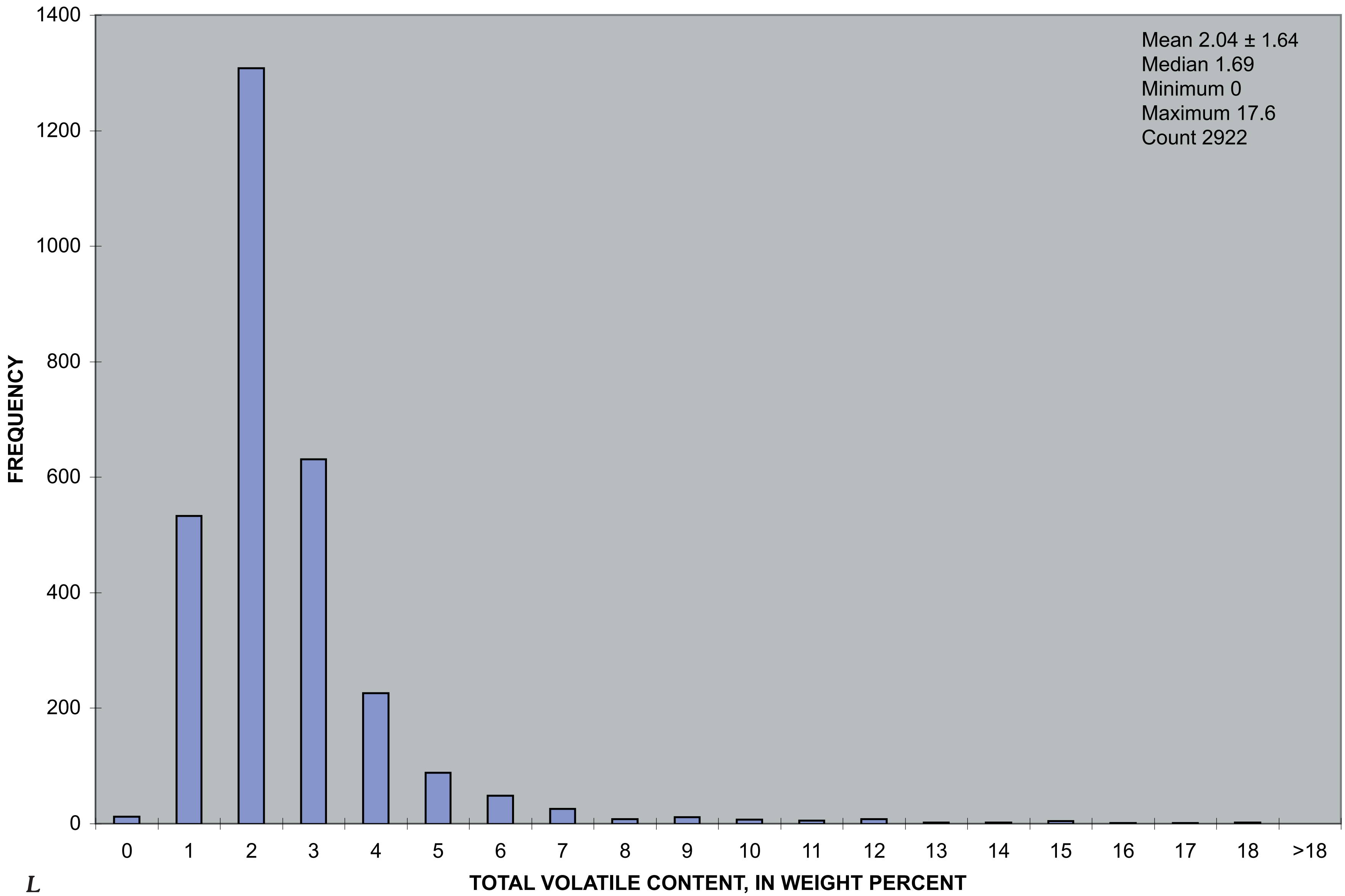
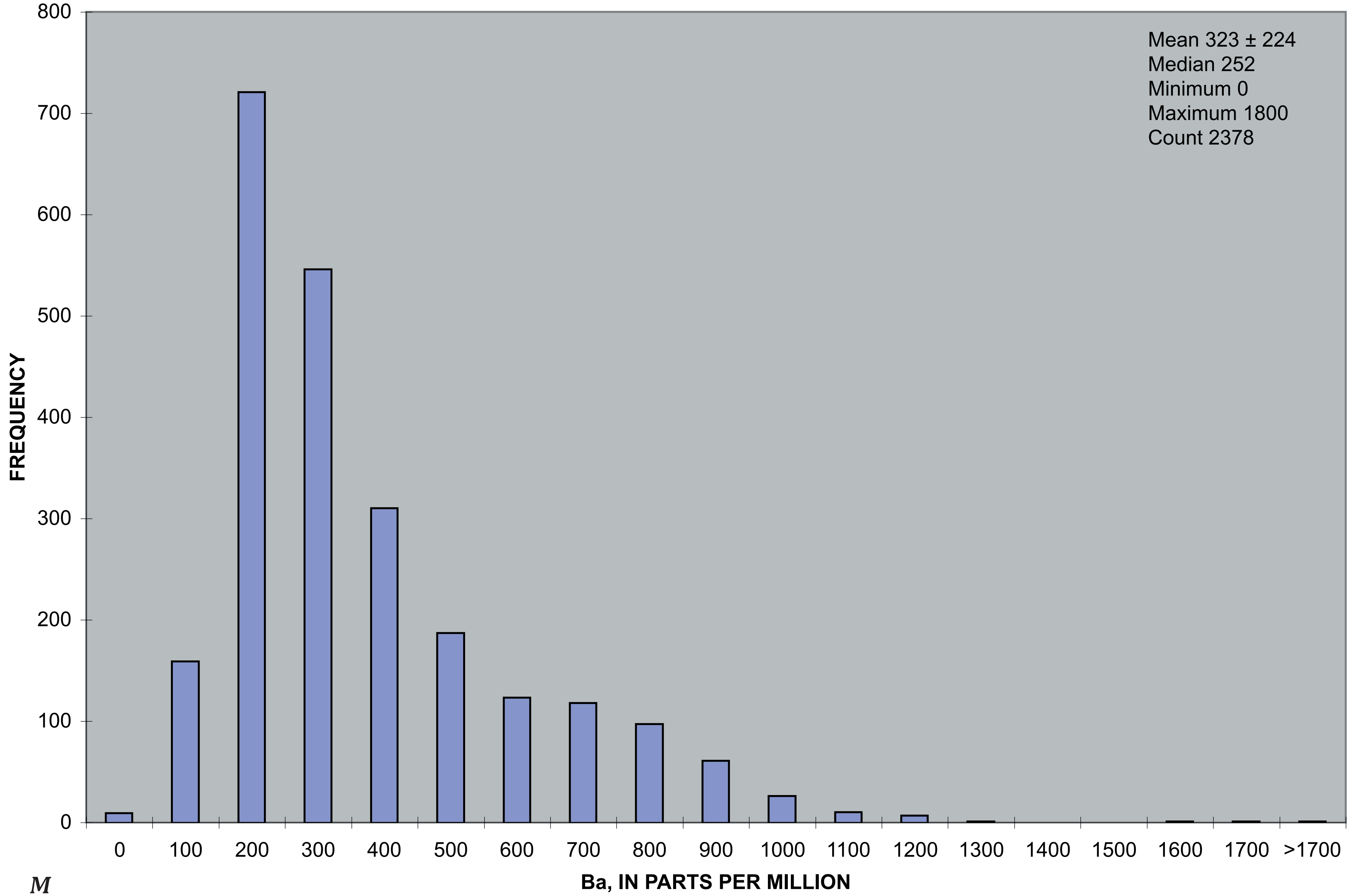


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



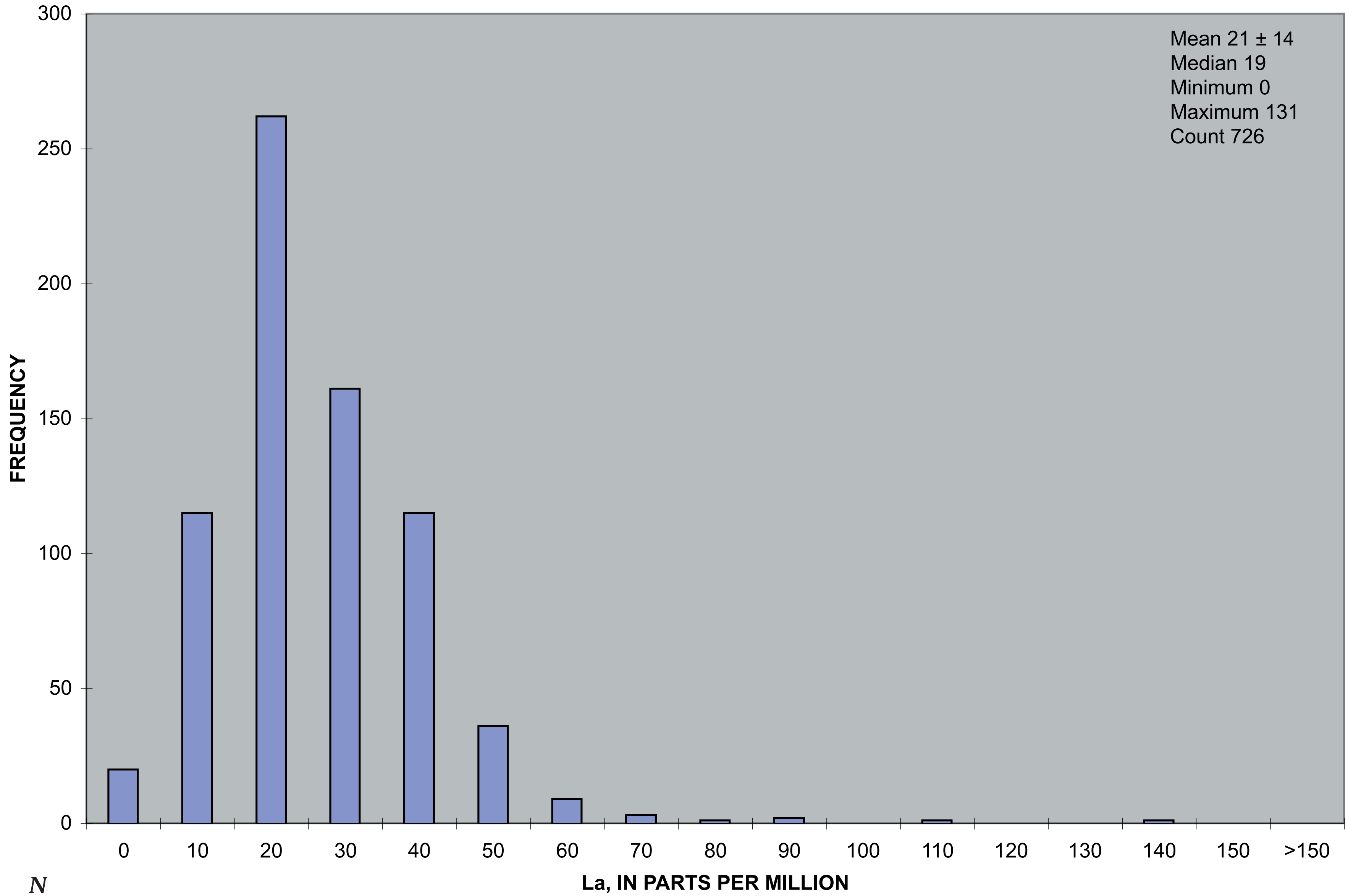
L

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



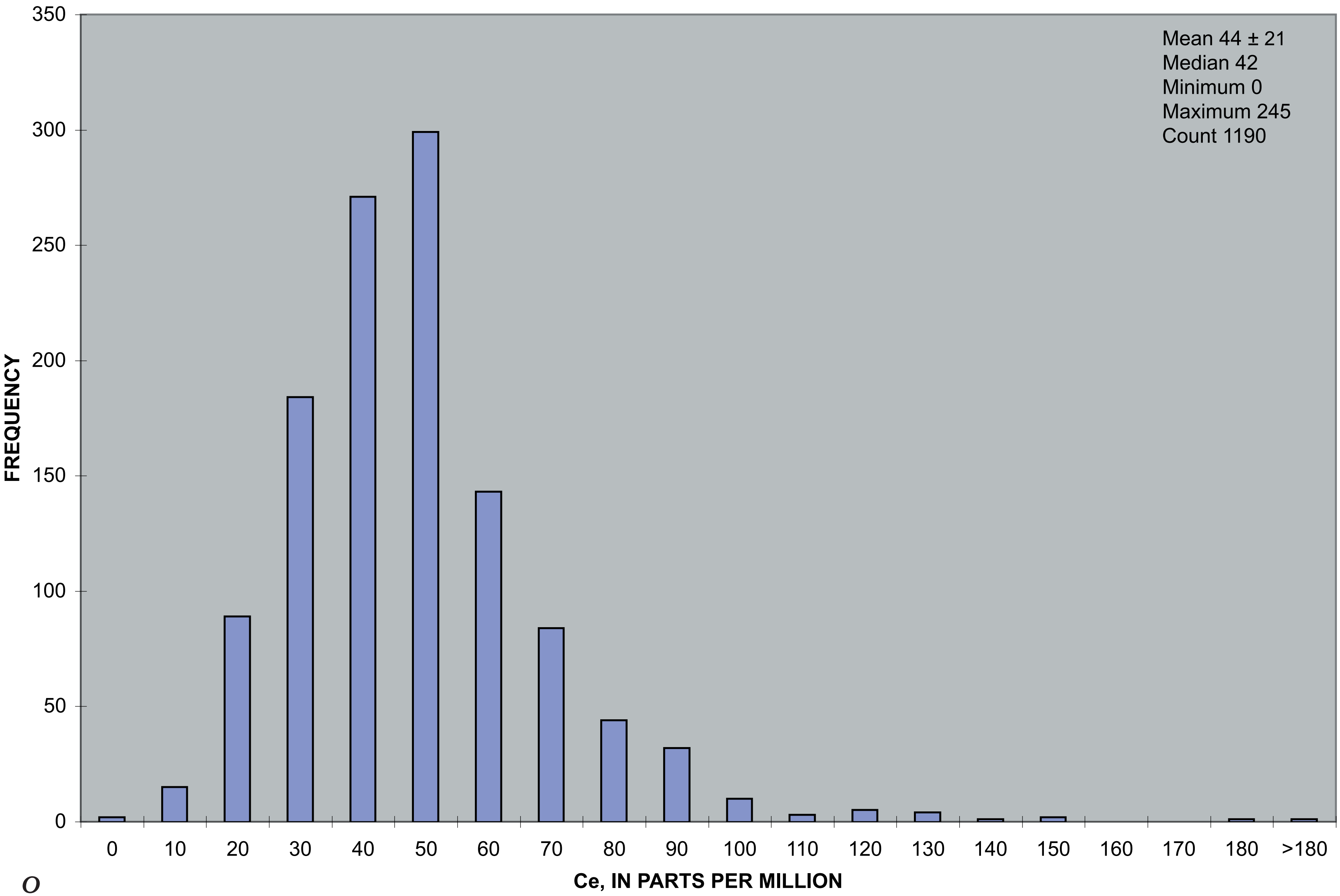
M

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



N

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



O

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

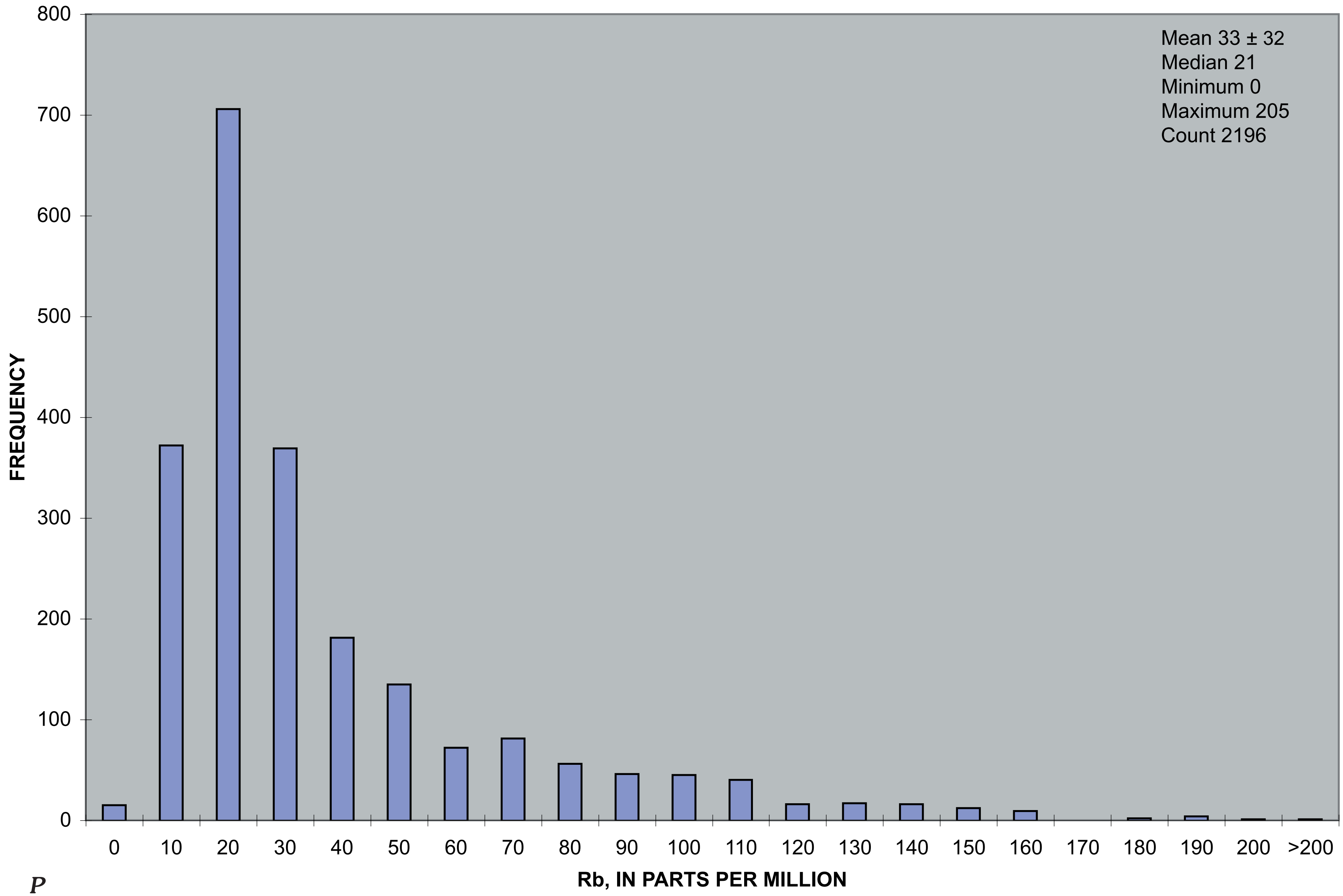
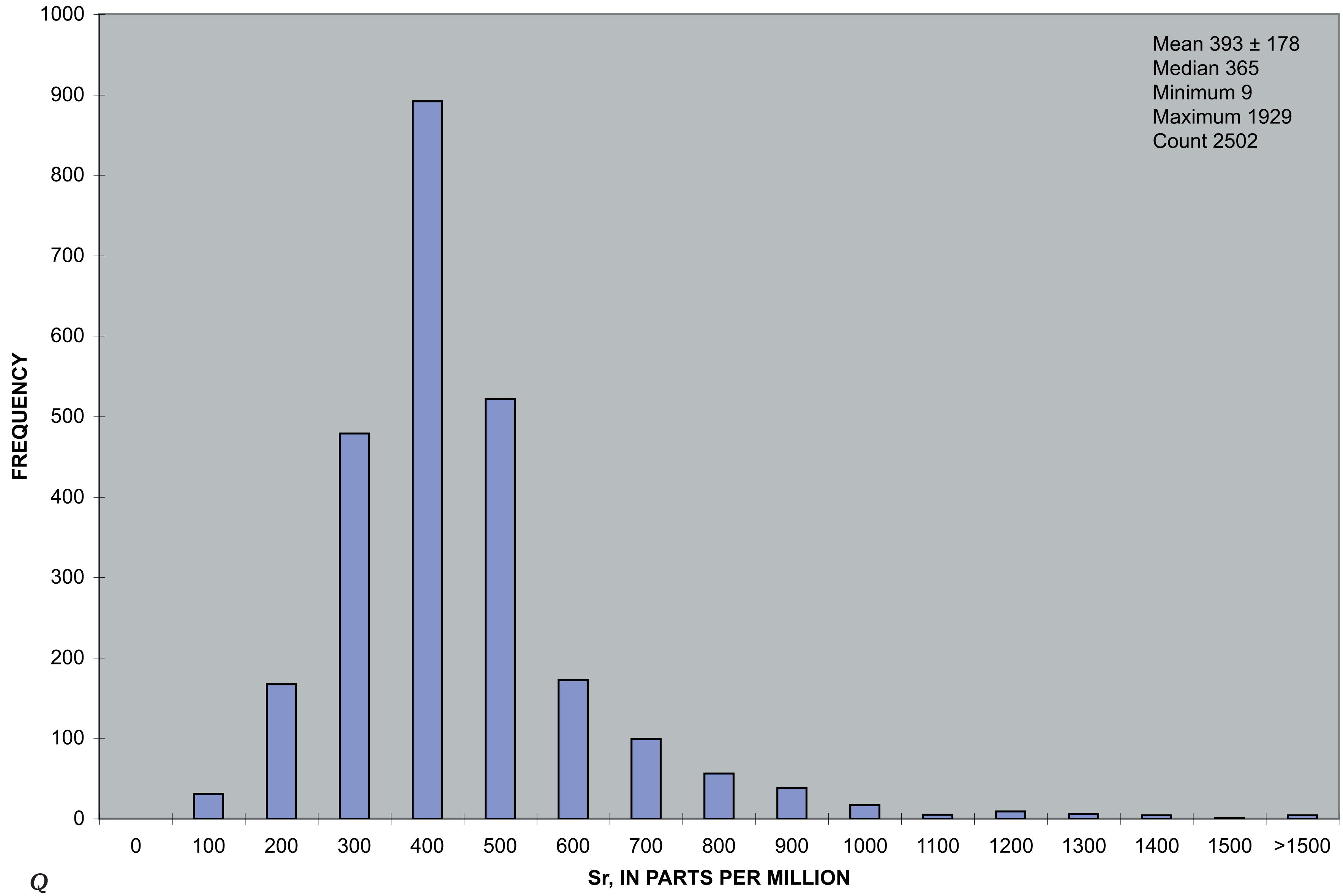
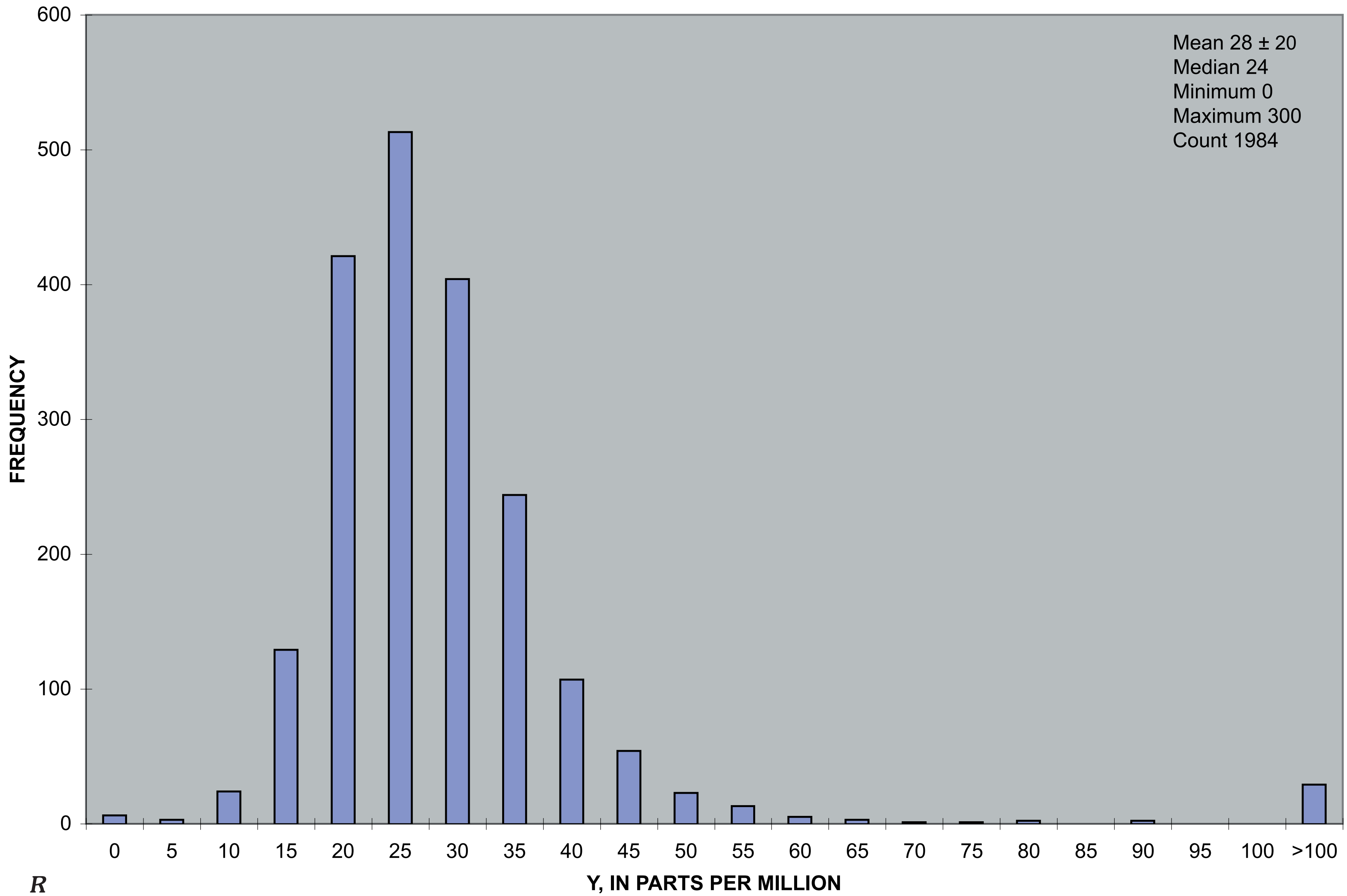


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



Q

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



R

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

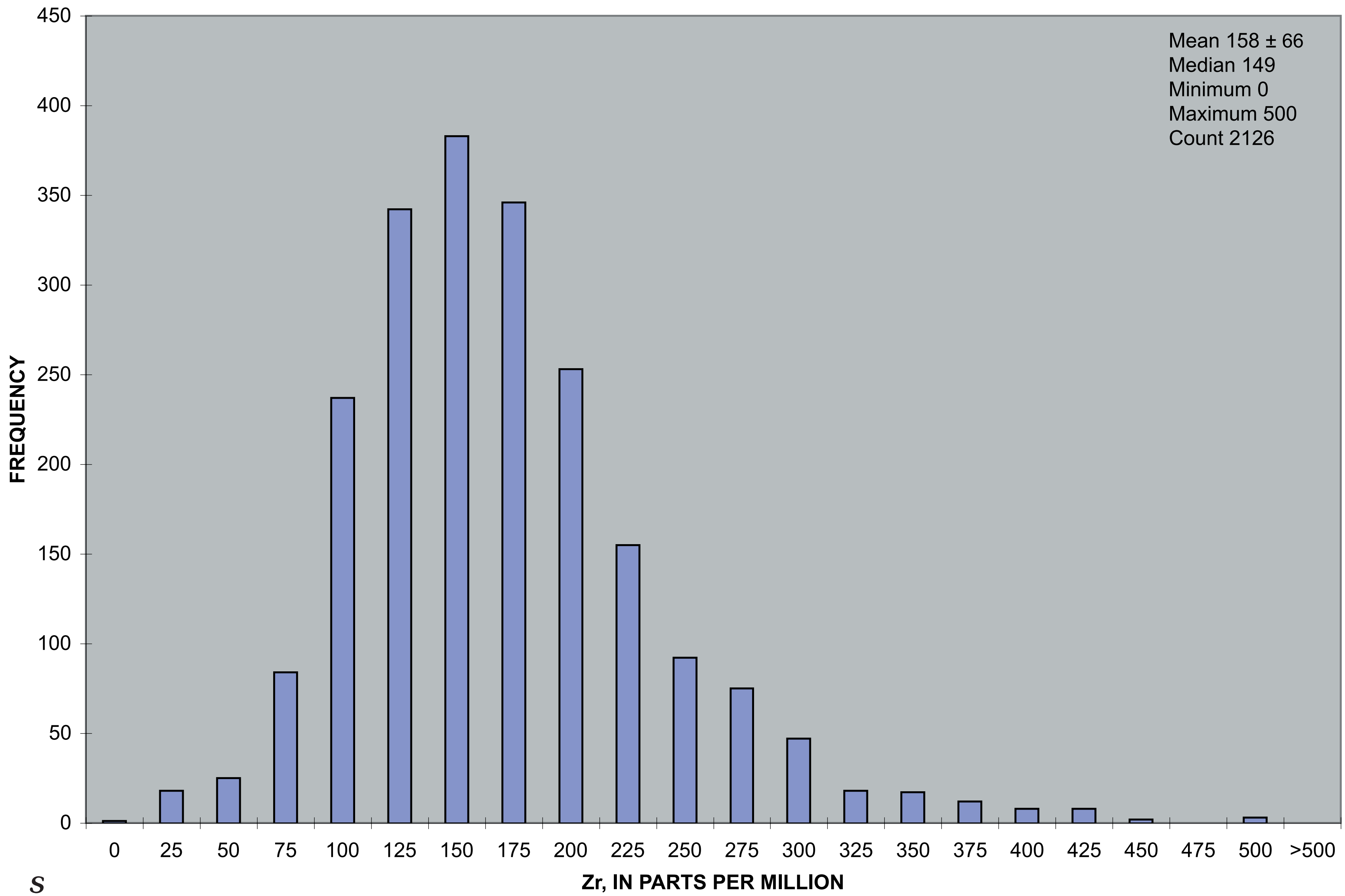


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

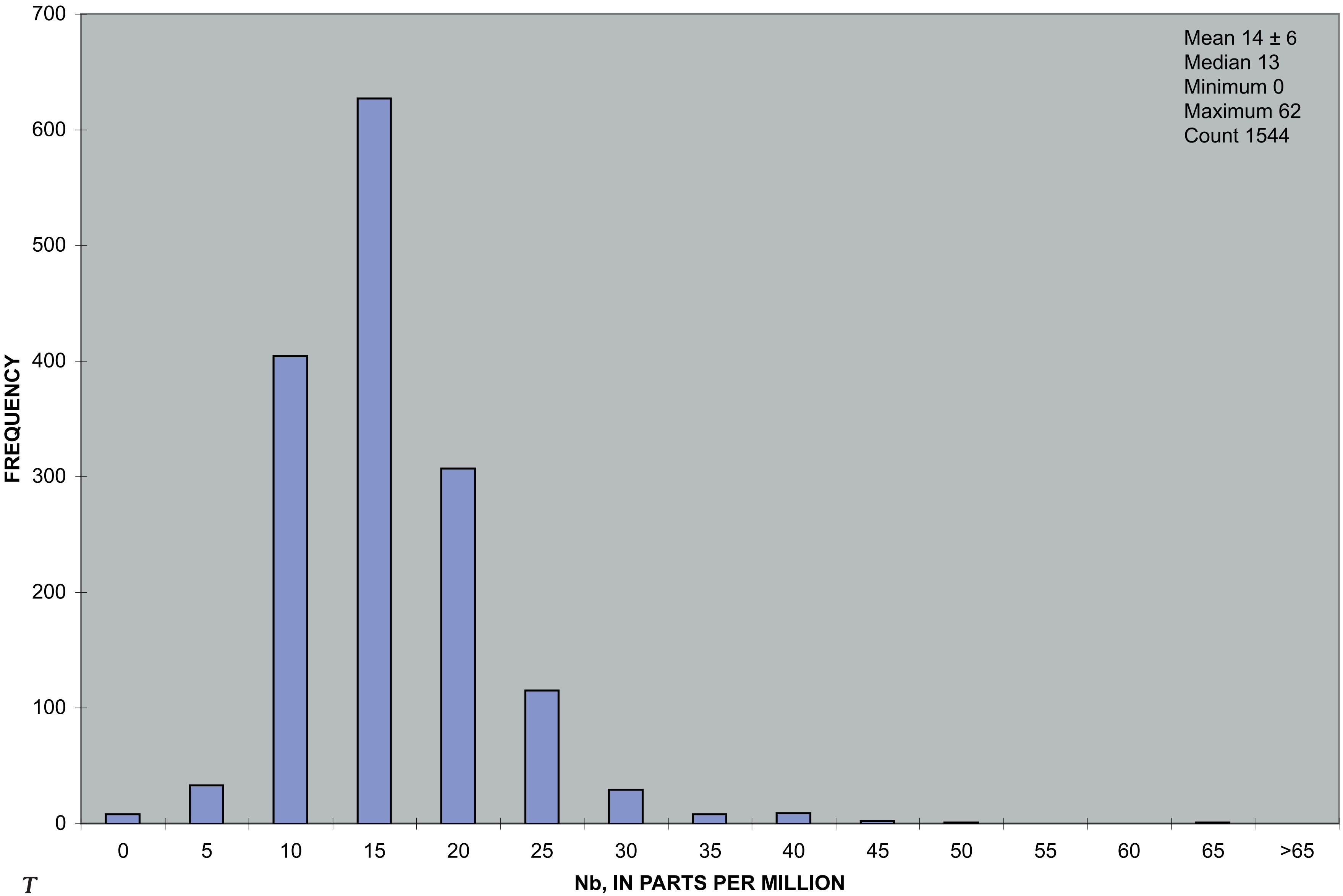


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

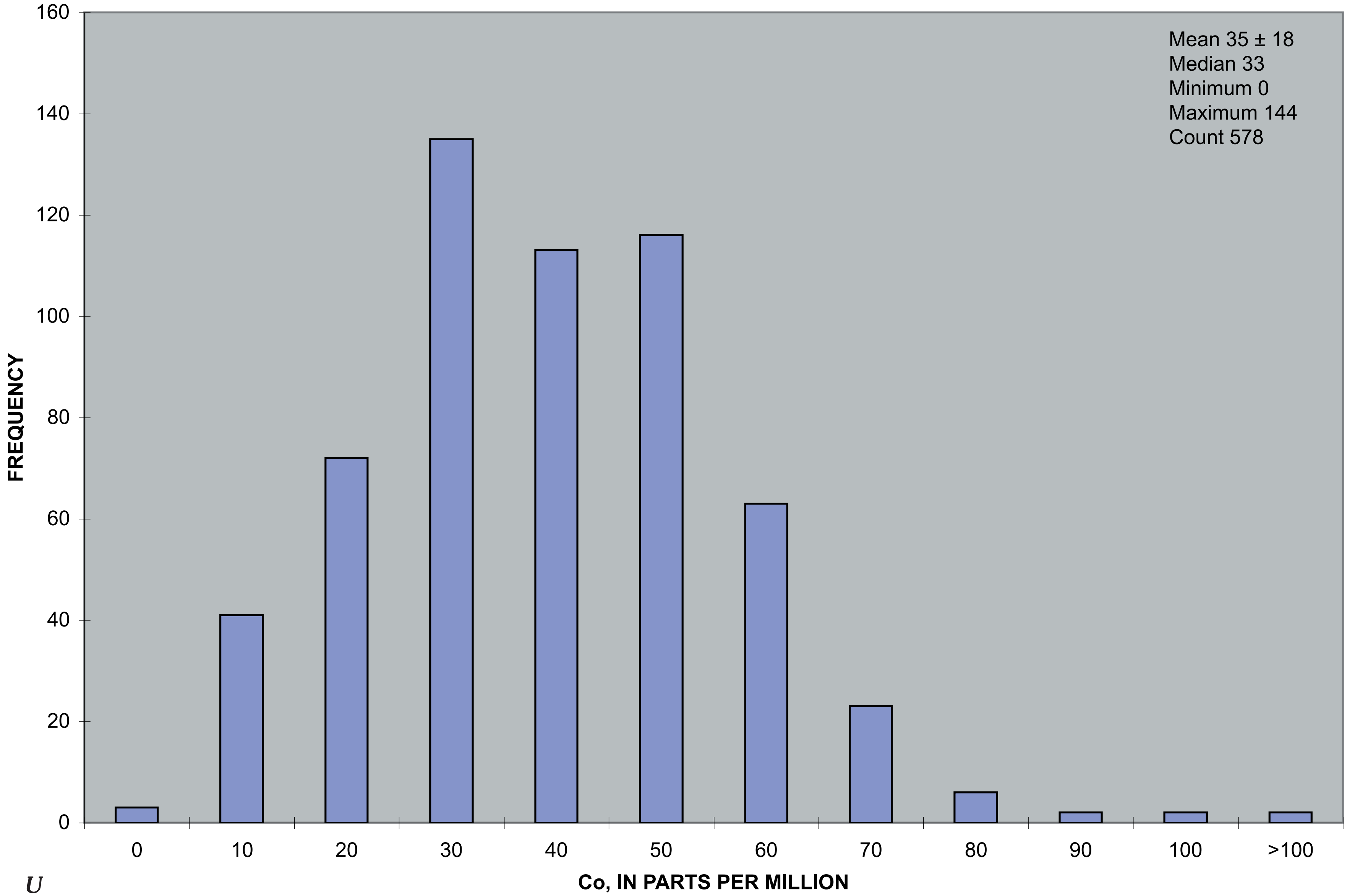


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

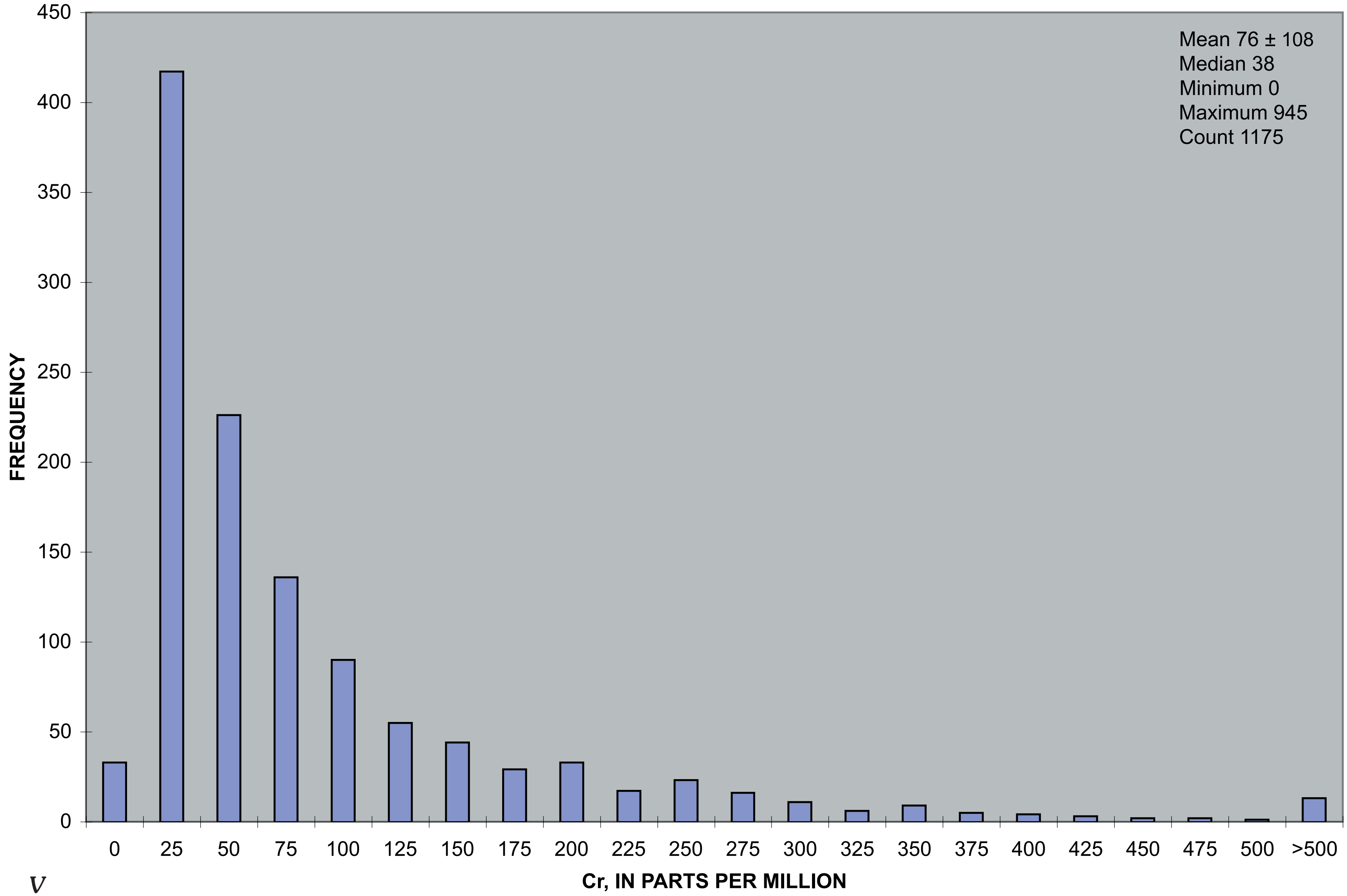


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

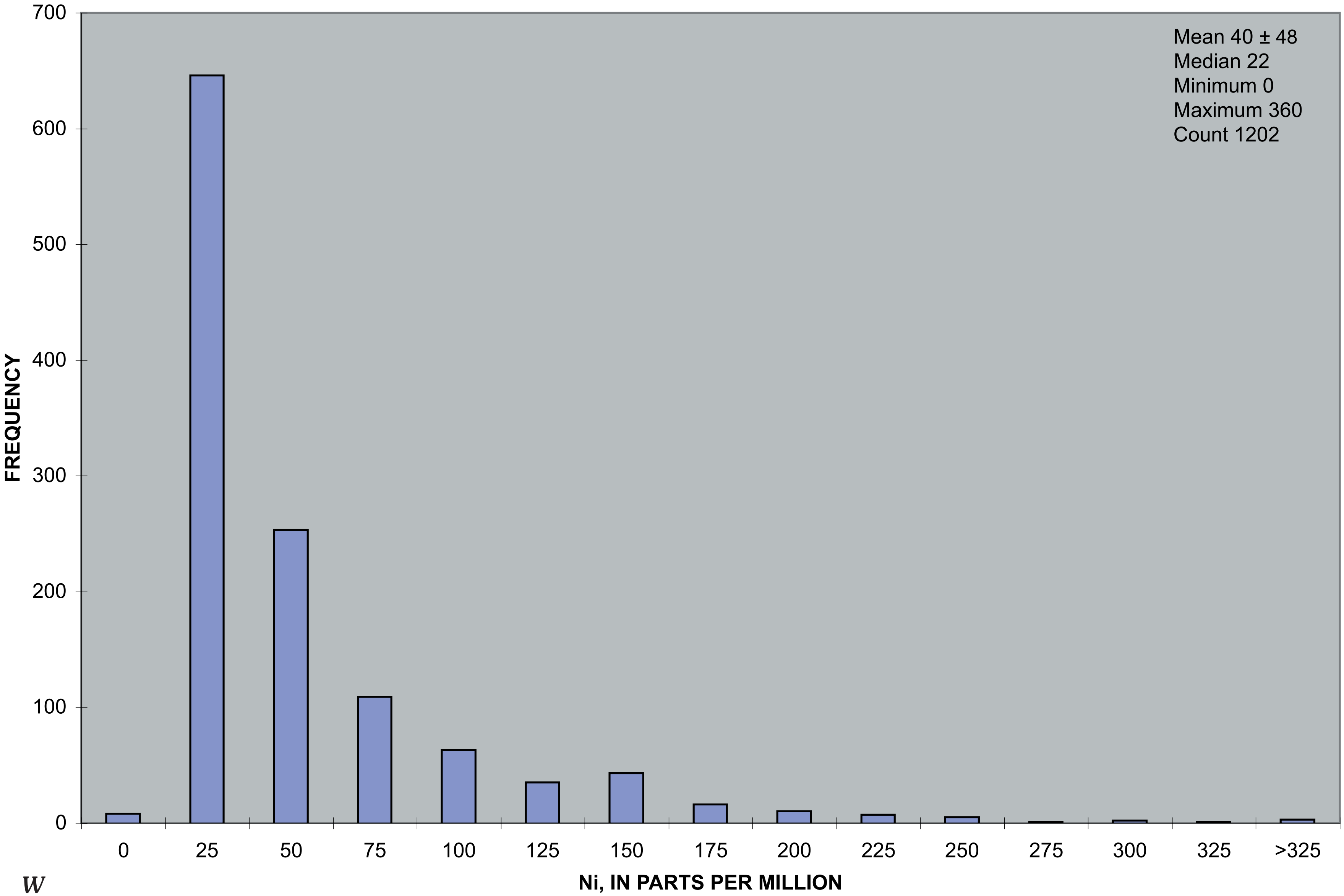


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

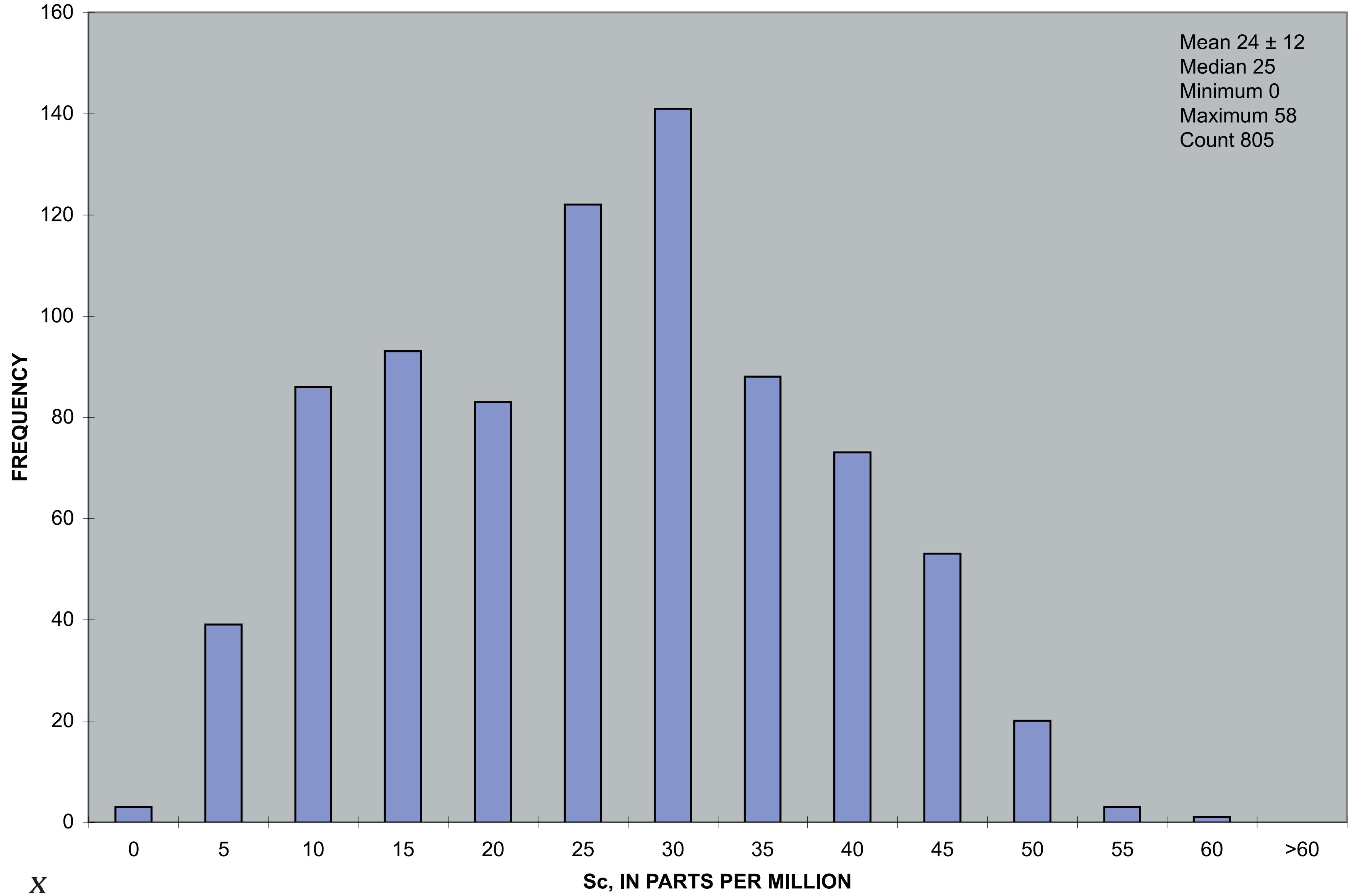


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

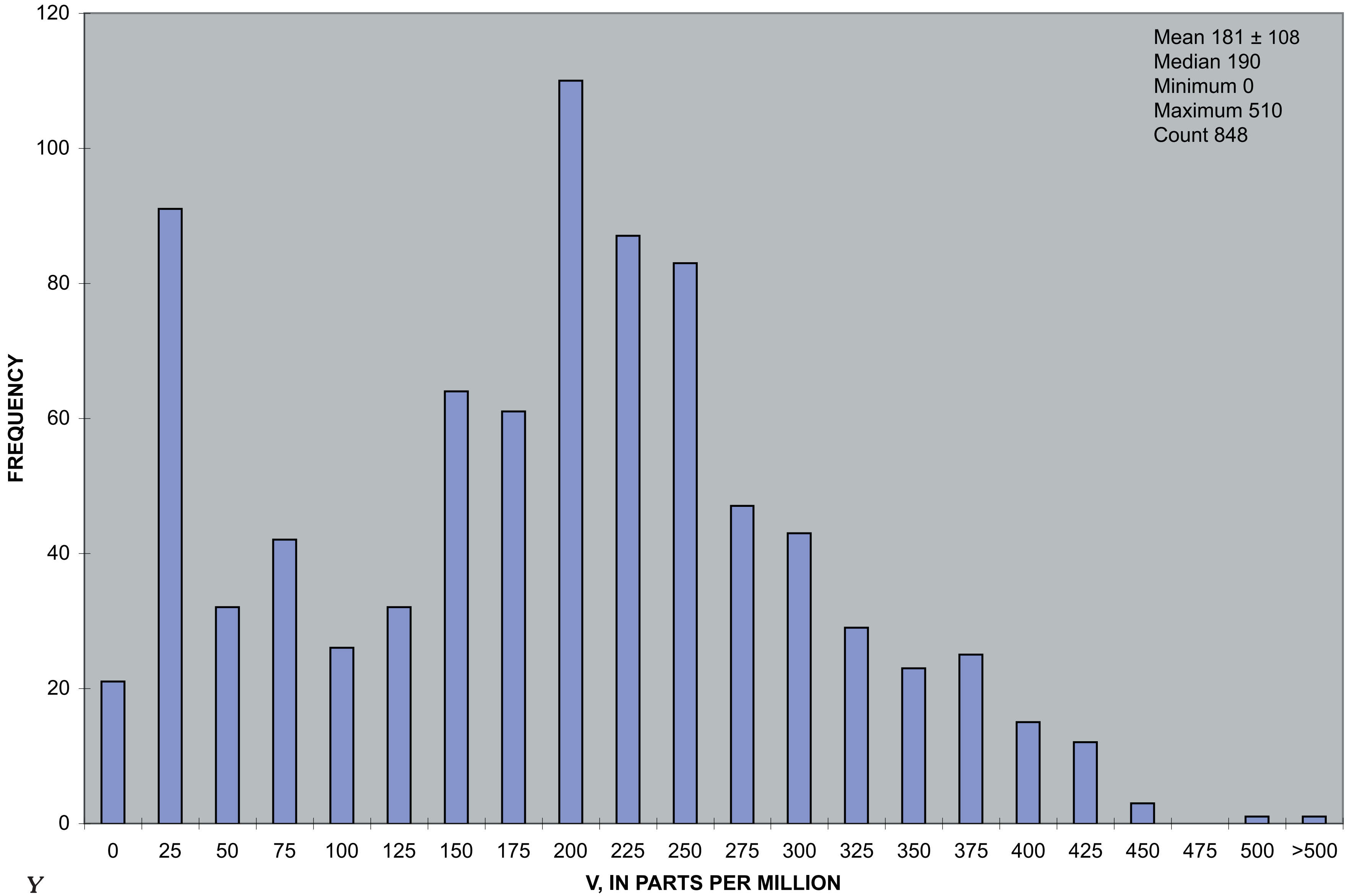


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

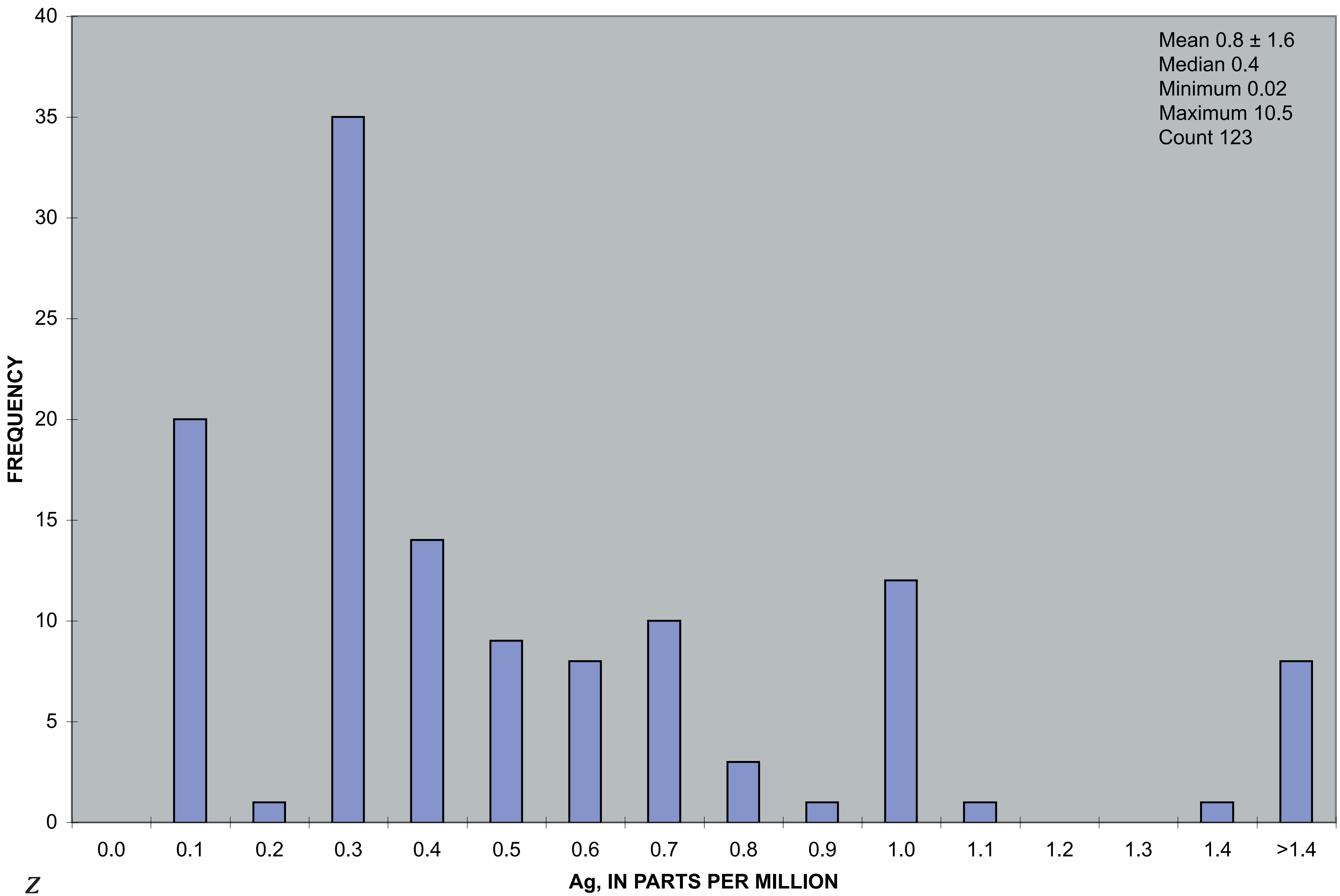
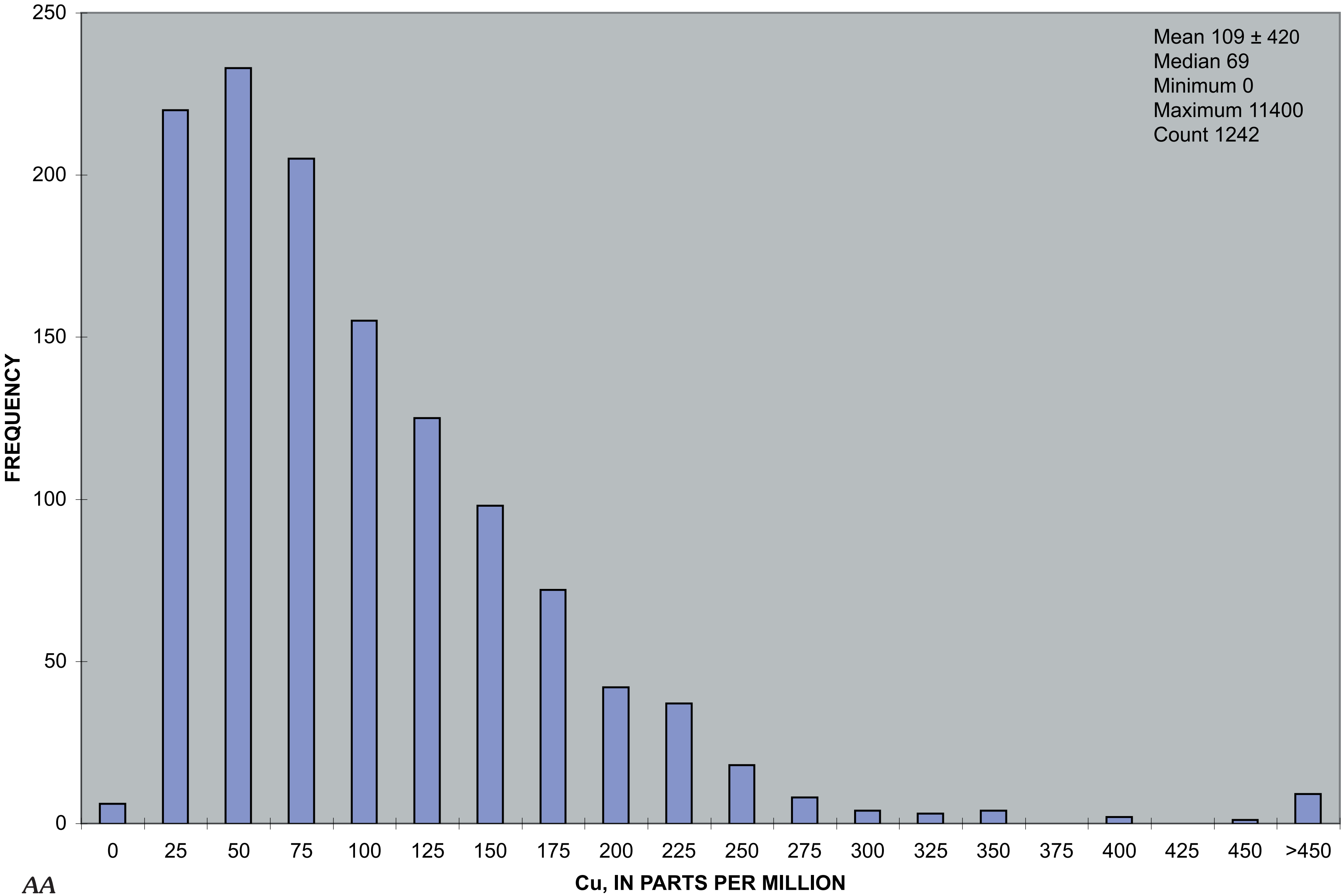
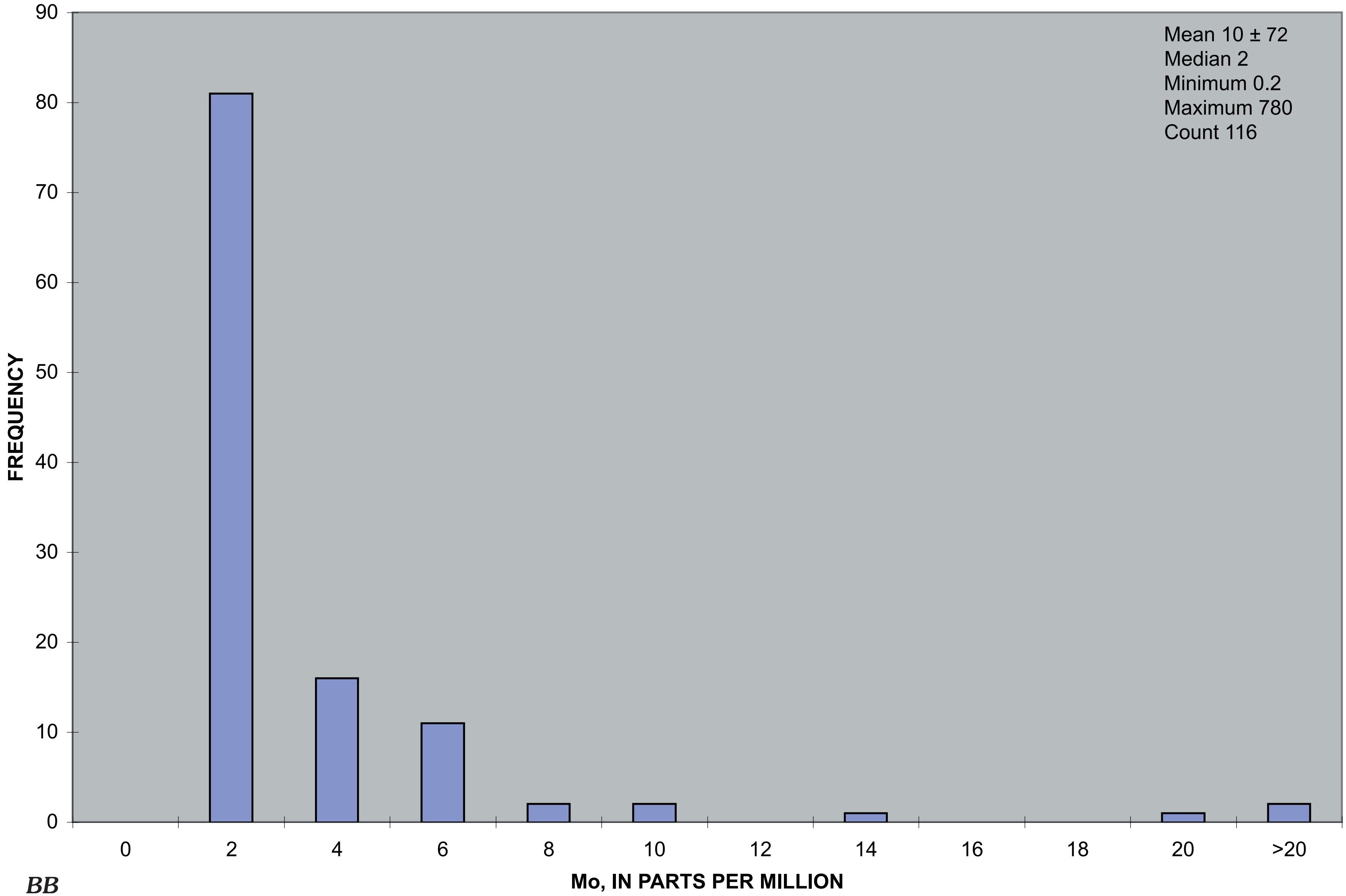


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



AA

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



BB

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

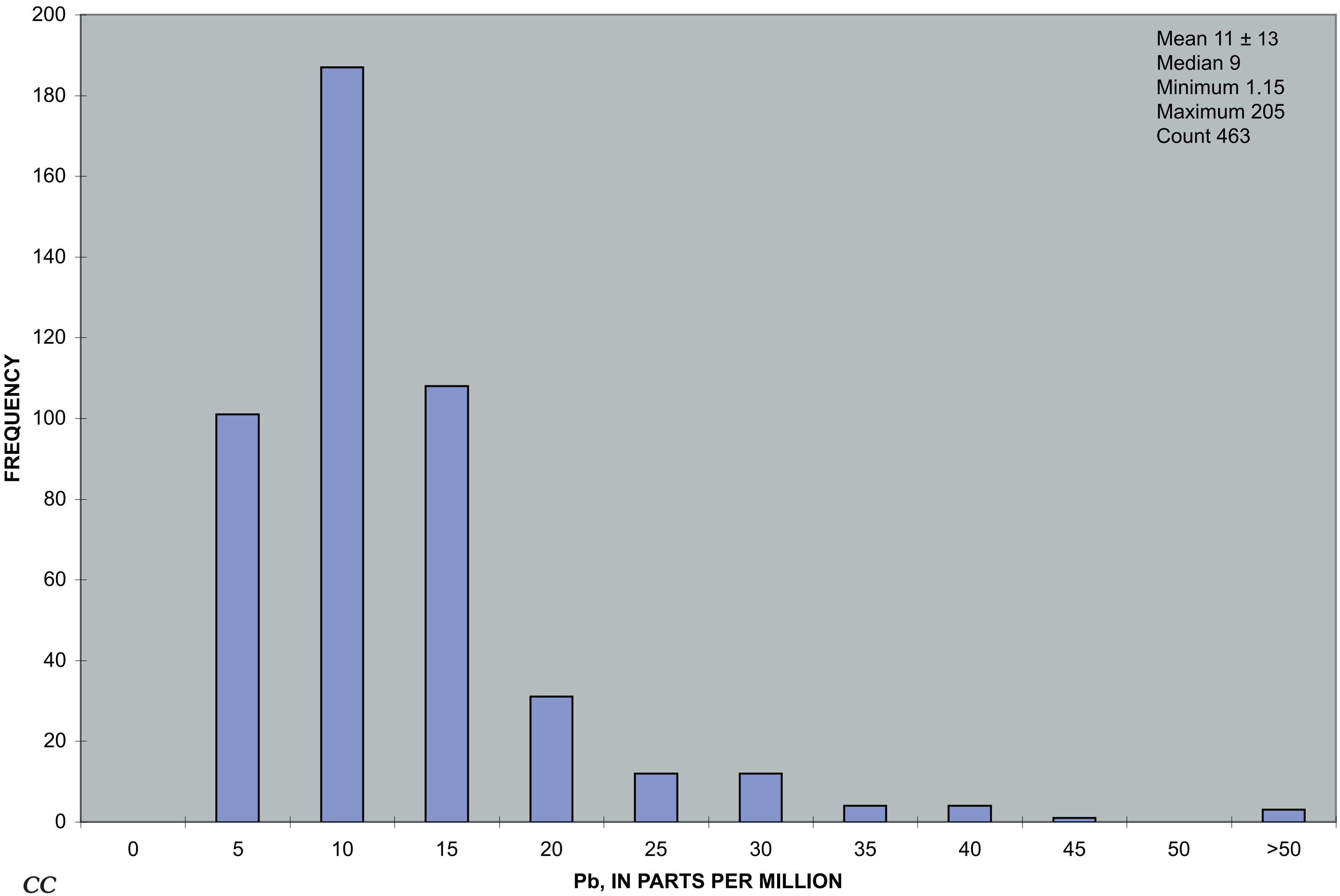
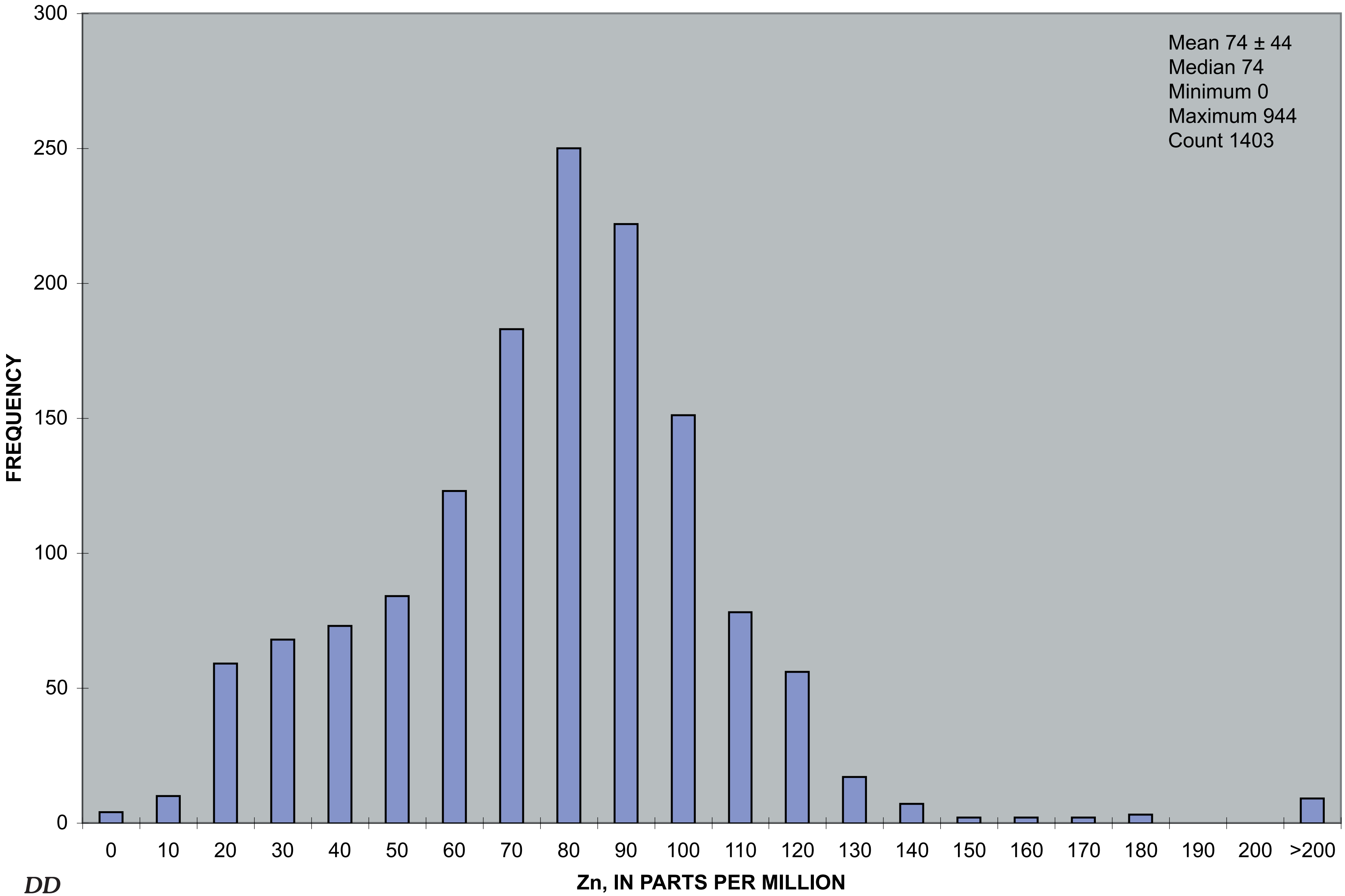
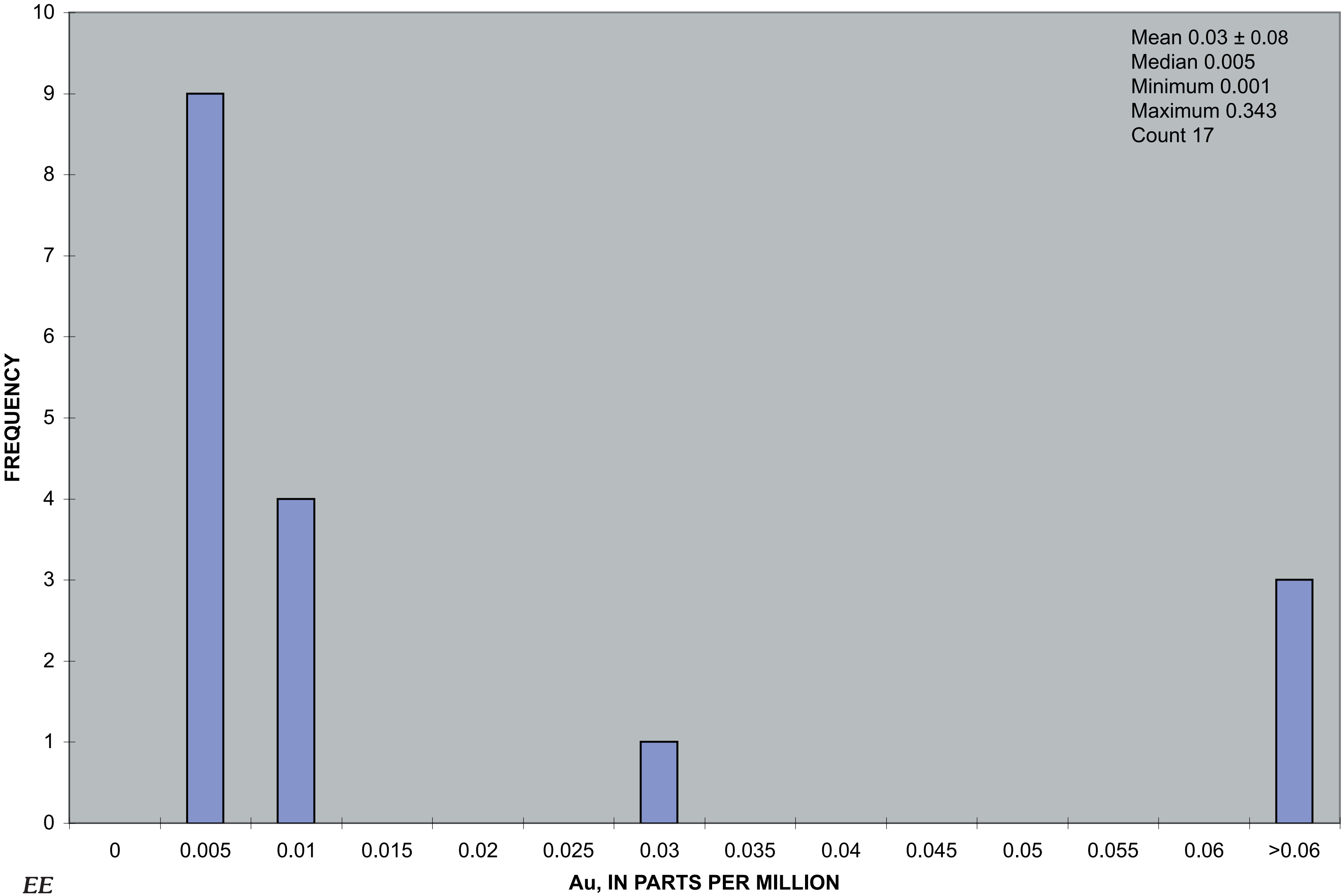


Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



DD

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.



EE

Figure 2. Frequency distribution histograms showing compositions of Western Cascades igneous rock samples—Continued.

Table 1. Number of observations (Freq) within each composition range (Bin) for Western Cascades database.

[Each bin denotes an abundance less than or equal to the indicated value but greater than that specified by the bin with the next lowest abundance. Bins for SiO_2, TiO_2, Al_2O_3, FeO*, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, initial analytical total (total I), and total volatile content (vol_sum) are in weight percent; all others in parts per million]

SiO_2		TiO_2		Al_2O_3		FeO*		MnO		MgO		CaO		Na_2O	
Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq
46	4	0	1	10	2	0	0	0	20	0	14	0	5	0.0	0
48	51	0.2	77	11	2	1	27	0.05	263	1	442	1	70	0.5	11
50	172	0.4	179	12	13	2	120	0.1	596	2	399	2	152	1.0	8
52	345	0.6	207	13	47	3	127	0.15	1286	3	683	3	170	1.5	19
54	657	0.8	430	14	108	4	219	0.2	1417	4	959	4	219	2.0	50
56	589	1	631	15	290	5	260	0.25	307	5	762	5	290	2.5	179
58	485	1.2	738	16	702	6	353	0.3	58	6	382	6	383	3.0	584
60	425	1.4	733	17	1113	7	440	0.35	16	7	220	7	511	3.5	1078
62	289	1.6	446	18	1050	8	620	0.4	7	8	117	8	624	4.0	1139
64	265	1.8	298	19	521	9	797	0.45	2	9	70	9	651	4.5	701
66	196	2	183	20	188	10	638	0.5	2	10	42	10	555	5.0	262
68	175	2.2	108	21	65	11	304	0.55	1	11	22	11	283	5.5	60
70	120	2.4	42	22	23	12	127	0.6	0	12	15	12	124	6.0	31
72	102	2.6	31	23	7	13	63	0.65	0	13	4	13	72	6.5	10
74	107	2.8	14	24	2	14	27	0.7	2	14	1	14	23	7.0	2
76	80	3	12	25	1	15	11	>0.7	3	15	1	15	1	>7.0	0
78	53	3.2	2	26	1	16	0			16	1	16	0		
80	15	3.4	2	>26	0	>16	2			>16	1	17	0		
82	2	>3.4	1									18	1		
84	3											19	1		
>84	0											>19	0		

Table 1. Number of observations (Freq) within each composition range (Bin) for Western Cascades database—Continued.

K_2O		P_2O_5		total I		vol_sum		Ba		La		Ce		Rb	
Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq
0.0	3	0.0	16	90	0	0	12	0	9	0	20	0	2	0	15
0.5	633	0.1	267	91	1	1	533	100	159	10	115	10	15	10	372
1.0	1341	0.2	1229	92	0	2	1308	200	721	20	262	20	89	20	706
1.5	938	0.3	1323	93	4	3	631	300	546	30	161	30	184	30	369
2.0	483	0.4	647	94	4	4	226	400	310	40	115	40	271	40	181
2.5	263	0.5	222	95	3	5	88	500	187	50	36	50	299	50	135
3.0	195	0.6	113	96	15	6	48	600	123	60	9	60	143	60	72
3.5	128	0.7	54	97	23	7	25	700	118	70	3	70	84	70	81
4.0	65	0.8	21	98	86	8	8	800	97	80	1	80	44	80	56
4.5	46	0.9	17	99	356	9	11	900	61	90	2	90	32	90	46
5.0	22	1.0	2	100	2268	10	7	1000	26	100	0	100	10	100	45
5.5	8	1.1	4	101	1249	11	5	1100	10	110	1	110	3	110	40
6.0	4	1.2	2	102	112	12	8	1200	7	120	0	120	5	120	16
6.5	1	1.3	1	103	10	13	2	1300	1	130	0	130	4	130	17
7.0	1	1.4	0	104	4	14	2	1400	0	140	1	140	1	140	16
7.5	3	1.5	0	>104	0	15	4	1500	0	150	0	150	2	150	12
>7.5	1	1.6	0			16	1	1600	1	>150	0	160	0	160	9
		1.7	1			17	1	1700	1			170	0	170	0
		>1.7	0			18	2	>1700	1			180	1	180	2
						>18	0					>180	1	190	4
														200	1
														>200	1

Table 1. Number of observations (Freq) within each composition range (Bin) for Western Cascades database—Continued.

Sr		**Y**		**Zr**		**Nb**		**Co**		**Cr**		**Ni**		**Sc**	
Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq
0	0	0	6	0	1	0	8	0	3	0	33	0	8	0	3
100	31	5	3	25	18	5	33	10	41	25	417	25	646	5	39
200	167	10	24	50	25	10	404	20	72	50	226	50	253	10	86
300	479	15	129	75	84	15	627	30	135	75	136	75	109	15	93
400	892	20	421	100	237	20	307	40	113	100	90	100	63	20	83
500	522	25	513	125	342	25	115	50	116	125	55	125	35	25	122
600	172	30	404	150	383	30	29	60	63	150	44	150	43	30	141
700	99	35	244	175	346	35	8	70	23	175	29	175	16	35	88
800	56	40	107	200	253	40	9	80	6	200	33	200	10	40	73
900	38	45	54	225	155	45	2	90	2	225	17	225	7	45	53
1000	17	50	23	250	92	50	1	100	2	250	23	250	5	50	20
1100	5	55	13	275	75	55	0	>100	2	275	16	275	1	55	3
1200	9	60	5	300	47	60	0			300	11	300	2	60	1
1300	6	65	3	325	18	65	1			325	6	325	1	>60	0
1400	4	70	1	350	17	>65	0			350	9	>325	3		
1500	1	75	1	375	12					375	5				
>1500	4	80	2	400	8					400	4				
		85	0	425	8					425	3				
		90	2	450	2					450	2				
		95	0	475	0					475	2				
		100	0	500	3					500	1				
		>100	29	>500	0					>500	13				

Table 1. Number of observations (Freq) within each composition range (Bin) for Western Cascades database—Continued.

V		Ag		Cu		Mo		Pb		Zn		Au	
Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq	Bin	Freq
0	21	0.0	0	0	6	0	0	0	0	0	4	0	0
25	91	0.1	20	25	220	2	81	5	101	10	10	0.005	9
50	32	0.2	1	50	233	4	16	10	187	20	59	0.01	4
75	42	0.3	35	75	205	6	11	15	108	30	68	0.015	0
100	26	0.4	14	100	155	8	2	20	31	40	73	0.02	0
125	32	0.5	9	125	125	10	2	25	12	50	84	0.025	0
150	64	0.6	8	150	98	12	0	30	12	60	123	0.03	1
175	61	0.7	10	175	72	14	1	35	4	70	183	0.035	0
200	110	0.8	3	200	42	16	0	40	4	80	250	0.04	0
225	87	0.9	1	225	37	18	0	45	1	90	222	0.045	0
250	83	1.0	12	250	18	20	1	50	0	100	151	0.05	0
275	47	1.1	1	275	8	>20	2	>50	3	110	78	0.055	0
300	43	1.2	0	300	4					120	56	0.06	0
325	29	1.3	0	325	3					130	17	>0.06	3
350	23	1.4	1	350	4					140	7		
375	25	>1.4	8	375	0					150	2		
400	15			400	2					160	2		
425	12			425	0					170	2		
450	3			450	1					180	3		
475	0			>450	9					190	0		
500	1									200	0		
>500	1									>200	9		