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Grade and tonnage model of tungsten skarn deposits, Nevada

by

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SUMMARY

The following preliminary observations and products have been made during the study:

- Grade and tonnage models are developed from data for 113 tungsten skarns in Nevada, primarily worked during times of war

- Tungsten skarns in Nevada, primarily worked in times of war, are 4 orders of magnitude smaller than tungsten skarns as defined by Menzie and Jones (1986, fig. 32) (fig. 11 herein)

- Tungsten skarns in Nevada have WO_3 grades indistinguishable from the tungsten skarns as defined by Menzie and Jones (1986, fig. 33) (fig. 12 herein)

- Sizes and WO_3 grades of tungsten skarns in Nevada are independent of pluton composition as defined by us (figs. 4 and 5)

- Sizes and WO_3 grades of tungsten skarns in Nevada are independent of pluton age

- Size of tungsten skarns in Nevada are independent of pluton oxidation state as defined by us (i.e., oxidized or reduced) (fig. 6)

- WO_3 grades of tungsten skarns associated with reduced plutons are significantly higher than those associated with oxidized plutons in Nevada (figs. 7, 13, and 14); Newberry (1983) suggests that reduced tungsten skarns have higher grades than oxidized tungsten skarns.

- Sizes and WO_3 grades of tungsten skarns in Nevada are independent of tectonostratigraphic terrane (figs. 8 and 9)

PREFACE

This report presents some of the results of a study of tungsten skarn deposits associated with plutons in Nevada. One reason, among several, that the study was undertaken was to determine if these deposits differ in grade and tonnage from those characterized by the W skarn model (number 14a) prepared by Menzie and Jones (1986). Only deposits with WO_3 as the primary commodity are considered. Because substantial amounts of geologic detail are available on a larger number of W skarn deposits in Nevada than in the worldwide model (Menzie and Jones, 1986), statistically significant relationships among W skarns, associated plutons, and host rocks may be identifiable. Not only will this help our understanding of W skarn formation, it may also help identify critical geologic factors (e.g., pluton oxidation state) that significantly affect size or grade distributions. A study of this type also may be used to help develop guidelines for predicting numbers of undiscovered deposits in poorly explored areas around plutons.

The sizes of most W skarns in our Nevada data set are not likely to be in the size range that are exploration targets under current economic conditions. One very important aspect of these "discoveries" is that they were the result of a country at war; most of these deposits were discovered and worked during World Wars I or II or during the Korean War. Cox and Singer (1986, p. 1) define a mineral deposit as "a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential." Under conditions of war, national governments will create favorable circumstances for some small-sized deposits like many W skarn deposits if the commodities present in the deposits are critical to the war effort. Simple Sb deposits were also the result of favorable circumstances provided by governments in Japan, Australia, the United States, and elsewhere in a time of war (Bliss and Orris, 1992).

The data compilations of plutons associated with W skarns could also be used as part of the data needed to demonstrate how a quantitative link can be made between mineral deposit models and geology using Bayes' theorem. One thing missing from our current data set is a list of comparable plutons (and associated attributes) that lack associated W skarns (see Chung and others, 1992, for a discussion of this particular application of Bayes' theorem).

The tungsten skarn deposits found in our data set for Nevada lack reserve data and are spatially defined somewhat differently than those in Menzie and Jones (1986). The two tungsten skarn models reflect different economic situations which need to be considered carefully by those making mineral resource assessments. Our model may be best used not in mineral resource assessment, but in examining the importance of geologic variables in the formation of W skarns. However, geologists who understand the limitations of our model may also want to use it if it works best with the specific goals of their assessment. However, they must recognize the limitations that the use of this model brings to the interpretation of the assessment.

The reviewers of this study have raised many questions, some which we are unable to answer without substantially more data collection. In some cases, the data do not exist. Although, we may be able to collect more data, we believe it is important that these preliminary results be made available. We hope that a healthy discussion will follow. See the last section on "FUTURE RESEARCH" for some of the ideas that we and others have about what may be done in the future. Bear in mind that the primary focus of this study is to identify which geologic variables affect the size and grades of W skarn deposits in Nevada. We look forward to receiving your additional comments which should by directed to Dave John, U.S. Geological Survey, 345 Middlefield Rd., MS 901, Menlo Park, CA 94025.

INTRODUCTION

These grade and tonnage models apply to deposits matching the descriptive model of W skarn, number 14a, by Cox (1986). Detailed descriptive summaries of tungsten skarn deposits are given by Einaudi and others (1981) and Einaudi and Burt (1982). The essential characteristic of tungsten skarns is the presence of scheelite in metasomatic calc-silicate rocks. Skarns form along margins and roofs of granitoid plutons and batholiths where they intrude calcareous wallrocks (commonly massive carbonate rocks). Pluton composition varies from granite to diorite, although most tungsten skarns are associated with granite to granodiorite compositions. In Nevada, intrusions related to tungsten skarns range in age from Late Triassic (about 220 Ma) to middle Tertiary (about 40 Ma), although Cretaceous-age intrusions are most abundant (Appendix A). Prograde skarn mineralogy is dominated by garnet and(or) clinopyroxene. Hydrous retrograde minerals commonly include epidote, chlorite, and actinolite. Scheelite is the dominant ore mineral. Other common opaque phases include pyrite and(or) pyrrhotite, magnetite, native bismuth or bismuthinite, and molybdenite. Einaudi and others (1981) suggest that tungsten skarns can be subdivided into reduced and oxidized types as characterized by their oxide and sulfide mineralogy. Reduced skarns contain pyrrhotite + magnetite ±pyrite and native bismuth, whereas oxidized skarns contain pyrite ± magnetite, pyrrhotite, and bismuthinite. They suggest that reduced skarns form in carbonaceous host rocks or in deep seated environments, whereas oxidized skarns form in non-carbonaceous or hematitic host rocks or at shallower depths.

EXPLANATION OF MODEL(S) USED

The definition of a mineral deposit model as given by Cox and Singer (1986, p. 2) is

"the systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. A model may be empirical (descriptive), in which instance, the various attributes are recognized as essential even though their relationships are unknown; or it may be theoretical (genetic), in which instance, the attributes are interrelated through some fundamental concepts."

Estimates of tonnage should be made at the lowest given cut-off grade. Grade and tonnage models are presented in a graphical format (plots) to make it easy to display the data and to compare with other models (Cox and Singer, 1986; Bliss, 1992). The plots show grade and tonnage on the horizontal axis and the cumulative proportion of deposits on the vertical axis. The units are metric, and a logarithmic scale is used for tonnage, grade, and target area. Each point on a plot represents a deposit. The definition of a deposit (how close to one another mine workings need to be for grouping, minimum size, etc.) needs to be provided by the modeler. In the case of the W skarn model given here, we treat workings or W skarn bodies within one kilometer of one another as one deposit. The deposits are cumulated in ascending grade, tonnage, or target area. Smoothed curves, representing percentiles of a lognormal distribution that have the same mean and standard deviation as the observed data, are plotted through the points. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distributions are identified. A detailed description of how these plots are generated is given by Singer and Bliss (1990).

DATA

The data used to prepare this grade and tonnage model are listed in Appendix A. Information given includes deposit name; district name; county; pluton name, age, type, average silica content, and oxidation state; deposit size in metric tons (mt); tungsten trioxide grade (WO_3) in weight percent; tectonostratigraphic terrane of host rocks; and data source(s). Deposits are sorted alphabetically by county. Data sources used in the compilation are listed at the end of Appendix A; references cited herein are found at the end of the text. Data are also examined to determine if grade and tonnage might be dependent on pluton age, or pluton type as described in the next section. Queried data are not used or are reassigned as unknown or missing.

Regrettably, a figure or map showing the locations of W skarns in Nevada is not included. Please see Stager and Tingley (1988) for maps showing locations of the mines and prospects that are used in this study.

Essentially all tungsten production in Nevada was subsidized during times of war as noted in the preface. Deposit size is based on past production. Data for production plus reserves is desired for the best model development. However, the lack of reliable data on reserves is a common problem for most vein-type deposits (e.g., low-sulfide Au quartz veins (Bliss, 1986)), and some other mineral deposit types (e.g., simple Sb (Bliss and Orris, 1986)); this is particularly true for mineral deposit types with small tonnages. Geologic resources are available for just 4 tungsten skarn deposits out of 114 deposits in the Nevada data (Appendix A).

DATA ANALYSIS

All deposits

A scatter plot of tungsten grade versus tonnage of deposits in Appendix A suggests that deposit size and grade are independent (fig. 1), and this is confirmed by a statistically insignificant (at the 1-percent level) correlation coefficient of 0.01 for 113 observations. Excluded from the scatter plot are the estimated/rumored reserve data and production from Indian Springs Prospect which has a anomalously low grade of 0.11 weight percent WO_3 for past production. Lognormality was rejected for deposit sizes using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level if these reserve figures are included in the data set. Lognormal was **not** rejected for deposit sizes using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level if the reserve figures are excluded. The geometric mean size of the remaining 113 deposits is 690 metric tons (mt) (fig. 2).

The lognormal distribution was not rejected (at the 1-percent confidence level) for tungsten grade (fig. 3). The distribution tends to be skewed to higher values. This may reflect selective reporting of grades for high grade or hand sorted material. This type of problem commonly plagues data for all types of mineral deposits, particularly those with small tonnage. The range in grades is also small--from 0.26 to 2.2 weight percent WO_3. The geometric mean grade is 0.65 weight percent WO_3.

Deposits classified by pluton type

Preliminary inspection of the data suggested that the data set might contain two populations, particularly in terms of deposit size. Cursory inspection of the data in the initial phases of the study suggested that tungsten skarns associated with hornblende-biotite granodiorite plutons seemed to be larger in tonnage. A three-fold classification was made of pluton types: unknown; biotite granites (commonly porphyritic and weakly peraluminous) were designated type 1 and hornblende-biotite granodiorite were designated type 2. The classification of tungsten skarn deposits and average SiO_2 contents of associated plutons are shown in Appendix A.

Notched box-and-whisker plots of deposit sizes of tungsten skarns grouped by pluton classification suggests that pluton type and tonnages may not be independent (fig. 4). For the purposes of this analysis, queried classifications have been grouped with unqueried ones (Appendix A). Deposits not classified by pluton type (n=22) tend to be smaller in size perhaps due to the lack of study they received because of their minor importance as a tungsten source. The situation between type 1 (n=42) and type 2 (n=49) plutons is somewhat less clear though the median values (type 1 median size is 710 mt; type 2 median size is 910 mt) and the associated 95 percent confidence level confidence interval (indicated by notches) suggests that they are quite similar. The lognormal distribution for deposit sizes was not rejected using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level for deposits associated with type 1 plutons; the same is also true for those associated with type 2 plutons. The geometric mean tonnage of skarns with type 1 plutons is 640 mt; type 2 plutons have tungsten skarn deposits with a geometric mean size of 1,700 mt. A t-test (a 1-tail test) of the two data sets did not reject the hypothesis that two types have equal mean tungsten grades at the one-percent confidence level; the alternative hypothesis was that deposits associated with type 2 plutons are larger in size. It should be noted that the resulting unpaired t value of -1.643 has a 1-tail probability of 0.052 and would be nearly significant at the 5-percent confidence level. Because all assumptions for the t-test may not be met, the nonparametric Mann-Whitney U test was also run. In this test, the hypothesis that the medians (see above) are equal was clearly not rejected (at the 5-percent confidence level). This is also suggested by the notched box-and-whisker plots (fig. 4). For purposes of modeling tungsten skarns in Nevada, pluton composition in this data set can **not** be used to prepare separate models. However, the idea that pluton composition may play a role in tungsten skarn deposit size is provocative and one that requires additional investigation, perhaps using a larger data set including tungsten skarn deposits beyond Nevada or better quality data, a goal that is not easily met.

Notched box-and-whisker plots of WO_3 grades in tungsten skarns grouped by pluton classification suggest that pluton type and tungsten grades are independent (fig. 5). The number of deposits per pluton type are the same as used in the analysis of tonnage. The lognormal distribution for tungsten grades was not rejected using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level for deposits associated with type 1 plutons; the same is true for those associated with type 2 plutons as well. The geometric mean grade for type 1 plutons is 0.68 percent WO_3; for type 2 plutons it is 0.60 percent WO_3. A t-test of WO_3 grades did not reject the hypothesis that the two types have equal mean WO_3 grades at the one-percent confidence level (a 2-tail test).

Steve Ludington (written commun, 1993) noted that of the 14 deposits in the data set with a gross value of 1 million dollars or more, 11 are associated with type 2 plutons and only 3 with type 1 plutons. This is consistent with our preliminary hypothesis concerning larger deposits with type 2 plutons, but it could not be confirmed statistically.

Deposits classified by age

Tungsten skarn deposits have been grouped by age of associated pluton--Jurassic, Cretaceous, Tertiary, and unknown. A number of queried Cretaceous-age plutons have been grouped with the unqueried ones (Appendix A). The numbers of Jurassic plutons (n=4) and Tertiary plutons (n=5) are small compared to the numbers of Cretaceous plutons (n=56) and plutons of unknown age (n=48). Due to the small number of deposits in some age groups, the nonparametric Kruskal-Wallis test was used to evaluate the data. The hypothesis that the median tonnages among the four age classes is equal was not rejected at the 1-percent confidence level. Therefore, one may conclude that tungsten skarn tonnages are independent of the age of the associated plutons. A similar analysis was made of WO_3 grade. The hypothesis that the median tungsten grades among the four age classes is equal was not rejected at the 1-percent confidence level. Therefore, one may conclude that tungsten skarn WO_3 grades are independent of the age of the associated plutons.

Steve Ludington (written commun, 1993) noted that all but one of the 14 deposits in the data set with a gross value of 1 million dollars or more are Cretaceous in age. However, most Cretaceous-age deposits are small.

Tungsten skarns were also grouped according to the age of the host rocks either Paleozoic or Mesozoic. The lognormal distribution for WO_3 grades and tonnages of deposits grouped by age of host rocks were not rejected using the skewness and kurtosis tests (Rock, 1988). The hypothesis that deposit sizes or WO_3 grades were independent of age of host rocks was not rejected as well (t-test, two tail).

Deposits classified by oxidized or reduced plutons

Einaudi and others (1981) and Einaudi and Burt (1982) suggested that tungsten skarns could be subdivided into oxidized and reduced types. Einaudi and others (1981) noted that in oxidized tungsten skarns the dominant opaque mineral is pyrite, whereas the dominant opaque minerals in reduced skarns are pyrrhotite + magnetite. They also noted differences in garnet and pyroxene compositions and relative abundances. Oxidized skarns tend to form in non-carbonaceous or hematitic wallrocks at relatively shallow depths, whereas reduced skarns form in carbonaceous wallrocks at intermediate depths. Einaudi and Burt (1982) also noted that reduced skarns tend to be associated with S-type or ilmenite series granitoids, whereas oxidized skarns are generally associated with I-type or magnetite series granitoids. Newberry (1983) noted that reduced skarns are characterized by higher scheelite contents and higher tungsten grades, possibly because they tend to have higher pyroxene/garnet ratios and consequently there is more Ca^{2+} available in hydrothermal fluids to allow precipitation of scheelite. Newberry (1991) concludes that there is considerable interskarn compositional variation in main stage garnet and pyroxene that is related to the intrinsic oxidation state of the skarn-forming systems. The intrinsic oxidation state of the skarn-forming system is a function both of the oxidation state of associated intrusions and of the oxidation state of the host rocks, and the oxidation state of the wall rocks can be buffered by the presence of graphite or hematite.

For most tungsten skarn deposits in Nevada, we lack detailed descriptions of opaque mineralogy and composition and relative abundance of garnet and pyroxene in the skarns, and data about the content of carbonaceous material in host rocks. Consequently, we divided the skarns into oxidized and reduced types using ferric:ferrous iron ratios (Fe_2O_3/FeO weight ratios) of associated plutonic rocks. Keith and others (1991) suggested that reduced granites have $Fe_2O_3/FeO<0.6$, weakly oxidized granites have Fe_2O_3/FeO between 0.4 and 0.9, and strongly oxidized granites have Fe_2O_3/FeO between 0.9 and 2. They suggested that reduced granites correspond to an ilmenite assemblage (ilmenite series), weakly oxidized correspond to magnetite + ilmenite assemblages, and strongly oxidized correspond to magnetite + sphene assemblages (magnetite series). We used their criteria (figure 22, Keith and others, 1991) and Fe_2O_3/FeO data from unaltered plutons (data sources listed in Appendix A) to separate oxidized plutons from reduced plutons (Appendix A). Using these data, we were able to divide about half of the Nevada tungsten skarn deposits into those associated with reduced plutons (17) and those associated with oxidized plutons (52) (Appendix A).

The lognormal distribution for deposit size was not rejected using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level for deposits associated with reduced plutons; the same is true for those associated with oxidized plutons. Notched box-and-whisker plots of deposit sizes for tungsten skarns grouped by oxidation state of associated pluton suggests that deposit size is independent of oxidation state (fig. 6).

The lognormal distribution for tungsten grades was not rejected using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level for deposits associated with reduced plutons; the same is true for those associated with oxidized plutons. Higher tungsten grades appear to be found in skarns associated with reduced plutons (fig. 7). The geometric mean grade for reduced plutons is 0.75 percent WO_3; for oxidized plutons it is 0.55 percent WO_3. A t-test (a 1-tail test) of tungsten grades **rejected** the hypothesis that the two types have equal mean tungsten grades at the one-percent confidence level. Therefore, the alternative hypothesis that the reduced plutons have skarns that are higher grade than those with oxidized plutons is accepted. Note that this is similar to the observations by Newberry (1983, fig. 12) that reduced skarns are higher grade than oxidized ones. One logical, but untested, conclusion is that reduced plutons are more likely to form reduced skarns. Although statistically significant, the difference between the geometric mean grades of the two groups in our study is just 0.20 percent WO_3.

A number of other variables might be considered in the analysis of controls of size and (or) grade including intrusion area (or volume) and complexity of intrusive system. Other properties of the host rocks including composition (pure versus impure limestones), presence of reducing agents (carbon), permeability, porosity, etc., and extent and nature of faulting and fractures also might be considered. Depth of emplacement is one variable among several noted above for distinguishing between oxidized and reduced plutons.

Deposits classified by tectonostratigraphic terrane

Nevada W skarns were statistically examined using tectonostratigraphic terranes of host rocks in an attempt to discover if any one terrane or terranes had tonnages or W grades significantly different from the rest. The classification of tectonostratigraphic terranes used was developed by N.J. Silberling (Silberling and others, 1987; Silberling, 1991) as modified by Steve Ludington (oral commun., 1993) for the Nevada statewide assessment (Cox and others, 1990). Four terranes (Black Rock, NAbc, NAUPz, and Roberts Mountain, see Appendix A) with five or fewer deposits were excluded from our analysis.

Notched box-and-whisker plots of WO_3 grades in tungsten skarns grouped by tectonostratigraphic terranes suggest that terranes and deposit sizes are independent (fig. 8). Because the number of observations in some terranes is still small (e.g. the Paradise terrane with 10 deposits), a nonparametric procedure (i.e., Kruskal-Wallis test) for three or more independent samples was used to determine if the median tonnages among the terranes were significantly different at the 1 percent confidence level. The assumption that the size of deposits is independent of terrane is not rejected (H=8.1, p=0.088). Although a particularly large deposit may occur in a specific terrane, the data suggest that exploring in the same terrane does not increase your chances of finding a second large deposit; the size of the next deposit to be discovered is expected to be comparable to the median tonnage of our model.

Notched box-and-whisker plots of WO_3 grades in tungsten skarns grouped by tectonostratigraphic terranes suggest that terranes and deposit grades may not be independent (fig. 9). The terrane designated as Mesozoic carbonate rock (Mzc) appears to have W skarn deposits with lower grades than the rest. Because the number of observations in some terranes is still small (e.g., the Paradise terrane with 10 deposits), a nonparametric procedure (i.e., Kruskal-Wallis test) for three or more independent samples was used to determine if the median W grades among the terranes were significantly different at the 1 percent confidence level. The assumption that the grades is independent of terrane is not rejected (H=9.5, p=0.049). Note that if we had chosen a lower confidence level (e.g., at the 5 percent level), the assumption of grade independence between the terranes would be rejected.

GRADE AND TONNAGE MODELS

The model for tungsten skarn deposits by Menzie and Jones (1986) is identified as the "general-type" model and the model given here differs as the "Nevada-type" (or W skarns worked in a time of war) model (fig. 10). Deposits used in the Nevada-type model that we developed are defined to be clusters of mines separated by a distance equal to, or less than, 1 kilometer. Menzie and Jones (1986, p. 55) included "all mines associated with the contact zone of a particular intrusive with a favorable host rock were combined to form a single deposit," or lacking detailed geologic information "mines within 10 km of each other were combined." They also attempt to use deposits that have both production and reserve data. Ideally, the data should represent the estimated pre-mining tonnages and grades. The absence of reserve data for the Nevada tungsten skarns represents a problem in their (and our) data collection effort. We have ignored the fact that reserves are absent in our data whereas Menzie and Jones (1986) did not. It is likely that some, but we do not know what part, of the data we used represents exhausted deposits. In addition, the Menzie and Jones model is based on a world-wide data set (it includes 4 deposits in Nevada); ours is based solely on tungsten skarn deposits in Nevada. This limitation may bias our model in ways not recognized. It is recommended that people conducting resource assessments consider using the Menzie and Jones (1986) model, because it better characterizes deposits likely to be of interest to modern explorationists.

Users clearly need to understand and consider the difference between these two models (fig. 8) in terms of spatial requirements and the implication of the large difference in tonnage (fig. 10 panel A, B), particularly in the estimate of undiscovered deposits. A number of combinations of grades and tonnages are possible and are graphically shown in figure 10. The following combinations are possible selections:

(1) the general-type model by Menzie and Jones (1986) with tonnage from panel A (Menzie and Jones, 1986, fig. 32) and WO_3 grade from panel C (Menzie and Jones, 1986, fig. 33),

(2) the Nevada-type model given herein with tonnage from panel B (fig. 11). If the pluton oxidation state is unknown, the grade of Nevada-type model (fig. 12) is the same as the WO_3 grade for the general model (Menzie and Jones, 1986, fig. 33),

(3) the Nevada-type model given herein with tonnage from panel B (fig. 11), and the grade from panel D (fig. 13) if associated with an oxidized pluton, and

(4) the Nevada-type model given herein with tonnage from panel B (fig. 11), the grade from panel E (fig. 14) if associated with a reduced pluton.

The lognormal distribution for all of the above models was not rejected using the skewness and kurtosis tests (Rock, 1988) at the 1-percent confidence level. The ratio of oxidized to reduced plutons is needed if the scheme for selecting grade and tonnage models in figure 8 is used as a layout for running Monte Carlo simulations to predict the amount of tungsten contained in undiscovered deposits in an area being assessed.

DISCUSSION OF TONNAGE MODELS

The 50th percentile sized deposit in the Nevada-type model is 4 orders of magnitude smaller than the 50th percentile sized deposit (i.e., 1,100,000 mt) in the tonnage model by Menzie and Jones (1986, fig. 32). In fact, their 90th percentile deposit (340,000 mt) is larger than our 10th percentile deposit (30,000 mt)! Although the tonnages are quite different, our grade model (fig. 12) is essentially the same as the one by Menzie and Jones (1986, fig. 33). This suggests that these two models are not different due to differences in cut-off grades for deposits included. As noted previously, size differences are primarily due to differences related to the effects of government subsidy, use of different spatial rules to define deposits, and absence/presence of reserve data. In an approximate sense, for every 28 deposits fitting the size distribution of the Nevada-type model (fig. 8), one might expect 1 deposit to fit the size distribution of the Menzie and Jones (1986, fig. 32) tonnage model based on the number of deposits from Nevada used in their model.

PLUTONS AND NUMBER OF DEPOSITS

Each pluton intruding suitably reactive host rocks has a probability of forming of one or more W skarn deposits. As the level of data improves, a new (higher or lower) probability can be calculated to reflect these refinements. However, people making assessments often need to make predictions with little data about undiscovered deposits. To help with this, one useful, but unavailable probability, is the one noted in the beginning of this discussion--the probability of the existence of a W skarn given a pluton of suitable composition that has intruded suitably reactive host rocks. In order to calculate this probability, the number of plutons meeting these criteria but **without** associated W skarns needs to be known. Given that the research community focuses on discovered deposits and their geologic setting, it comes as no surprise that barren plutons intruding suitable host rocks are not well documented.

The probability that a pluton will have just one Nevada-type skarn deposit is 0.62 (fig. 15). It is expected that this deposit will fit our grade and tonnage model (figs. 11-14). One W skarn deposit per pluton is the most common occurrence. The probability of two more deposits is 0.38, three or more deposits is 0.15, and so on (fig. 15). No pluton was reported to have 7 to 10 associated W skarn deposits. The 11 tungsten skarn deposits associated with the Osgood Mountain stock are much more than are associated with any other intrusion. This stock is relatively small (19 km^2) compared to many other plutons in our data set, and the large number of associated W skarn deposits appears highly anomalous. Perhaps the size of the stock or, more likely, the length of exposed contact of the stock with suitable host rocks, are observations useful in making better predictions about numbers of expected skarn deposits around stocks. For the Osgood Mountain stock, approximately one W skarn deposit is present for each 1 km of exposed intrusive contact and for each 2.0 km^2 of area. In contrast, Newberry (1986) suggested that one generic skarn occurrence can be expected for approximately each 4.8 km of intrusive-contact length. Note that the relation is for "occurrence" and not for deposit, and the deposit type is "generic." Bliss and others (1988), using data for copper skarn deposits in the Chandalar and

Survey Pass 1° x 3° quadrangles in the Brooks Range, Alaska, found an average of one deposit per 145 km and 130 km of contact length, respectively. The sizes of areas mapped as hornfels and tactite associated with intrusions were also examined. In the Chandalar 1° x 3° quadrangle, one copper skarn was noted for each 2.2 km^2 of hornfels (Bliss and others, 1988). The size of area mapped as intrusive rock in Chandalar 1° x 3° quadrangle together with number of known skarns suggests that there are 6.5 km^2 of intrusive rocks exposed for each copper skarn occurrence and 52 km^2 of intrusive rocks exposed for each lead-zinc skarn. These ranges are not for W skarn deposits and obviously don't fit the Osgood Mountain stock, but the methods used may be applicable to W skarn deposits elsewhere.

The areas around the plutons used to make these estimates should be exhaustively explored for skarn deposits; the level of exploration is usually unknown, but we suspect that most readily exposed deposits have been located. However, the lack of data on the level of exploration reduces the reliability of the relationships suggested here.

FUTURE RESEARCH

Tungsten skarns found in Nevada and worked in wartime are generally small. Undiscovered deposits like these can not be considered to be an important future source of tungsten. A number of interesting questions have been raised during the preparation of this report and others were raised by reviewers. Additional data collection is needed to answer these questions. Some these questions requiring additional research, in no particular order, include:

(1) Are the tungsten skarns worked in wartime in Nevada comparable to those found elsewhere in the Great Basin? In the rest of the United States? In the world?

(2) Can the area or contact length of an exposed pluton (or some other measure of total size) be used to predict the number of associated W skarns? How do these or other characteristics of the pluton and their host rocks (e.g., structural setting, depth of emplacement, lithology of host rocks, areas of hornfels, etc.) affect size, grade, and numbers of associated W skarns?

(3) What is the nature, number, and size and grades of other mineral deposits (if any) found with the plutons? Can their presence or absence (or details of their size, grade and number) be used to develop predictive tools for number, size, and grade of W skarn(s) associated with the pluton?

(4) If the W skarn model by Menzie and Jones is disaggregated and mines or skarn bodies are grouped using the same spatial rule that is used in this study, how different would this model be from (a) their original model and (b) from the model in this study?

(5) Are there differences in the sizes and grades of W skarns classified as oxidized and reduced? Note that this is a separate issue from the classification using oxidation state of the associated pluton. Newberry (1983) suggested that reduced W skarns are higher grade but this relationship has not been tested statistically.

(6) Does classification of W skarns by tectonostratigraphic terranes affect other deposit attributes not considered in this preliminary study?

REFERENCES CITED

Bliss, J.D., 1986, Grade and tonnage model of low-sulfide Au-quartz veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 239-243.

Bliss, J.D., ed., 1992, Developments in mineral deposits modeling: U.S. Geological Survey Bulletin 2004, 168 p .

Bliss, J.D., Brosgé, W.P., Dillon, J.T., Dutro, J.T., Jr., Cathrall, J.B., and Cady, J.W., 1988, Mineral resource assessment of the Wiseman 1° by 3° Quadrangle, Alaska: U.S. Geological Survey Open-File Report 88-553, 84 p.

Bliss, J.D., and Orris, G.J., 1986, Grade and tonnage for simple Sb deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 184-186.

Cox, D.P., 1986, Descriptive model of W skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 55.

Cox, D.P., Ludington, Steve, Sherlock, M.G., Singer, D.A., Berger, B.R., and Tingley, J.V., 1990, Mineralization patterns in time and space in the Great Basin of Nevada [abs.]: Reno, Geological Society of Nevada, Geology and Ore Deposits of the Great Basin Program with Abstracts, p. 53-54.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

Chung, C.F., Jefferson, C.W., and Singer, D. A., 1992, A quantitative link among mineral deposit modeling, geoscience mapping, and exploration-resource assessment: Economic Geology, v. 87, no. 1, p. 194-197.

Einaudi M.T., and Burt, D.M., 1982, Introduction--terminology, classification, and composition of skarn deposits: Economic Geology, v. 77, no. 4, p. 745-754.

Einaudi, M.T., Meinert, L.D., and Newberry, R.J., 1981, Skarn deposits, *in* Skinner, B.J., ed., Seventy-Fifth Anniversary Volume: Economic Geology Publishing Co., p. 317-391.

Keith, S.B., Laux, D.P., Maughan, Jerald, Schwab, Karen, Ruff, Steven, Swan, M.M., Abbott, Earl, and Friberg, Steve, 1991, Magma series and metallogeny: A case study from Nevada and environs, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and Ore Deposits of the Great Basin, Field Trip Guidebook Compendium: Reno, Geological Society of Nevada, p. 404-493.

Menzie, W. D., and Jones, G.M., 1986, Grade and tonnage model of W skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 55-57.

Newberry, R.J., 1983, The formation of subcalcic garnet in scheelite-bearing skarns: Canadian Mineralogist, v. 21, p. 529-544.

Newberry, R.J., 1986, Quantification of the DGGS Rockval scheme for appraisals of skarn deposits, final report: Alaska Division of Geology & Geophysical Surveys unpublished report, 39 p.

Newberry, R.J., 1991, Scheelite-bearing skarns in the Sierra Nevada region, California: Contrasts in zoning and mineral compositions and tests of infiltration metasomatism theory, *in* Skarns-their genesis and metallogeny: Athens, Greece, Theophrastus Publications S.A., p. 343-383.

Rock, N.M.S., 1988, Numerical geology: New York, Springer-Verlag, 427 p.

Silberling, N.J., 1991, Allochthonous terranes of western Nevada, current status, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, Symposium proceedings: Reno, Geological Society of Nevada and U.S. Geological Survey, p. 101-102.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., and Howell, D.G., 1987, Lithotectonic terrane map of the western conterminous United States: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-C, scale 1:2,500,000.

Singer, D.A., and Bliss, J.D., 1990, Program to prepare standard figures for grade-tonnage model on a Macintosh, *in* Hanley, J.T., and Merriam, D.F., eds., Microcomputer applications in geology, II: New York, Pergamon Press, p. 241-250.

Appendix A

The following is a list of data used to model tungsten skarns found in Nevada. Multiple names given for deposit/mine are the mines grouped as a single deposits. Grade, in percent WO_3, and tonnage, in metric tons (mt), are given as reported; values likely only reliable to two significant figures. See end of listing for footnotes and references used as sources of data.

Appendix A. Characteristics of Tungsten Skarn Deposits in Nevada

	Deposit/mine	District	County	Size (mt)	Grade (%WO_3)	Pluton name	Pluton age	Pluton type[1]	Oxidized/ Reduced[2]	Average SiO_2 content[3]	Terrane[4]	Sources of data[5]
1	Kings Canyon Mine	Voltaire	Carson City	37	0.73	Unnamed	Cretaceous	2			PN	1,16
2	Midnight Mine	Fairview	Churchill	40	0.50	Slate Mountain pluton	Cretaceous	1	Ox	73.2 (2)	PA	1,2,3,9
3	Red Top Mine	Sand Springs	Churchill	838	0.75	Sand Springs pluton	Cretaceous	2	Ox	65.4 (3)	PA	1,2,3,9
4	Scheelite Queen Prospect	Sand Springs	Churchill	54	0.50	Sand Springs pluton	Cretaceous	2	Ox	65.4 (3)	PA	1,2,3,9
5	Stardust Claims	Sand Springs	Churchill	264	1.00	Sand Springs pluton	Cretaceous	2	Ox	65.4 (3)	PA	1,2,3,9
6	Granite Mine	Toy	Churchill	914	1.00	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,9
7	Payday and Lobo Claims	Toy	Churchill	2,722	1.67	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,3
8	St. Anthony Mine	Toy	Churchill	15,366	1.35	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,3
9	Gila Peak Mine	Tungsten Mountain	Churchill	91	0.50	Tungsten Mountain pluton	Unknown	2	Ox	68.6 (1)	J	1,3,9
10	Hilltop	Tungsten Mountain	Churchill	3,613	1.00	Tungsten Mountain pluton	Unknown	2	Ox	68.6 (1)	J	1,3,9
11	Gardnerville Mine	Gardnerville	Douglas	7,827	1.50	Pine Nut stock	Cretaceous(?)	1			PN	1,13
12	Pioneer Mine	Gardnerville	Douglas	73	0.60	Pine Nut stock	Cretaceous(?)	1			PN	1,13
13	Tungsten Hills Mine	Gardnerville	Douglas	426	1.00	Pine Nut stock	Cretaceous(?)	1			PN	1,13
14	Divide Mine	Gardnerville	Douglas	817	2.20	Pine Nut stock	Cretaceous(?)	1			PN	1,13
15	A & C Prospect	Mountain House	Douglas	4	1.60	Unnamed	Unknown	0			PN	1
16	High Jacks Prospect	Wellington	Douglas	4	0.50	Unnamed	Unknown	1			PN	1
17	Sweetwater Mine	Wellington	Douglas	73	0.84	Unnamed	Unknown	1?			PN	1
18	Garnet Mine	Alder	Elko	14,519	0.50	Coffeepot stock	Cretaceous	2?	Ox	69.4 (2)	NALPz	1,3,4,22
19	Batholith Mine	Charleston	Elko	858	0.48	Unnamed	Unknown	2?			NALPz	1,4
20	Tunnel Prospect	Contact	Elko	191	0.56	Contact pluton	Jurassic	2	Ox	66.0 (4)	NAUPz	1,3,4,22
21	S & L Mother No. 1 Claim	Corral Creek	Elko	11	0.60	Harrison Pass pluton	Tertiary	1	R	72.1 (7)	NALPz	1,3,4,25
22	Indian Springs Prospect	Delano	Elko	113	0.11	Indian Springs pluton	Cretaceous	1?			NAUPz	1,3,4
23	Pyramid Mine	Elk Mountain	Elko	363	0.50	Elk Mountain pluton	Unknown	2?			NAUPz	1,3,4
24	Campbell Mine	Harrsion Pass	Elko	157	1.00	Harrison Pass pluton	Tertiary	1	R	72.1 (7)	NALPz	1,3,4,25
25	Climax Mine	Harrsion Pass	Elko	8,167	0.38	Harrison Pass pluton	Tertiary	1	R	72.1 (7)	NALPz	1,3,4,25
26	Star Tungsten Mine	Harrsion Pass	Elko	10,580	1.00	Harrison Pass pluton	Tertiary	1	R	72.1 (7)	NALPz	1,3,4,25
27	Coon Creek Mine	Jarbridge	Elko	907	0.61	Coffeepot stock	Cretaceous	2?	Ox	69.4 (2)	NALPz	1,3,4,22
28	Phalen Mine	Kinsley	Elko	115	1.00	Unnamed	Tertiary	1?			NALPz	1,4
29	Kathleen Claim	White Horse	Elko	18	1.40	White Horse pluton	Jurassic	2?			NALPz	1,3,4
30	Army Claims	Sylvania	Esmeralda	1	0.50	Sylvania pluton	Jurassic	1	Ox	71.4 (3)	NAbc	1,3
31	Green Top Mine	Sylvania	Esmeralda	45	0.30	Sylvania pluton	Jurassic	1	Ox	71.4 (3)	NAbc	1,3
32	Copper King Mine	Tokop	Esmeralda	127	0.36	Unnamed	Unknown	2			NAbc	1,12
33	Saddle Mine	Leonard	Humboldt	213	0.48	Unnamed	Unknown	0			BR	1
34	Alpine Mine	Potosi	Humboldt	47,368	0.50	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
35	Granite Creek Mine	Potosi	Humboldt	229,246	0.59	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
36	Kirby Mine	Potosi	Humboldt	60,436	0.36	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
37	Markus Mine	Potosi	Humboldt	19,328	0.50	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
38	Mountain King Mine	Potosi	Humboldt	16,252	0.60	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
39	Mountain Queen Mine	Potosi	Humboldt	652	0.87	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24

	Deposit/mine	District	County	Size (mt)	Grade (%WO_3)	Pluton name	Pluton age	Pluton type[1]	Oxidized/ Reduced[2]	Average SiO_2 content[3]	Terrane[4]	Sources of data[5]
40	Richmond Mine	Potosi	Humboldt	31,125	0.44	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
41	Riley Mine, Riley Extension Mine	Potosi	Humboldt	848,457	0.59	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
42	Top Row Mine	Potosi	Humboldt	2,541	0.32	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
43	Valley View Mine, Pacific Mine	Potosi	Humboldt	66,724	0.56	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
44	Tonopah Mine	Potosi	Humboldt	39,020	0.29	Osgood Mountain stock	Cretaceous	2	Ox	66.3 (4)	NALPz	1,3,23,24
45	Great Northern Claims	Shon	Humboldt	29	1.06	Unnamed	Unknown	0			J	1
46	Ledge Mine	Shon	Humboldt	188	0.75	Unnamed	Unknown	0			J	1
47	Golden Scheelite Prospect	Varyville	Humboldt	5	0.71	Unnamed	Unknown	0			BR	1
48	Defense Mine	Warm Springs	Humboldt	2,722	0.80	Pine Forest stock	Cretaceous	2	Ox	65.6 (1)	BR	1,3,17
49	Last Chance Claims	Warm Springs	Humboldt	10	0.58	Pine Forest stock	Cretaceous	2	Ox	65.6 (1)	BR	1,3,17
50	Birch Creek Mine	Birch Creek	Lander	726	0.30	Austin pluton	Jurassic	1?	Ox	67.5 (3)	NALPz	1,3,10
51	Gold Acres Tungsten Prospect	Bullion	Lander	18	0.40	Unnamed	Cretaceous	0			NALPz	1
52	Conquest Mine, Linka Mine	Spencer Hot Springs	Lander	61,361	0.77	Unnamed	Jurassic	1		64.9 (1)	NALPz	1,3,4,11,20
53	Emerson (Tempiute) Mine	Tempiute	Lincoln	1,134,301	0.40	Unnamed	Cretaceous	1	Ox	70.3 (2)	NAUPz	1,3,22
54	Schofield Mine	Tempiute	Lincoln	4,220	0.40	Unnamed	Cretaceous	1	Ox	70.3 (2)	NAUPz	1,3,22
55	Churchill Butte Mine (Ruth Mine)	Churchill	Lyon	340	0.55	Churchill Butte pluton	Cretaceous(?)	1	Ox	66.7 (3)	PN	1,2,3
56	Pearl Harbor Mine	Red Mountain	Lyon	345	0.89	Unnamed	Cretaceous(?)	0			PN	1
57	Cowboy Mine	Wilson	Lyon	476	1.14	granite of Nye Canyon	Cretaceous	1			PN	1,6
58	Blue Bird Mine	Bell	Mineral	263	0.30	granodiorite of Cedar Summit	Cretaceous(?)	2	Ox	70.1 (3)	Mzc	1,3,7,26
59	Cedar Summit Mine	Bell	Mineral	52	0.30	granodiorite of Cedar Summit	Cretaceous(?)	2	Ox	70.1 (3)	Mzc	1,3,7,26
60	Cedar Chest Mine	Bell	Mineral	726	0.72	granodiorite of Cedar Summit	Cretaceous(?)	2	Ox	70.1 (3)	Mzc	1,3,7,26
61	Moonlight and Silver Moon Claims	Buena Vista	Mineral	18	0.60	Unnamed	Unknown	0			RA	1
62	Bataan, Mabel, and Mollie Claims	Garfield	Mineral	115	0.26	Unnamed	Unknown	1?	Ox	75.4 (2)	Mzc	1,22
63	Flying Cloud Mine	Hawthorne	Mineral	230	1.00	granite of Cory Creek	Unknown	1	Ox	72.0 (1)	PN	1,3,6
64	Lucky Four Mine	none	Mineral	485	1.50	Unnamed	Unknown	2			PA	1,6
65	Slim Pickens Mine	none	Mineral	544	2.00	Unnamed	Unknown	0			PA	1
66	Desert Scheelite Mine	Pilot Mountains	Mineral	1,470	0.31	Gunmetal stock	Cretaceous	2	Ox	67.6 (1)	Mzc	1,7,14,26
67	Garnet Mine	Pilot Mountains	Mineral	1,021	0.40	Gunmetal stock	Cretaceous	2	Ox	67.6 (1)	Mzc	1,7,14,26
68	Gunmetal Mine	Pilot Mountains	Mineral	41,742	0.50	Gunmetal stock	Cretaceous	2	Ox	67.6 (1)	Mzc	1,7,14,26
69	Nevada Scheelite Mine, Hooper Mine	Regent	Mineral	284,165	1.00	Scheelite pluton	Cretaceous	2	Ox	65.8 (4)	PA	1,2,3
70	Crystal Claims	Regent	Mineral	350	0.74	Unnamed	Cretaceous	2			PA	1
71	Rawhide Tungsten Mine	Regent	Mineral	694	0.50	Unnamed	Cretaceous	1?			PA	1
72	Thorne Mine	Regent	Mineral	1,724	0.60	Unnamed	Cretaceous	2?			PA	1,2
73	Eagle Mine	Santa Fe	Mineral	7,055	0.60	Todd Mountain stock	Cretaceous	1	Ox?		Mzc	1,6

	Deposit/mine	District	County	Size (mt)	Grade (%WO_3)	Pluton name	Pluton age	Pluton type[1]	Oxidized/ Reduced[2]	Average SiO_2 content[3]	Terrane[4]	Sources of data[5]
74	Emma Mine	Santa Fe	Mineral	91	0.86	Todd Mountain stock	Cretaceous	1	Ox?		Mzc	1,6
75	Western Metals Mine	Santa Fe	Mineral	21	0.30	Todd Mountain stock	Cretaceous	1	Ox?		Mzc	1,6
76	York Mine	Santa Fe	Mineral	241	0.50	Todd Mountain stock	Cretaceous	1	Ox?		Mzc	1,6
77	Isabell Mine	Santa Fe	Mineral	172	0.76	Unnamed	Unknown	0			Mzc	1
78	Defender Mine	Silver Star	Mineral	835	0.51	granite of Whiskey Flat	Cretaceous	1	Ox	73.4 (3)	PN	1,3,6
79	Silver Ace Mine	Bare Mountain	Nye	191	0.40	Unnamed	Unknown	0			NALPz	1
80	Climax Mine	Oak Springs	Nye	1,007	0.54	Climax stock	Cretaceous	1	Ox	69.4 (2)	NALPz	1,3,27
81	Gametyte Lode Claim	Oak Springs	Nye	2,269	0.30	Climax stock	Cretaceous	1	Ox	69.4 (2)	NALPz	1,3,27
82	Pegleg Mine	Tonopah	Nye	227	0.40	Fraziers Well pluton	Triassic	2	Ox	64.9 (3)	RA	1,7,21,22
83	Nye Mine	Troy	Nye	222	1.80	Troy Mountain pluton	Tertiary	1	Ox	72.4 (2)	NALPz	1,3,15,22
84	Terrell Mine	Troy	Nye	2,922	0.60	Troy Mountain pluton	Tertiary	1	Ox	72.4 (2)	NALPz	1,3,15,22
85	Ophir Tungsten Mine	Twin Rivers	Nye	2,269	1.20	Ophir pluton	Cretaceous	1	Ox	71.2 (3)	NALPz	1,3,7,26
86	Cactus Prospect	Twin Rivers	Nye	4	1.00	Timblin Creek pluton	Cretaceous	2	Ox	62.4 (3)	NALPz	1,3,7,26
87	Broken Arm Property	Twin Rivers	Nye	181	0.75	Unnamed	Cretaceous	2			NALPz	1,7
88	Millet Mines	Twin Rivers	Nye	59	1.50	Unnamed	Cretaceous	0			NALPz	1
89	Dog Claims	Washington	Nye	91	1.00	Aiken Creek pluton	Jurassic(?)	2?	Ox	70.1 (2)	NALPz	1,3,22
90	Haywire Prospect	Washington	Nye	21	1.00	Aiken Creek pluton	Jurassic(?)	2?	Ox	70.1 (2)	NALPz	1,3,22
91	Copper King Mine	Copper Valley	Pershing	856	0.70	Unnamed	Unknown	0			J	1
92	Snowstorm Prospect	Gold Butte	Pershing	7	0.50	Unnamed	Cretaceous	0			J	1
93	Stormy Day Mine	Hooker	Pershing	18,149	0.80	Unnamed	Cretaceous	2			J	1,3
94	Jenkins Mine	Hooker	Pershing	58	0.70	Unnamed	Cretaceous	0			J	1
95	Mill City District	Mill City	Pershing	3,411,978	0.69	Springer stock	Cretaceous	2	Ox	69.2 (7)	J	1,3,5
96	Alpine Mine	Nightingale	Pershing	39,322	0.60	Unnamed	Cretaceous(?)	2?	R	65.4 (1)	J	1,18
97	M.G.L. Mine	Nightingale	Pershing	34,483	0.85	Unnamed	Cretaceous(?)	2	R	65.4 (1)	J	1,18,19
98	Nightingale Mine	Nightingale	Pershing	72,595	0.50	Unnamed	Cretaceous(?)	2	R	65.4 (1)	J	1,18,19
99	Mather Mine	none	Pershing	531	0.60	Unnamed	Unknown	0			J	1
100	Ragged Top Mine	Ragged Top	Pershing	11,343	1.00	Ragged Top pluton	Cretaceous	2?	Ox	64.6 (1)	J	1,17
101	Coon Can Mine	Ragged Top (east Toy)	Pershing	2,269	0.70	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,3
102	Royal Ann Group	Ragged Top (east Toy)	Pershing	13	0.50	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,3
103	Sheby Mine	Ragged Top (east Toy)	Pershing	426	0.50	St Anthony pluton	Cretaceous(?)	1	R	69.6 (3)	J	1,2,3
104	Rose Creek Mine	Rose Creek	Pershing	2,232	1.50	Rose Creek	Jurassic(?)	2?			Mzc	1,3
105	Holiday Mine	Seven Troughs	Pershing	2,722	0.67	Seven Troughs pluton	Unknown	0	R	63.2 (1)	J	1,17
106	Hilltop Prospect	Staggs	Pershing	168	1.24	Heineke pluton	Cretaceous(?)	0	R	63.8 (1)	J	1,17
107	Esther Mine	Trinity	Pershing	36	0.50	Trinity Range	Cretaceous	2?	Ox	62.8 (1)	J	1,17
108	Long Lease Mine	Wild Horse	Pershing	8,115	0.70	Unnamed	Cretaceous	0			J	1
109	Blackhawk Mine	Red Mountain	Storey	30	0.30	Unnamed	Unknown	0			PN	1
110	Crosby Mine	Nightingale	Washoe	1,113	0.50	Coyote Canyon pluton	Cretaceous	1	R	71.5 (3)	J	1,2
111	Jaybird Mine	Nightingale	Washoe	181	0.75	Jay Bird pluton	Cretaceous	2	R	69.4 (2)	J	1,2
112	Derby Mine	Olinghouse	Washoe	363	0.50	Unnamed	Cretaceous(?)	0			PN	1
113	Bald Mountain Mine	Bald Mountain	White Pine	5,445	1.00	Unnamed	Tertiary	1?			NALPz	1,8
114	Monte Cristo Mine	White Pine	White Pine	394	0.45	Seligman stock	Cretaceous	2			NALPz	1,3

Deposit/mine	District	County	Size (mt)	Grade (%WO_3)	Pluton name	Pluton age	Pluton type[1]	Oxidized/ Reduced[2]	Average SiO_2 content[3]	Terrane[4]	Sources of data[5]
Estimated/rumored reserves											
Desert Scheelite	Pilot Mountains	Mineral	7,259,528	0.32	Gunmetal stock	Cretaceous	2	Ox	69.4 (2)	NALPz	1,7,14
Indian Springs Prospect	Delano	Elko	15,789,474	0.19	Indian Springs pluton	Cretaceous	1?			NAUPz	1,3,4
Monte Cristo	White Pine	White Pine	4,990,926	0.30	Seligman stock	Cretaceous	2			Mzc	1,3
Garnet Mine	Alder	Elko	490,018	0.40	Coffeepot stock	Cretaceous	2?	Ox	67.6 (1)	NALPz	1,3,4

[1]pluton types: 0, unknown; 1, biotite granite, commonly porphyritic and weakly peraluminous; 2, hornblende-biotite granodiorite, quartz monzodiorite, and diorite

[2]Oxidized (Ox) or reduced (R) plutons using Fe^{+3}:Fe^{+2} ratios and classification of Keith and others (1991).

[3]Average SiO_2 content of pluton associated with tungsten skarn deposit. Number of analyses given in parentheses.

[4]Tectonostratigraphic terranes of Silberling (1991) and Silberling and others (1987) as modified by S.D. Ludington (oral commun., 1993). BR, Black Rock terrane; J, Jungo terrane; Mzc, Mesozoic carbonate rocks; NAbc, North American miogeocline, basal clastic rocks; NALPz, North American miogeocline, Lower Paleozoic carbonate rocks; NAUPz, North American miogeocline, Upper Paleozoic carbonate rocks; PA, Paradise terrane; PN, Pine Nut terrane; RM, Roberts Mountains allochthon.

[5]Sources of data: 1, Stager and Tingley, 1988; 2, John, 1992; 3, S.B. Keith, written commun., 1991 (Magmachem files); 4, Coats, 1987; 5, Johnson and Keith, 1991; 6, John, 1983; 7, John, 1987; 8, Hose and Blake, 1976; 9, Willden and Speed, 1974; 10, Stewart and McKee, 1977; 11, McKee, 1976; 12, Albers and Stewart, 1972; 13, Doebrich and others, in press; 14, Grabher, 1984; 15, Kleinhampl and Ziony, 1984; 16, Trexler, 1977; 17, Smith and others, 1971; 18, D.P. Cox, oral commun., 1993; 19, Smith and Guild, 1942; 20, Meinert, 1991a,b; 21, Bonham and Garside, 1979; 22, Lee, 1984; 23, Hotz and Willden, 1964; 24, Silberman and others, 1974; 25, Kistler and others, 1981; 26, D.A. John, unpub. data; 27, Cornwall, 1972.

REFERENCES FOR APPENDIX A.

Bonham, H.F., Jr., and Garside, L.J., 1979, Geology of the Tonopah, Lone Mountain, Klondike, and northern Mud Lake quadrangles, Nevada: Nevada Bureau of Mines and Geology Bulletin 92, 148 p.

Coats, R.R., 1987, Geology of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 101, 112 p.

Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 49 p.

Doebrich, J.L., Garside, L.J., and Shawe, D.R., in press, Triassic-Jurassic magmatic arc of western Nevada and eastern California—Chapter III: Mineral deposits: U.S. Geological Survey Bulletin.

Einaudi, M.T., Meinert, L.D., and Newberry, R.J., 1981, Skarn deposits, *in* Skinner, B.J., ed., Economic Geology Seventy-fifth Anniversary Volume: Economic Geology Publishing Co., p. 317-391.

Grabher, D.E., 1984, Union Carbide's Pilot Mountain project, geologic setting and field trip guide, *in* Johnson, J.L., ed., Exploration for ore deposits of the American Cordilleria: Association of Exploration Geochemists, p. FT5-FT24.

Hose, R.K., and Blake, M.C., Jr., 1976, Geology and mineral resources of White Pine County, Nevada: Nevada Bureau of Mines and Geology Bulletin 85, 105 p.

Hotz, P.E., and Willden, Ronald, 1964, Geology and mineral deposits of the northern Osgood Mountains, Humboldt County, Nevada: U.S. Geological Survey Professional Paper 431, 128 p.

John, D.A., 1983, Map showing the distribution, ages, and petrographic characteristics of Mesozoic plutonic rocks, Walker Lake 1° x 2° quadrangle, California and Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1382-B, scale 1:250,000.

John, D.A., 1987, Map showing the distribution and characteristics of plutonic rocks in the Tonopah 1° by 2° quadrangle, central Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1877-J, scale 1:250,000.

John, D.A., 1992, Chemical analyses of granitic rocks in the Reno 1° by 2° quadrangle and in the northern Pine Nut Mountains, west-central Nevada: U.S. Geological Survey Open-File Report 92-246, 35 p.

Johnson, M.G., 1977, Geology and mineral deposits of Pershing County, Nevada: Nevada Bureau of Mines and Geology Bulletin 89, 115 p.

Johnson, V.Y., and Keith, J.D., 1991, Petrology and geochemistry of the Springer Scheelite skarn deposit, Mill City, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, v. 1, p. 553-578.

Keith, S.B., Laux, D.P., Maughan, Jerald, Schwab, Karen, Ruff, Steven, Swan, M.M., Abbott, Earl, and Friberg, Steve, 1991, Magma series and metallogeny: A case study from Nevada and environs, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and Ore Deposits of the Great Basin, Field Trip Guidebook Compendium: Reno, Geological Society of Nevada, p. 404-493.

Kistler, R.W., Ghent, E.D., and O'Neil, J.R., 1981, Petrogenesis of garnet two-mica granites in the Ruby Mountains, Nevada: Journal of Geophysical Research, v. 86, no. B11, p. 10591-10606.

Kleinhampl, F.J., and Ziony, J.I., 1984, Mineral resources of northern Nye County: Nevada Bureau of Mines and Geology, Bulletin 99B, 241 p.

Lee, D.E., 1984, Analytical data for a suite of granitoid rocks from the Basin and Range Province: U.S. Geological Survey Bulletin 1602, 54 p.

McKee, E.H., 1976, Geology of the northern Toquima Range, Lander, Eureka, and Nye Counties, Nevada: U.S. Geological Survey Professional Paper 931, 49 p.

Meinert, L.D., 1991a, Skarn deposits in Nevada - Geology, mineralogy, and petrology of Au, Cu, W, and Zn skarns, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and Ore Deposits of the Great Basin, Field Trip Guidebook Compendium: Reno, Geological Society of Nevada, p. 41-71.

Meinert, L.D., 1991b, Whole rock geochemistry and contrasts among skarn types, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and Ore Deposits of the Great Basin, Field Trip Guidebook Compendium: Reno, Geological Society of Nevada, p. 72-80.

Silberling, N.J., 1991, Allochthonous terranes of western Nevada—current status, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, Symposium proceedings: Reno, Geological Society of Nevada and U.S. Geological Survey, p. 101-102.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., and Howell, D.G., 1987, Lithotectonic map of the western conterminous United States: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-C, scale 1:2,500,000.

Silberman, M.L., Berger, B.R., and Koski, R.A., 1974, K-Ar age relations of granodiorite emplacement and tungsten and gold mineralization near the Getchell mine, Humboldt County, Nevada: Economic Geology, v. 69, p. 646-656.

Smith, J.G., McKee, E.H., Tatlock, D.B., and Marvin, R.B., 1971, Mesozoic granitic rocks in northwestern Nevada—a link between the Sierra Nevada and Idaho batholiths: Geological Society of America Bulletin, v. 82, p. 2933-2944.

Smith, W.C., and Guild, P.W., 1942, Tungsten deposits of the Nightingale district, Pershing County, Nevada: U.S. Geological Survey Bulletin 936-B, 58 p.

Stager, H.K., and Tingley, J.V., 1988, Tungsten deposits in Nevada: Nevada Bureau of Mines and Geology Bulletin 105, 256 p.

Stewart, J.H., and McKee, E.H., 1977, Geology and mineral deposits of Lander County, Nevada: Nevada Bureau of Mines and Geology Bulletin 88, 106 p.

Trexler, D.T., 1977, Carson City folio, geologic map: Nevada Bureau of Mines and Geology Map 1Ag, scale 1:24,000.

Willden, Ronald, and Speed, R.C., 1974, Geology and mineral deposits of Churchill County, Nevada: Nevada Bureau of Mines and Geology, Bulletin 83, 95 p.

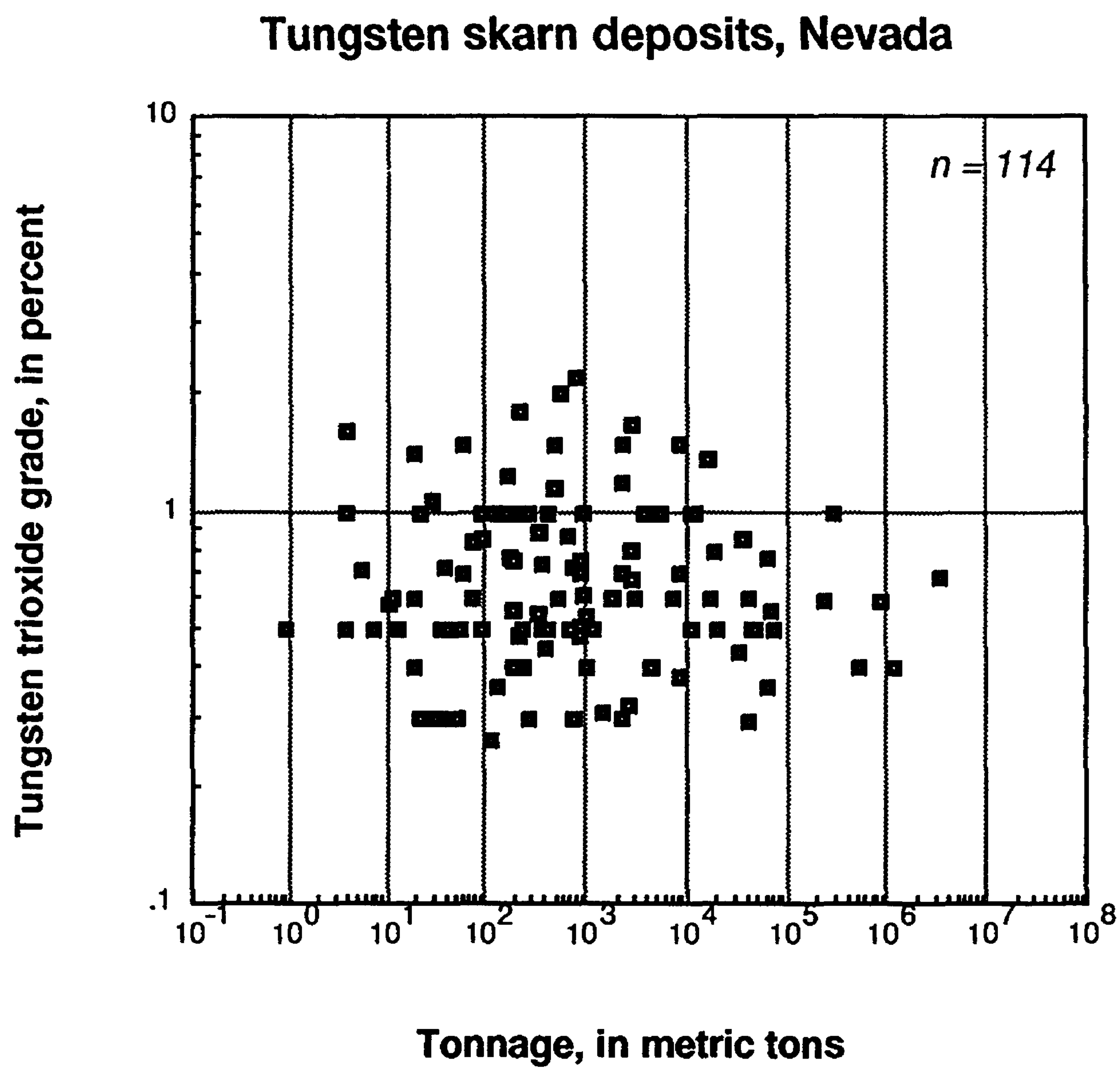

Figure 1. Scatter plot of tungsten trioxide grades and tonnages for tungsten skarn deposits in Nevada. See Appendix A for full listing of data.

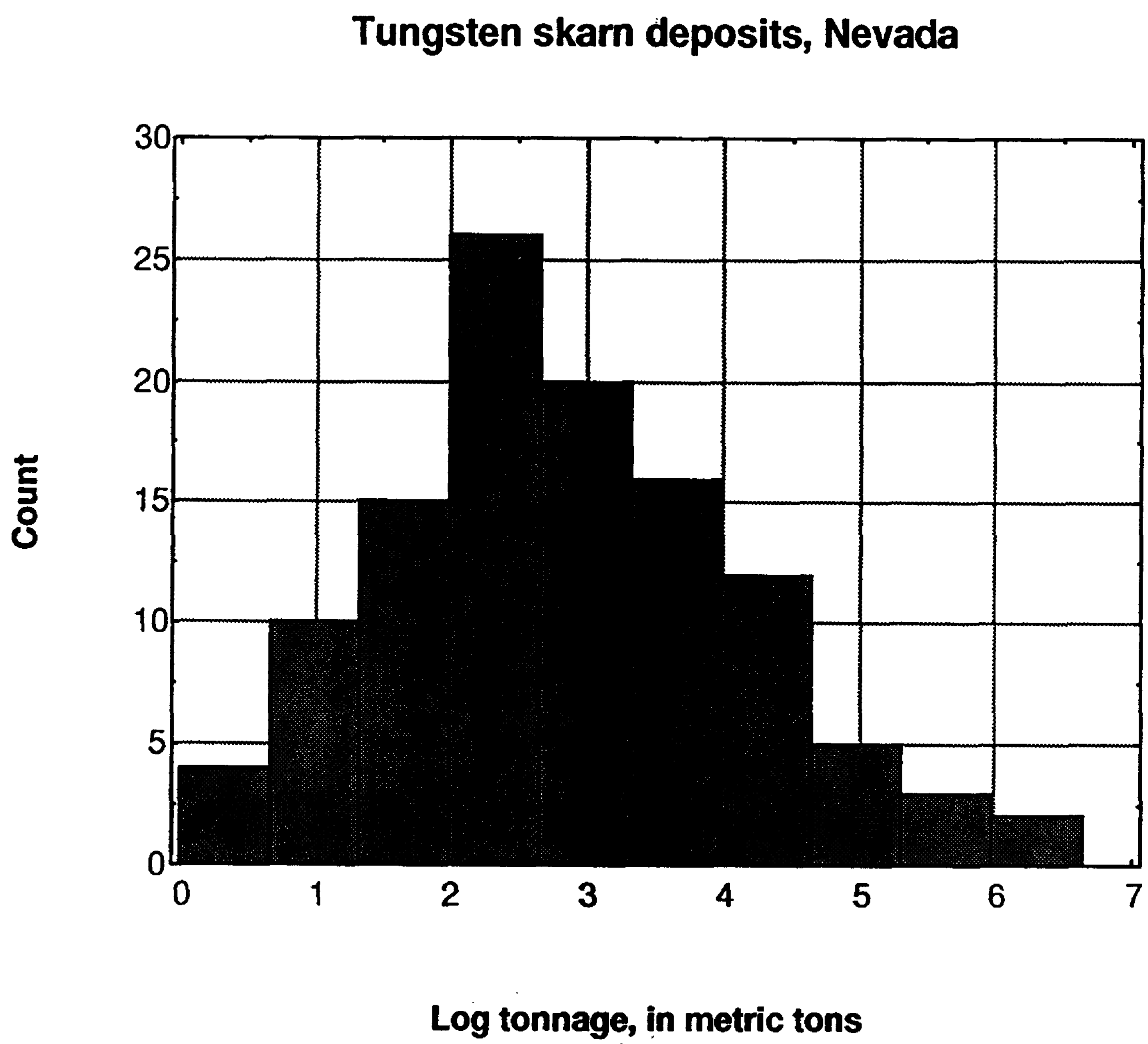

Figure 2. Histrogram of log tonnage of tungsten skarn deposits, Nevada (n=113). See Appendix A for full listing of data.

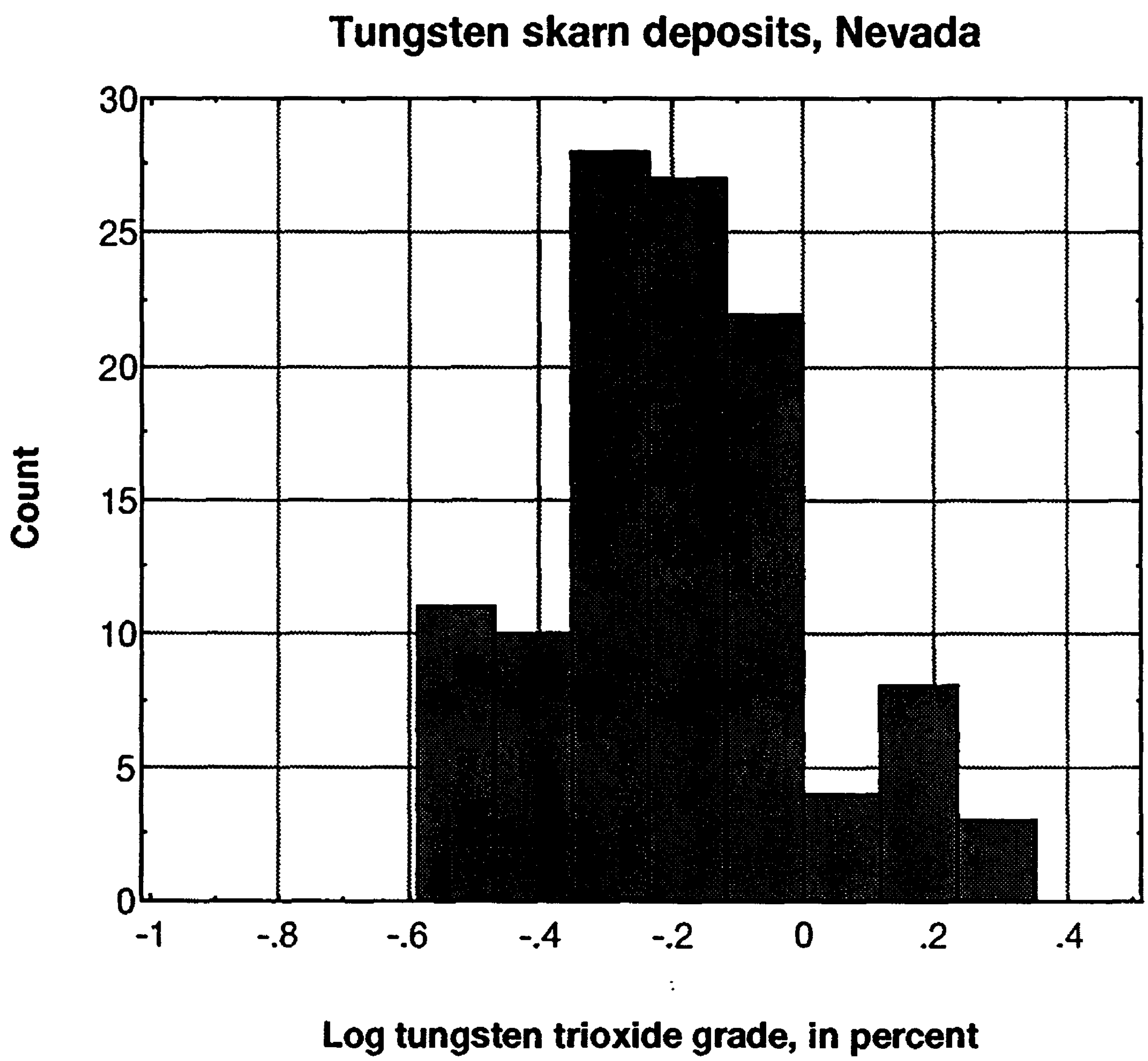

Figure 3. Histogram of log tungsten trioxide grades (n=113) of tungsten skarn deposits, Nevada. See Appendix A for full data listing.

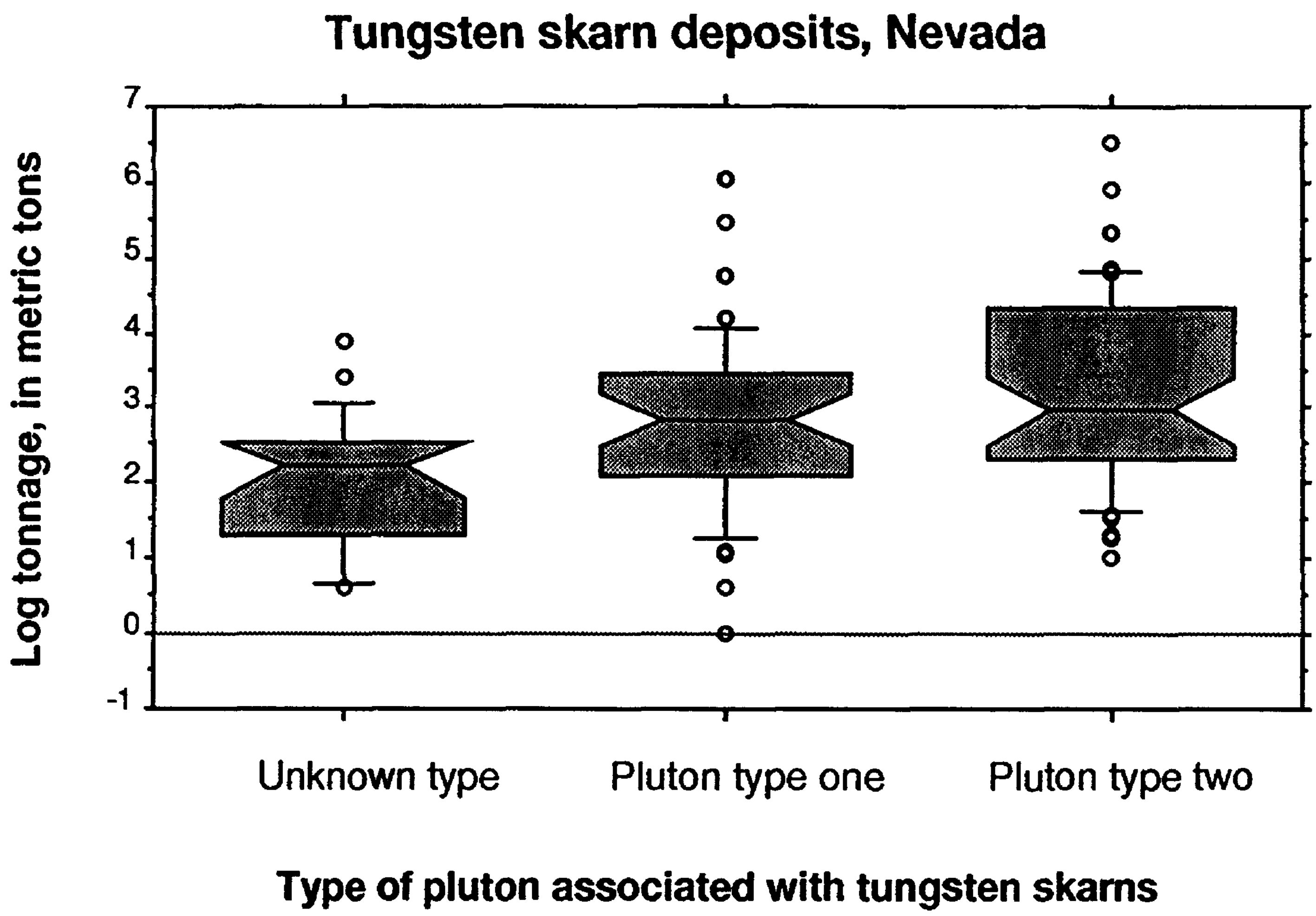

Figure 4. Notched box-and-whisker plots of tonnages of tungsten skarns associated with unknown pluton types, pluton type one (biotite granite, commonly porphyritic and weakly peraluminous), and pluton type two (hornblende-biotite granodiorite). The boxes are notched at the median and return to full width at the lower and upper 95 precent confidence interval values. Values outside of the 10th and 90th percentiles shown as points.

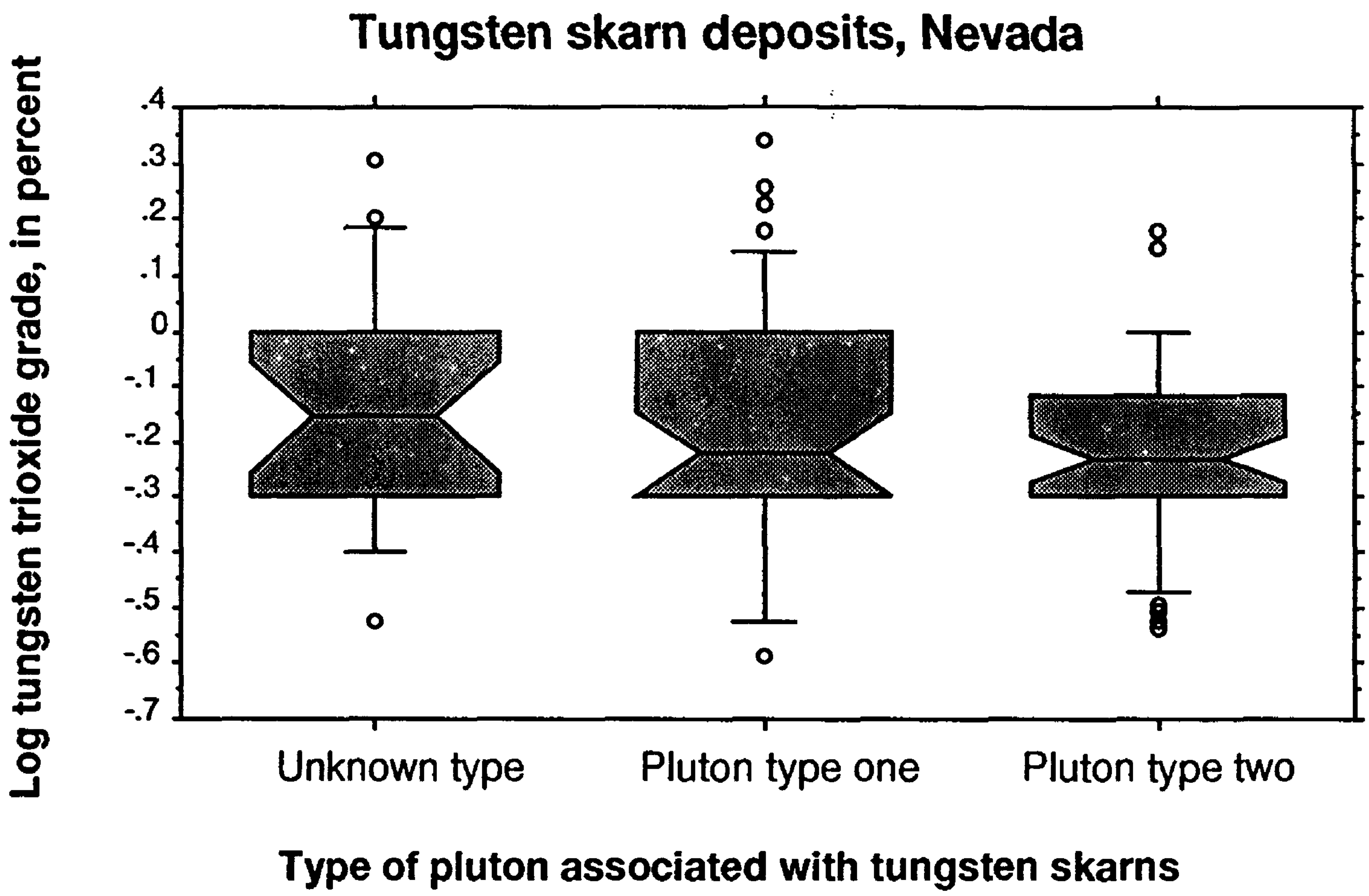

Figure 5. Notched box-and-whisker plots of tungsten trioxide grades in skarns associated with unknown pluton types, pluton type one (biotite granite, commonly porphyritic and weakly peraluminous), and pluton type two (hornblende-biotite granodiorite). Five horizontal lines on the box give the 10, 25, 50, 75. and 90th percentiles. The boxes are notched at the median and return to full width at the lower and upper 95 precent confidence interval values. Values outside of the 10th and 90th percentiles shown as points.

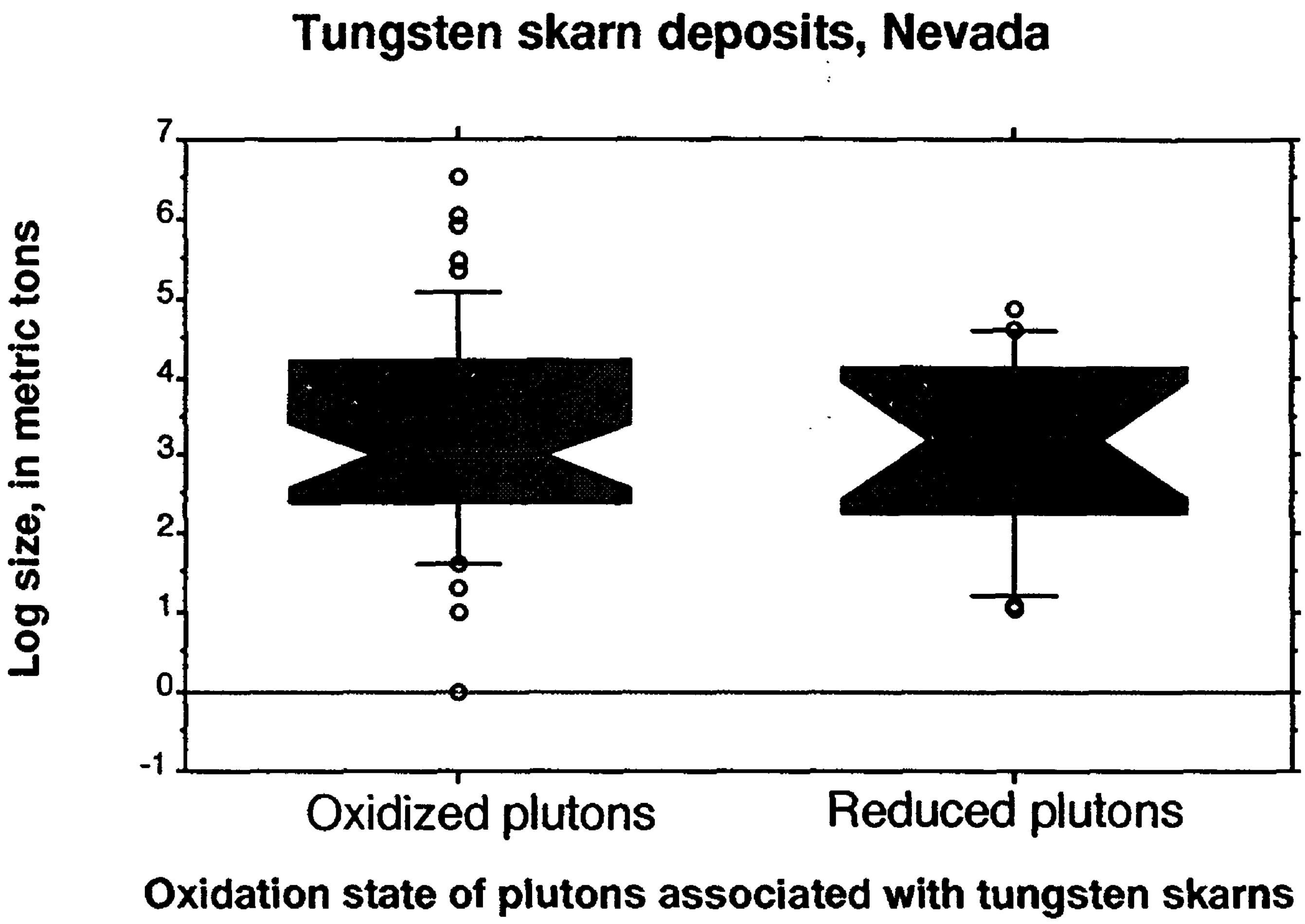

Figure 6. Notched box-and-whisker plots of tonnage of tungsten skarns associated with oxidized and reduced plutons in Nevada. The oxidation state of the skarn may not be the same as that of the associated pluton. Five horizontal lines on the box give the 10, 25, 50, 75. and 90th percentiles. The boxes are notched at the median and return to the full width at the lower and upper 95 precent confidence interval values. Values outside of the 10th and 90th percentiles shown as points.

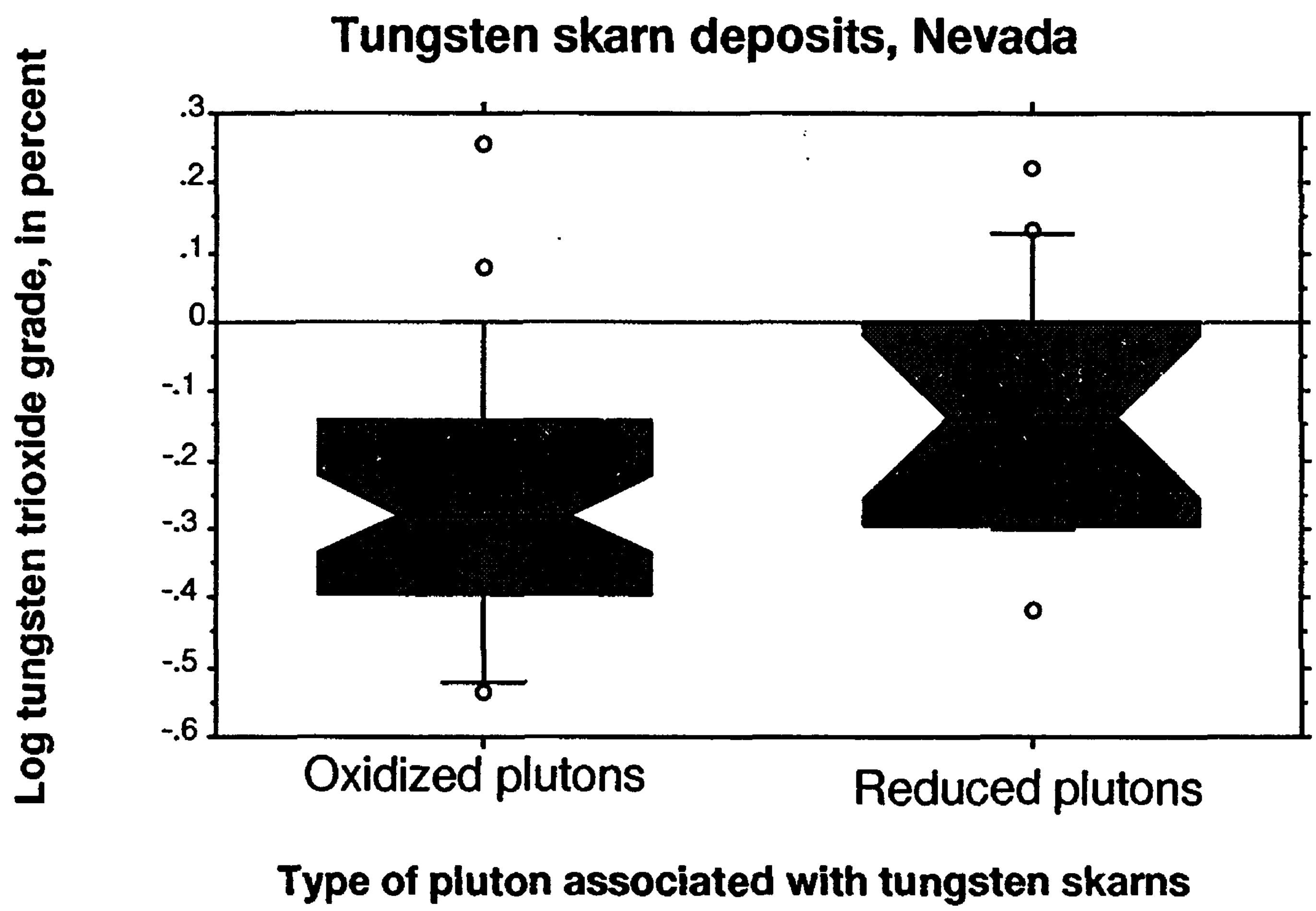

Figure 7. Notched box-and-whisker plots of tungsten grades in skarns associated with oxidized and reduced plutons in Nevada. The oxidation state of the skarn may not be the same as the pluton. Five horizontal lines on the box give the 10, 25, 50, 75, and 90th percentiles. The boxes are notched at the median and return to full width at the lower and upper 95 precent confidence interval values. Values outside of the 10th and 90th percentiles shown as points.

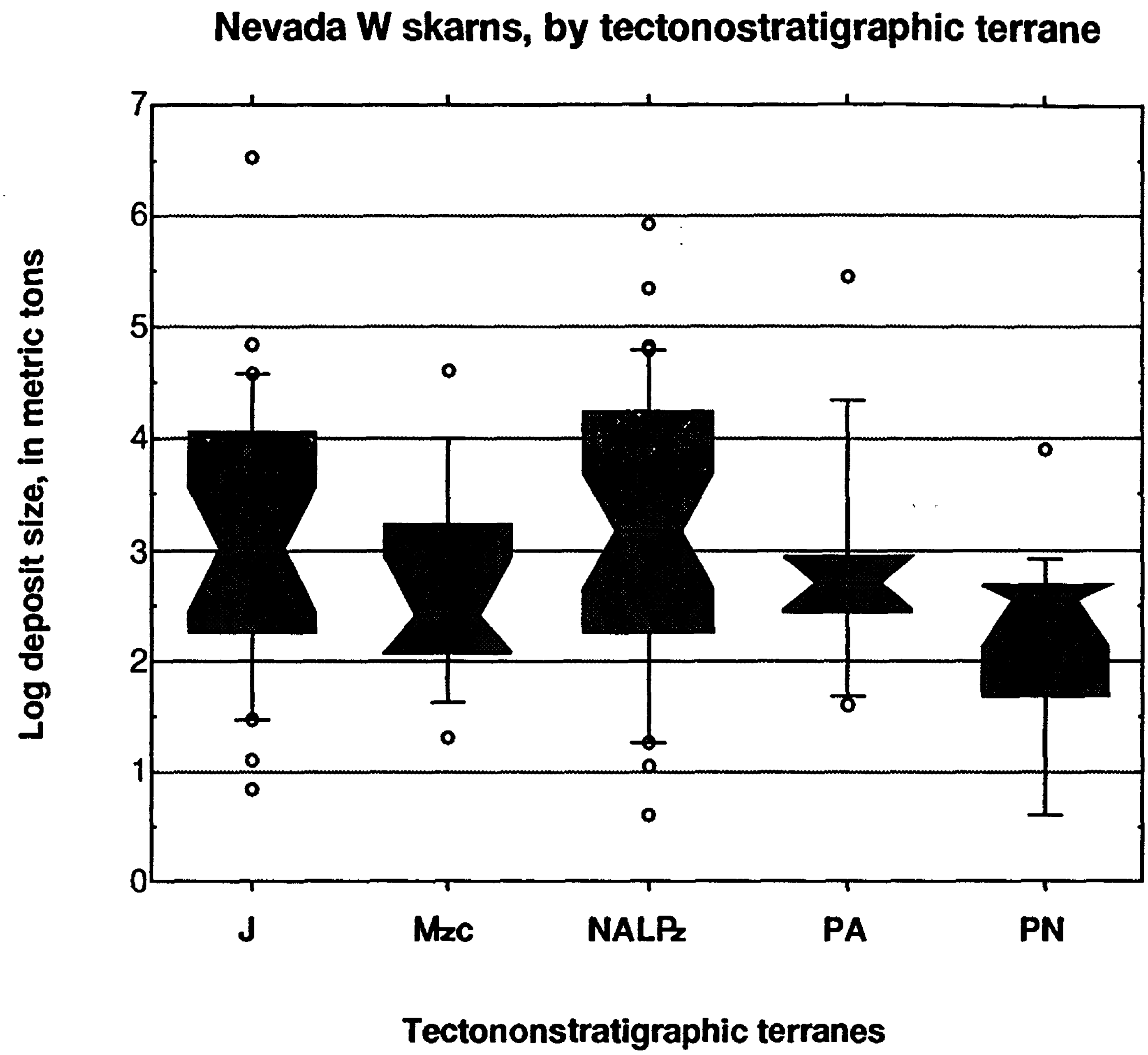

Figure 8. Tonnages by tectonostratigraphic terranes for W skarns in Nevada (see Appendix A for individual deposit classification). Terranes and number of deposits (n=) in each are as follows: J - Jungo (n=26); Mzc - Mesozoic carbonate rocks (n=13); NALPz - North America miogeocline, Lower Paleozoic carbonate rocks (n=36); PA - Paradise (n=10); and PN - Pine Nut (n=15). Terranes with five or fewer deposits are not shown. Five horizontal lines on the boxes give the 10, 25, 50, 75, and 90th percentiles. The boxes are notched at the median and return to full width at the lower and upper 95 percent confidence interval values.

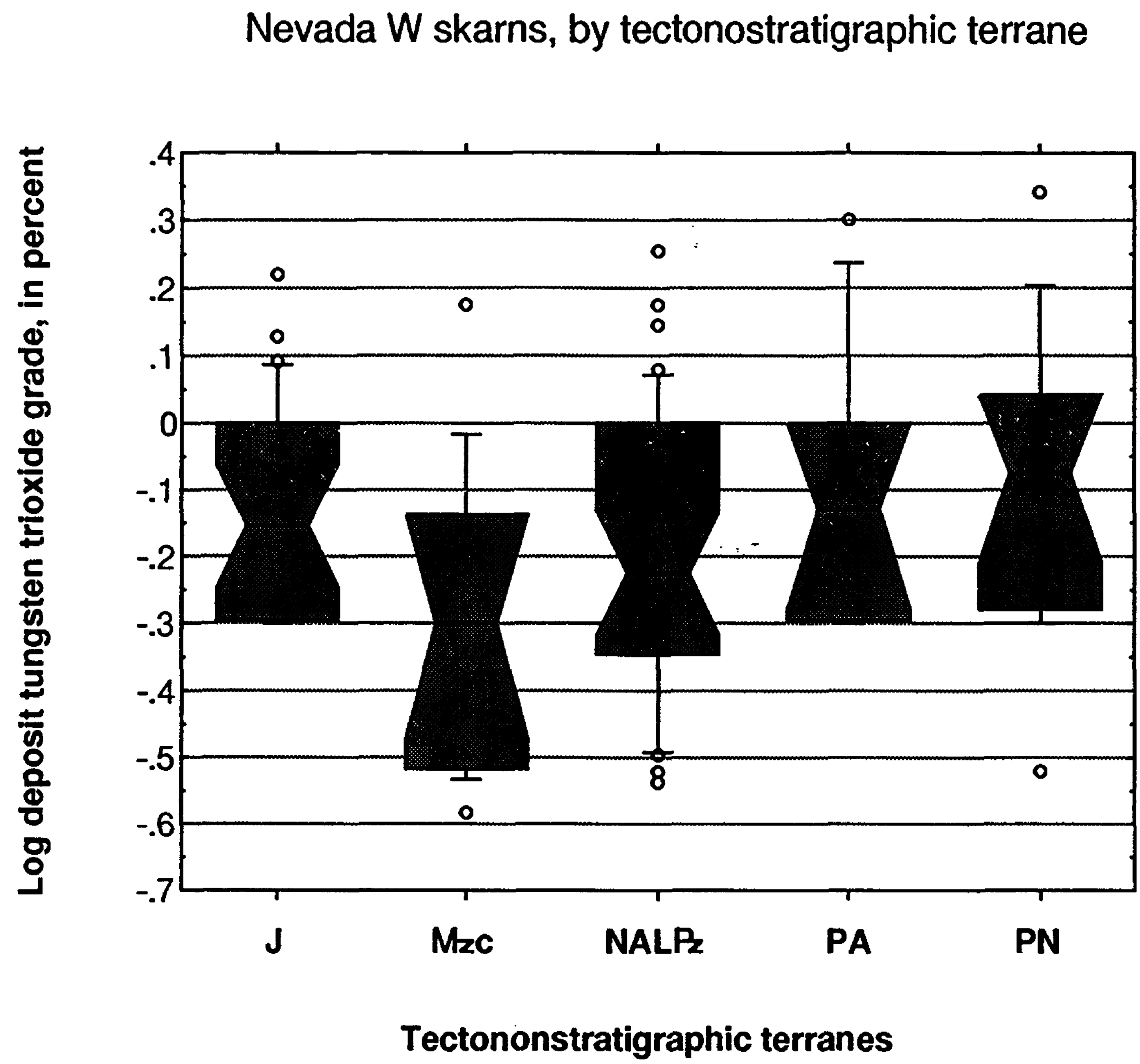

Figure 9. Tungsten trioxide grades by tectonostratigraphic terranes for W skarns in Nevada (see Appendix A for individual deposit classification). Terranes and number of deposits (n=) in each are as follows: J - Jungo (n=26); MzC - Mesozoic carbonate rocks (n=13); NALPz - North America miogeocline, Lower Paleozoic carbonate rocks (n=36); PA - Paradise (n=10); and PN - Pine Nut (n=15). Terranes with five or fewer deposits are not shown. Five horizontal lines on the boxes give the 10, 25, 50, 75, and 90th percentiles. The boxes are notched at the median and return to full width at the lower and upper 95 percent confidence interval values.

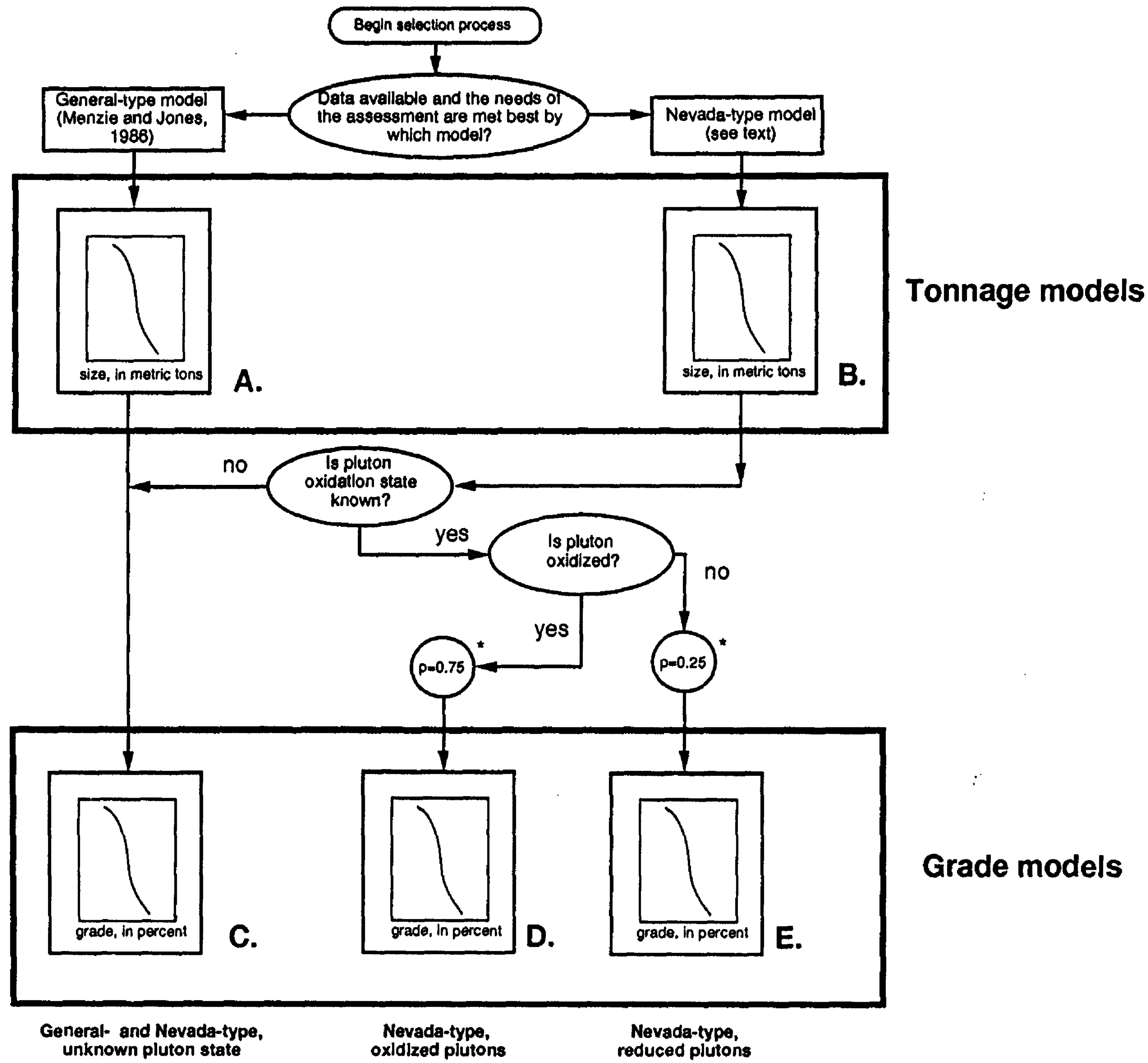

Figure 10. Scheme for selecting grade and tonnage models applicable to W skarns (*-probabilities based on Nevada W skarns only).

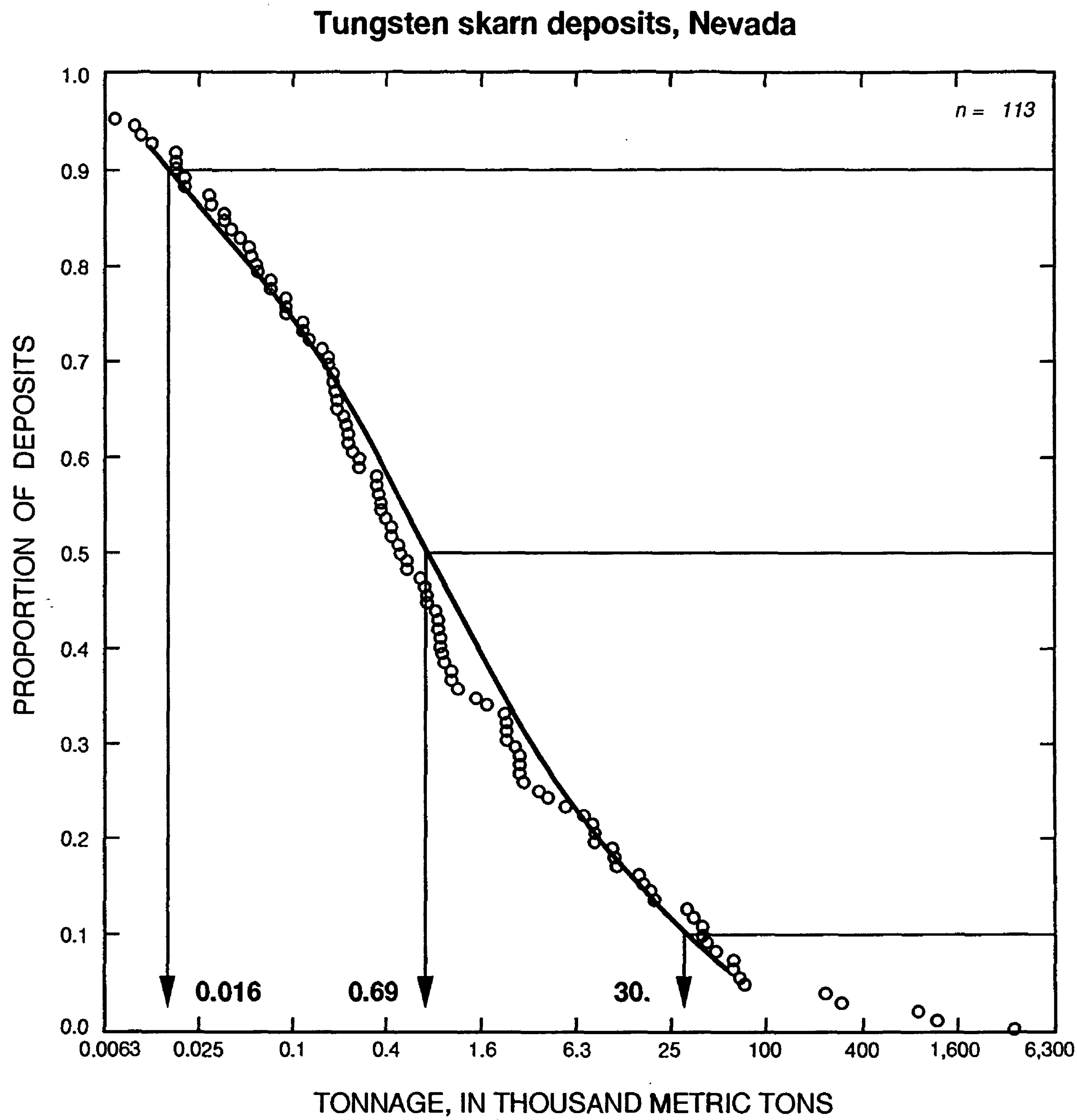

Figure 11. Tonnages of tungsten skarn deposits, Nevada. See Appendix A for full listing of data used.

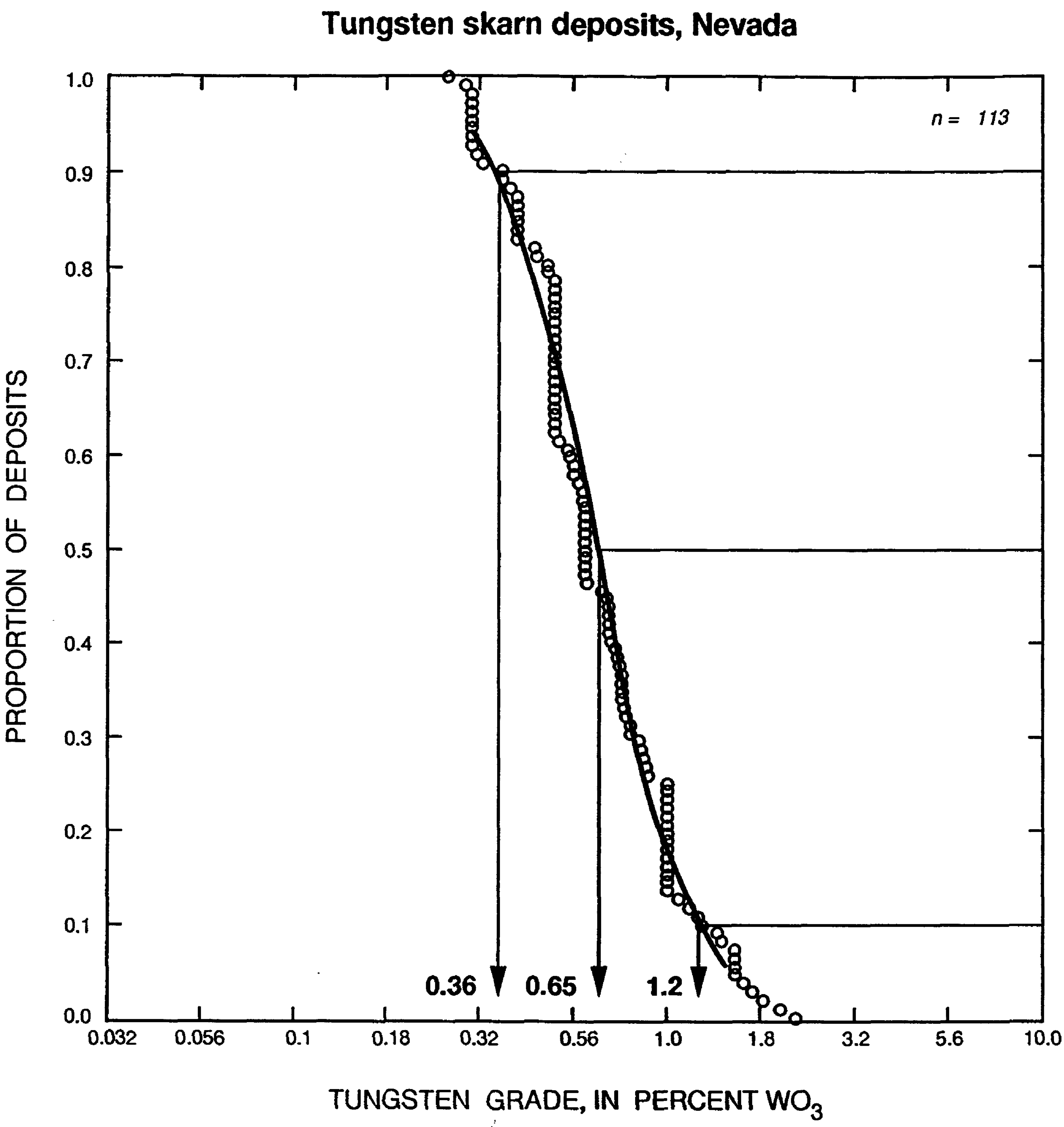

Figure 12. Tungsten trioxide grades of tungsten skarn deposits, Nevada. See Appendix A for full listing of data.

Tungsten skarn deposits associated with oxidized plutons, Nevada

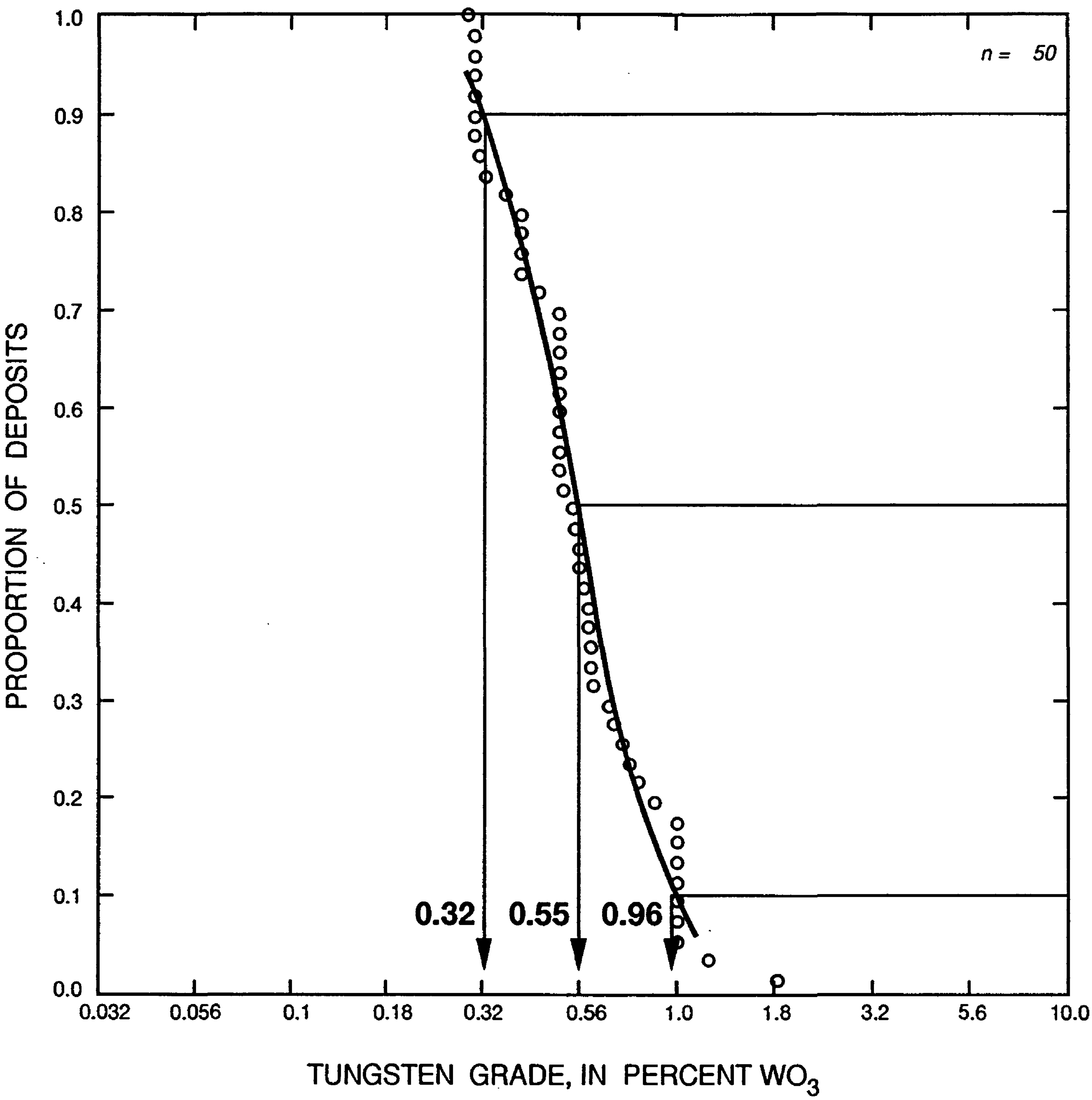

Figure 13. Tungsten trioxide grade of tungsten skarn deposits associated with oxidized plutons in Nevada. See Appendix A for full listing of data.

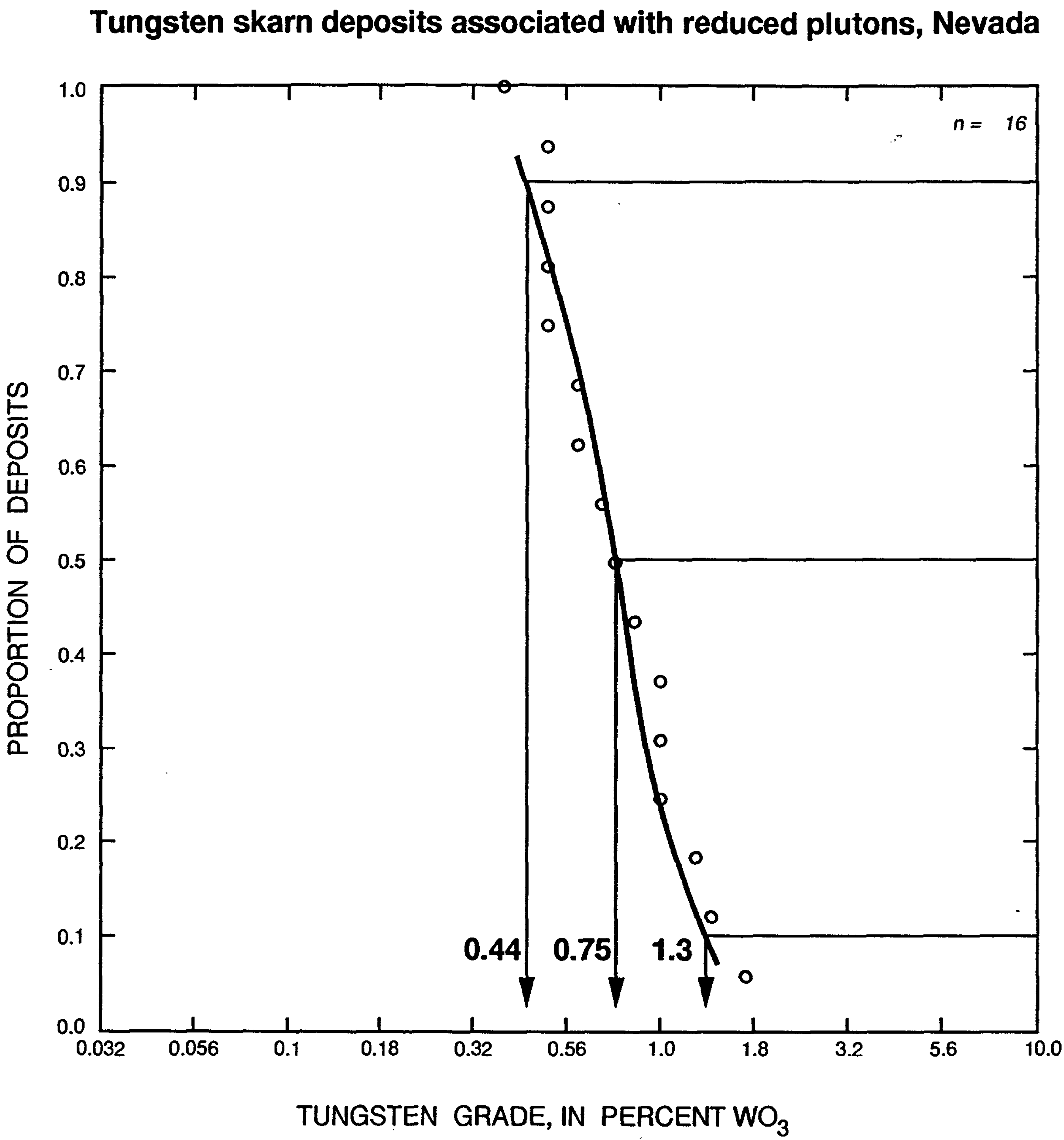

Figure 14. Tungsten trioxide grade of tungsten skarn deposits associated with reduced plutons in Nevada. See Appendix A for full listing of data.

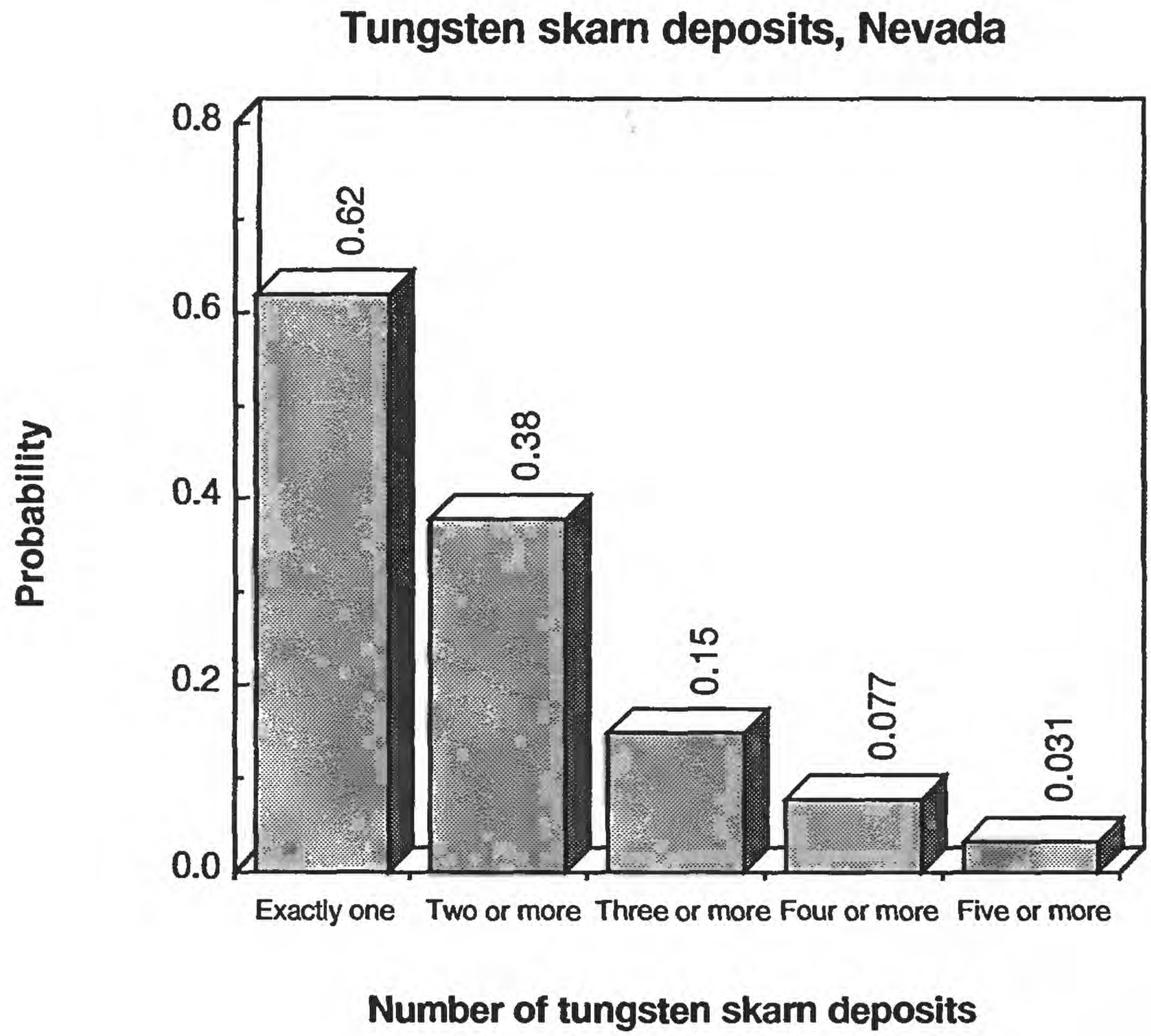

Figure 15. Histogram giving probabilities of numbers of tungsten skarn deposits found associated with plutons.