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COPPER DISTRIBUTION PATTERNS IN SOILS AND DRAINAGE IN CENTRAL CHILE

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ABSTRACT

Results of metal distribution patterns from geochemical surveys carried out in Central Chile are presented graphically. In soils near ore deposits the dispersion may be complex, but in drainage at a distance from the source of the metal, the pattern becomes simpler. The distribution patterns appear to be lognormal.

INTRODUCTION

THE distribution of trace elements in a particular environment is known to be lognormal (2). A quick test for lognormality can be made if, when the cumulative percentages of the concentrations of the elements are plotted on lognormal probability paper, a straight line is obtained (3). The steeper the slope of the line the greater the range of dispersion that could result from rapid variations in the availability of the metal or of favorable locations for the concentrations of the metal over short distances (5). On the other hand a low slope of the line indicates only a narrow range of values and evenness in the distribution. If there is a sympathetic relationship between two metals in the same environment, the cumulative distribution lines will be parallel, or in other words, the distributions are similar but the means differ. Cousins (5) applied this method to demonstrate a placer for gold, silver, uranium and osmiridium in the Witwatersrand System.

Tennant and White (6) used cumulative distribution percentages of metals to distinguish background and anomalous distributions in geochemical dispersion studies. A mixed distribution when plotted on lognormal probability paper is indicated by a change in the slope of the line.

Any metal might be expected to show different dispersion patterns depending on the environment. The dispersion patterns depend not only on the

TABLE 1. STATISTICAL PARAMETERS FOR SOIL AND DRAINAGE SURVEYS OF CENTRAL CHILE.

Survey.	Sample.	Median.	Mean.	Variance.
Teno	Sediments	3.951	4.053	.203
Pucón	"	3.584	3.667	.165
La Ligua	"	5.393	5,628	.650
Tinguiririca	"	4.491	5.248	.615
Andean streams	"	3.091	3.427	.671
Coastal streams	"	4.007	4.286	.558
Year survey of	"	4.407	4.551	.287
11 streams	Waters	2.944	3.259	.629
Rinconada de lo Cerda	Soils	4.787	5.145	.716
La Serena	"	4.605	5.557	1.904
Yaquil	"	3.871	4.627	1.513
Patagua	"	5.193	5.569	.752
Patagua	Banks	5.521	6.229	1.142
Patagua	Sediments	5.247	6.433	2.372

metal concentrations but also on the agents involved in the dispersion, whether this is by chemical or physical processes or a mixture of both. In the case of ore deposition, or primary dispersion, a continual but gradual accumulation of metal in a host rock can theoretically be shown to generate a lognormal distribution curve (1). In secondary dispersion the process could either be considered as a breakdown as the ore body is being oxidized, altered or leached; or as a build-up with the deposition of small increments of metal in new environment, i.e., soils, alluvium, drainage, etc. Near an ore body the dispersion pattern may tend to become complicated as there is the original primary dispersion, which is being altered, and superimposed on this a secondary dispersion due to the weathering of the original ore body. In environments remote from the ore body some regularity of dispersion might be obtained when the amount of metal introduced is balanced by that removed. Therefore soils near a metal deposit may have an irregular dispersion pattern while in drainage, at a distance from the ore body, the dispersion is simpler.

This study summarizes results from soil and drainage surveys carried out in Central Chile. It includes overall sediment surveys from rivers draining an area in the Central Chilean Andes and another in the Coast Range. Also discussed are sediment surveys from four individual Andean rivers. The soil surveys cover four areas—La Serena in north-central Chile, and Rinconada de lo Cerda, Patagua and Yaquil are all within a radius of 200 km of Santiago. Results from the surveys are presented graphically on lognormal probability paper and estimates of the statistical parameters are also made graphically. No rigorous mathematical treatment of the dispersion patterns has been attempted.

COPPER DISTRIBUTION PATTERNS IN DRAINAGE

Two backgrounds, i.e., not known to contain mineral deposits—the Teno and the Pucón rivers, and two anomalous streams, the La Ligua and the Tinguiririca, were sampled at regular spatial intervals for sediments and the samples were analyzed for copper content by standard dithizone techniques. All four streams flow across the Andes in areas of similar topographic and geologic characteristics. The geology consists of sediments and volcanics from the Jurassic upwards, which have been folded and intruded by granodioritic batholiths. The Teno and Pucón have no metal deposits in their drainage areas. In the headwaters of the Tinguiririca are some chalcopyrite veins associated with batholith contacts. The deposits along the La Ligua are "manto-type" with chalcopyrite and/or bornite together with pyrite, the minerals replacing limestone (4).

None of the deposits along the Tinguiririca are being exploited at present although towards the turn of the century extensive small-scale operations were being carried out. In the La Ligua drainage system there are several medium-sized mines, e.g., Patagua, Los Maquis, besides numerous small workings.

In Figure 1 the cumulative distribution percentages for the copper values are plotted. The two background streams have parallel straight lines and the anomalous streams are also parallel to one another but the slopes are steeper than those of the background streams. Although mineralization and exploitation of the deposits differ in the La Ligua and Tinguiririca areas there is still a tendency for evenness in the distribution. As the La Ligua river is subject to active contamination because the mines within its drainage system are being worked at present the metal rapidly attains an equilibrium with its environment to produce a regular distribution pattern.

It appears that the processes involved in the copper distribution in the two anomalous streams are the same or similar. Likewise the metal distribution in the background streams is affected by a similar set of conditions that need not necessarily be the same as those operating in the anomalous streams. If more streams had been sampled there might have been obtained a series of lines that close the gap between the Tinguiririca and the Teno on the graph. Some of these hypothetical streams would have values that can neither be regarded as anomalous or background, in other words these streams would have threshold values.

If the metal values for the streams themselves show lognormal distribution,

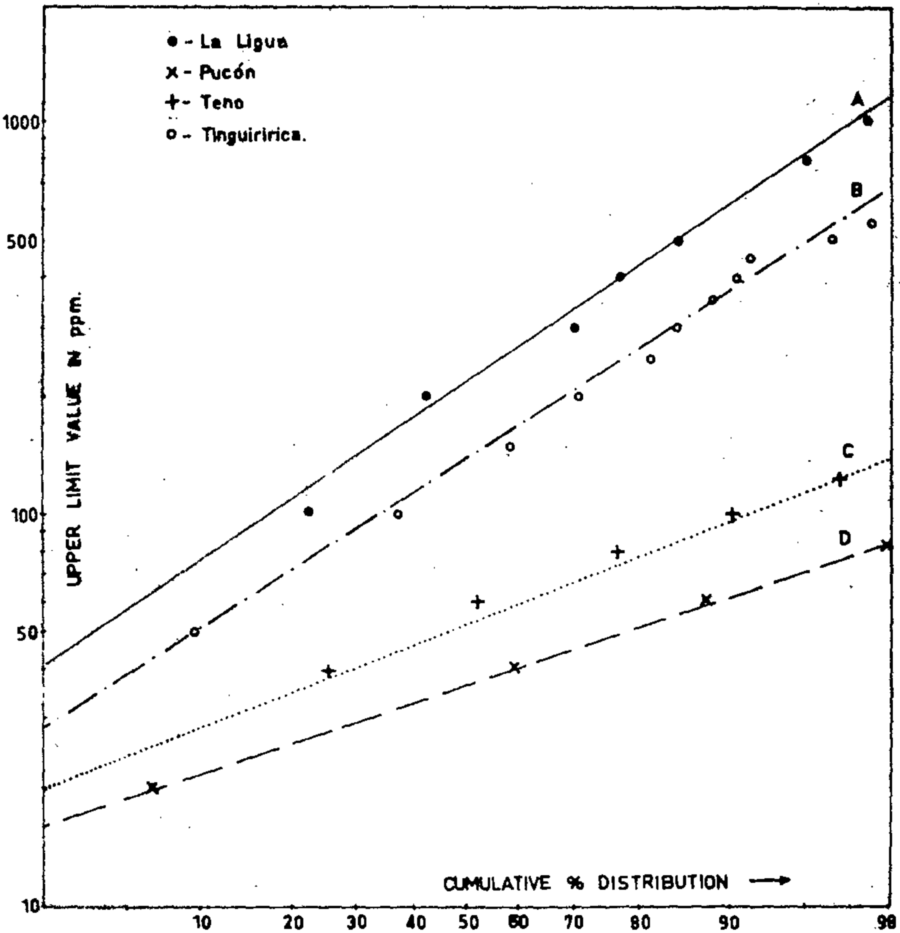

Fig 1: Cumulative percentage distribution for copper in sediments from the rivers La Ligua A, Tinguiririca B, Teno C, Pucón D.

representative samples collected from separate streams on a regional basis should also have a lognormal distribution. In Figure 2 the cumulative percentages of copper values from two areal surveys are shown. One area extends from Rancagua to Puerto Montt and streams sampled were those issuing from the Andes into the Central Valley. The other area consists of streams flowing through the Coastal Range between Curico and Rancagua. These two surveys show lines parallel to those of the two anomalous streams mentioned above. The processes involved in the metal dispersion in the anomalous streams are also responsible for the dispersion over the entire area.

In Figure 3 are the composite results of single water and sediment samples taken from eleven streams over a thirteen-month period. The metal in the sediment and water have different dispersion patterns. For the sediments the dispersion is simple and the line obtained is roughly parallel to those obtained for the regional surveys as well as for the anomalous streams. On the other hand, the results for the waters show a change in slope, indicating a mixed distribution. There is also a larger spread of values in the water samples. It appears from this that the processes involved in the metal dispersion in the sediments operates on both a spatial and time basis, but a different set of processes affect the dispersion in water. For geochemical prospecting purposes water sampling would give a greater contrast between the anomalous and background values, but the sampling would have to be carried out in a relatively short time interval, not always a practical proposi-

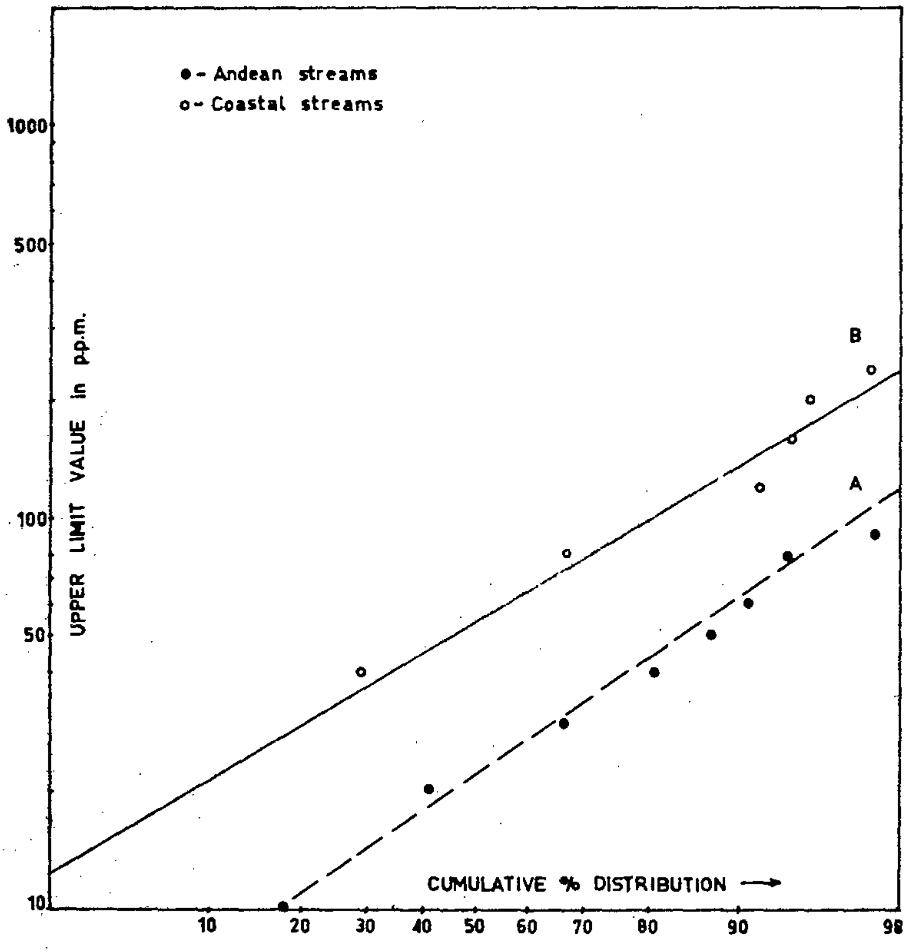

Fig 2 : Cumulative percentage distribution for copper for Andean stream sediments (A) and Coastal stream sediments (B).

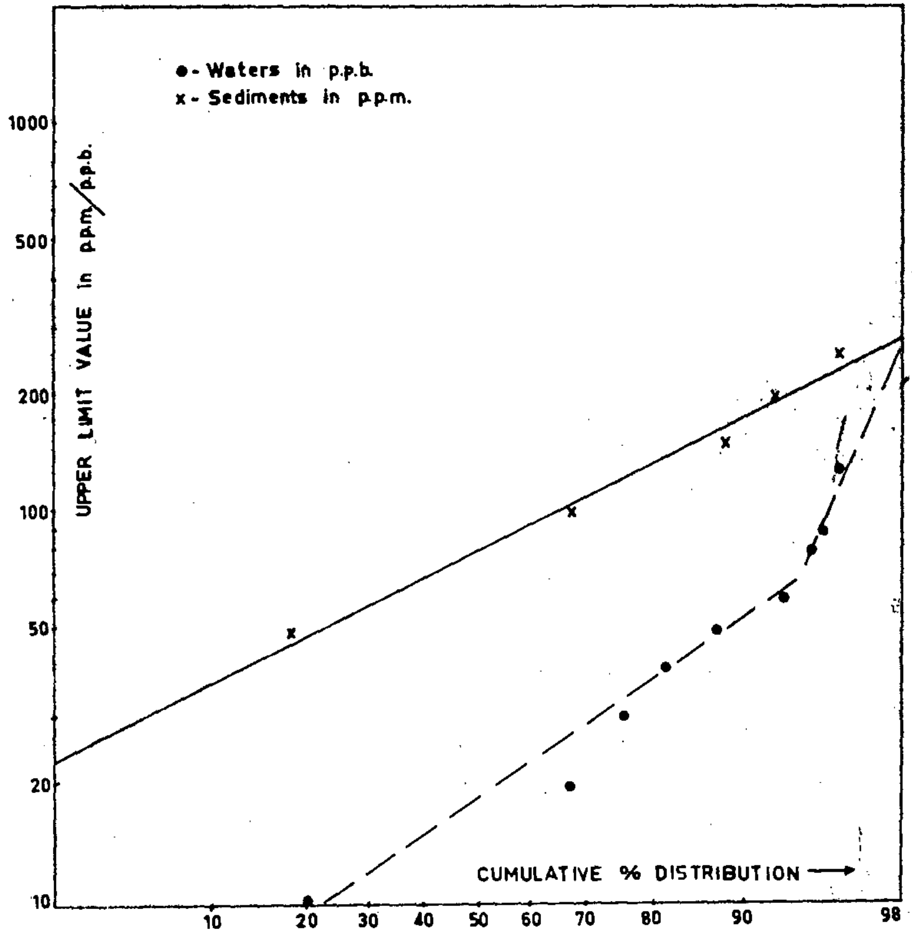

Fig 3: Cumulative percentage distribution for copper in sediments and water for some Andean streams sampling monthly over the period of a year.

tion. Although sediment sampling would give less contrast in the values, it could be carried out over a larger time span.

COPPER DISTRIBUTION PATTERNS IN THE SOIL

All four surveys were carried out in hilly country. For La Serena the climate is semi-desert. The other areas, Patagua, Rinconada de lo Cerda and Yaquil all experience a Mediterranean climate. The mineralization for Rinconada de lo Cerda, Yaquil and La Serena is in each case related to a batholith contact and consists of chalcopyrite. In the Patagua area, however, the mineralization consists of a "manto-type" deposit in limestone. Yaquil differs from the other areas in that the copper is accompanied by arsenopyrite and gold.

For the three areas, Rinconada de lo Cerda, Yaquil and La Serena the results are presented in Figure 4. The distributions are divergent and are parallel neither to one another nor to those of the drainage, but they are still simple. By contrast, Patagua, where soil, bank, and sediment samples were collected, has extremely complicated distribution patterns. These samples were all taken near the deposit that is being exploited and the observed pattern may be due to contamination superimposed upon normal distribution pattern of the superficial environment.

It appears that in soils the nearer the source of the metal the more complex

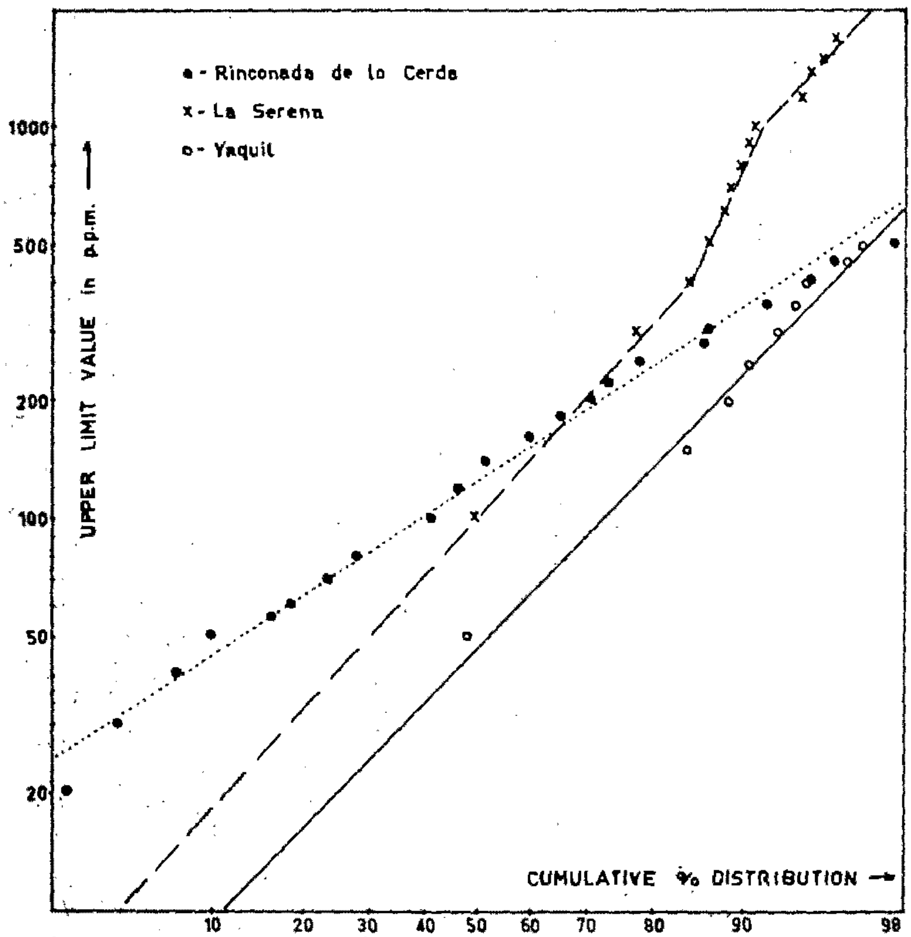

Fig. 4: Cumulative percentage distribution for copper fron soil surveys from La Serena, Rinconada de lo Cerda and Yaquil.

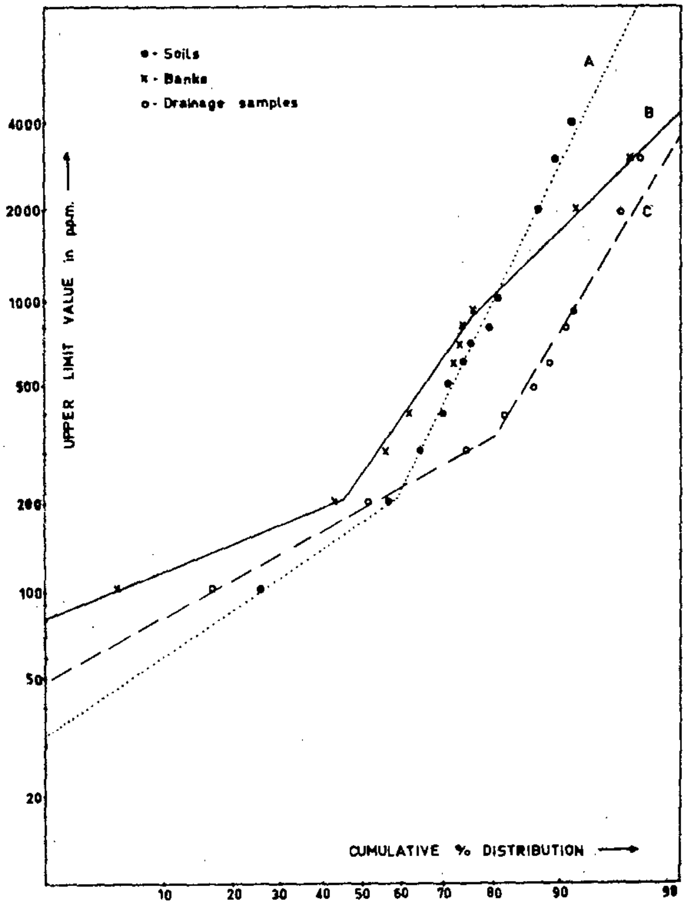

Fig. 5: Cumulative percentage distribution for Cu in Patagua samples. A Soils B Banks and C Drainage samples.

is the dispersion pattern, and the farther removed the simpler the pattern becomes.

ESTIMATION OF MEAN AND VARIANCE

In all cases straight lines have been obtained on the graphs, indicating that the distributions are probably lognormal. The lognormal distribution is a two-parameter distribution (3) and is defined by the standard deviation and the mean, the first and second moments of the distribution.

These statistical measures of mean and standard deviation can be determined either mathematically by the method of moments, or graphically by reading off selected percentiles from the cumulative curves. The graphical method has been used in this study and this method gives values that are close

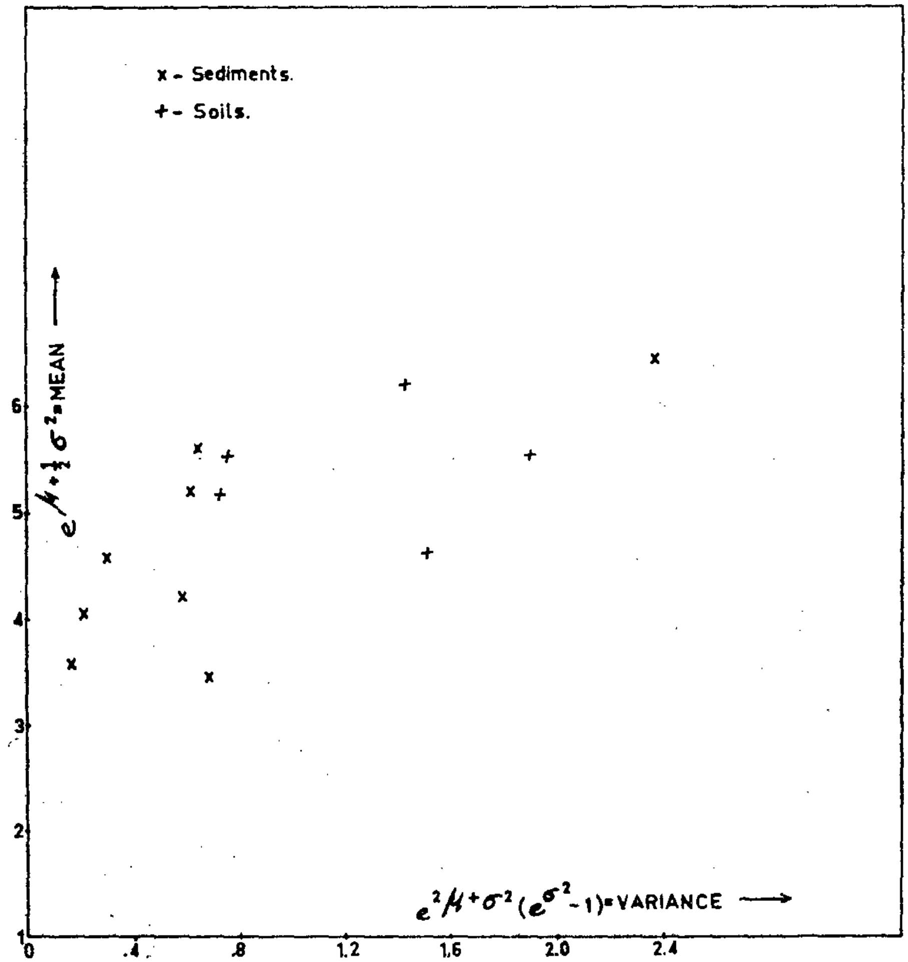

Fig. 6: Scatter plot of mean versus variance.

enough to be calculated. The formulae used are those suggested by Aitchson and Brown (3).

The Median.—This can be read off from the graph at the 50% percentile, and corresponds to the point e^{μ}.

The values vary from 20 to 250 ppm. The lowest values are from the background streams and from the regional surveys. Higher means are encountered for the soil surveys, the highest of all are obtained from the La Ligua samples and the Patagua bank samples. The La Ligua high is due to contamination in the drainage. Contamination is also true for the Patagua samples, the dispersion in the bank samples could be caused by a mixed dispersion of the metal derived from two sources, the soil and drainage.

The Variance can be estimated from the graph. If ξ is the percentile to be read off, then the standard deviation, β, is

$$\log \frac{1}{2}\left(\frac{\xi_{50}}{\xi_{16}} + \frac{\xi_{84}}{\xi_{50}}\right).$$

The variance β^2 is $e^{2\mu+\sigma^2}(e^{\sigma^2} - 1)$.

The background streams have the lowest spread of values, which is what would be expected. The remaining drainage surveys, but for two exceptions, fall in the range 0.50 to 0.70 and there is no great spread of values. One exception is the year survey of sediment samples, which has a variance of 0.28. Comparing this value with the variance of the water samples (0.63) it is again noted that the waters have a greater spread of values on a time and spatial basis than the soils. This point has already been discussed.

Another exception is the Patagua sediments, probably because of proximity to the source of the metal. However, the spread of values is less for the soils that are rich in carbonates and precipitate the copper, diminishing the distribution range. (The difference between the dispersion of copper in the drainage and soils will be discussed in detail in a future paper.) The spread of values of the bank samples is between that of the soils and sediments, because the metal in the banks is a mixture of the dispersion patterns derived from the soil and drainage.

The Mean is equal to $e^{\mu + \frac{1}{2}\sigma^2}$.

The mean is always greater than the median for a lognormal distribution, i.e., $e^{\mu + \frac{1}{2}\sigma^2}$ and e^{μ} are, respectively, the median and the mean (3).

The significance of the mean and the median for the various surveys is the same and has already been discussed above.

The Mean versus the Variance.—(Fig. 6.) It has already been noted that for some surveys the cumulative distribution curves are parallel. This suggests that there is a relationship between the mean and the variance, and in Figure 6 a linearity between the parameters is noted. As the mean increases so does the spread of values. This would indicate that the pattern of the distribution in the soil or drainage is guided by the same factors.

CONCLUSIONS

Distribution patterns can be complex near the origin of the metal as, for example, in contaminated mines areas, Patagua.

In the drainage surveys the distribution patterns tend to become similar, either because the drainage processes are more effective in obtaining regularity of distribution, or because the metal is farther removed from its source and has had more opportunity to achieve equilibrium with its environment. In both regional drainage and single river surveys the same or similar processes operate to give a similar dispersion pattern.

Metal content in waters does not appear to have the same dispersion pattern as that of sediments. The range of metal values is greater for waters than for sediments.

A study of the mean and variance demonstrates a linear relationship between these two parameters.

It is not intended to imply that the results discussed here are universally applicable as only a limited number of surveys for one metal from one area have been studied. It was only aimed to show some differences in the dispersion patterns for copper in drainage and soils, and how these differences may be interpreted.

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