A. DIMITRIU
L. CURTA
V. DUMITRU
A. IOSIFESCU

# Determination of Statistical Criteria to Substantiate Some Geological Conclusions

*Among the more important geological works that can be optimized by statistical-mathematical basic operations, the authors have tackled the geological exploration of manganese deposits in view of estimating their most probable chemical composition, so as to also determine the minimum number of samples required.*

Mathematical statistics has lately proved to be of considerable assistance in the efficient solving of problems related to geology. For every single domain where the geological magnitudes have measurable properties the methods of this discipline are now used. Numerous applications have been obtained, a series of monographs [1], [2], [3] being dedicated to them. The introduction of new expressions such as *geostatistics* [4], *statistical petrology* [5], *mathematical geology* [6], proves obviously the proportions acquired by the use of mathematical statistics in the study of geological phenomena.

In Romania, the application of mathematical statistical methods to geological research has led to a series of results regarding particularly the statistical nature of the distribution of chemical components and the correlation between the chemical components in various rocks and ores [7], [8], [9]. Likewise, some papers deal with the testing of the identity between the chemistry of two rocks, thus proving the capability of the mathematical statistical methods to substantiate geological conclusions in a probabilistic manner [10].

Concomitantly, it is particularly important in geological activity that the acceptance of the conclusions — generally, of some working hypotheses usually entailing important investments — should be carried out with a negligible risk. Hence, the use of mathematical statistics with an aim to substantiate the conclusions of geological surveys stands out imperatively as an objective of major importance. The collaboration between the State Committee for

Geology and the Centre of Economic Computation and Economic Cybernetics in Bucharest was concluded in this sense, research being centred — in a first stage — on the determination of the minimum number of samples required in the works of geological exploration, in view of estimating the quality of the ore and its most probable chemical composition. The results obtained at this stage of research are shown in the present paper.

It is well known that the decision to exploit a deposit is only reached when two hypotheses are fulfilled:

1) the available ore metal contents should exceeed the quantity required to be of economic interest, and

2) the state of chemical combination in which the metal is found should be favourable for metal extraction.

The object of the present paper is a study of the manganese deposits in Romania. At present, numerous manganese deposits are exploited and are even under exploitation; each of them could make up the object of a separate study. Geological and geochemical grounds show, however, that these deposits can be divided into 4 groups according to the ore type [10].

The diagram shows the statistical distribution of the chemical components of a few typical ores.

One notices that in most deposits the basic chemical components of the ores (manganese, iron, silicon) tend towards the normal law of distribution, the one preferred when choosing the criteria to determine the minimum volume of selection.

In these conditions we have decided to subject one or two deposits, that are representative for each type in part, to statistical investigation.

In this first part of the study, four representative deposits have been investigated, belonging to the types most frequently found: the deposits at Sebeș I, Sebeș II and Delinești of the predominantly siliceous manganiferrous type, and the deposits at Iacobeni, of the siliceous manganiferrous ore type, for which the normality of distribution was checked.

Only the MnO, $Fe_2O_3$ and $SiO_2$ components were included in the investigations since they form the largest part in the ore mass (these three components make up 66—83.5% of all the manganese ores in Romania; the minimum value of the modulus is 65.7 and its maximum value 85). Other components are: CaO, $P_2O_5$, S.

The arithmetic mean and the modulus of the sum of MnO%, $Fe_2O_3$% and $SiO_2$% contents varies as follows for the deposits under study:

**Table 1**

| Deposit | Mean ($\bar{x}$) | Modulus ($Mo$) |
|---|---|---|
| Sebeș I | 75.5 | 78.5 |
| Sebeș II | 79.9 | 80.5 |
| Delinești | 76.2 | 77.2 |
| Iacobeni | 77.4 | 76.8 |

Another factor that was taken into account when choosing these components was that manganese and iron are also useful components (i.e. the ores turned to account from the manganese ores).

To compute the minimum volume of selection in view of estimating the ore quality, formula $n = \frac{t^2 \sigma^2}{\Delta \bar{x}^2}$ was applied, which is used in the case of repeated selection for a non-alternative characteristic having a significance level of 0.98.

In determining the limit error mean ( the value $\Delta \bar{x}$ ), the fact was taken into account that in the case of this observation unit (ore deposits), the actual characteristics ( mean contents, variance, etc. ) are not known, their value being approximated on basis of laboratory measurements. In this sense the hypothesis was admitetd that the statistical indicators $\bar{x}$ and $\sigma^2$ computed for a large collectivity reach values very close to the theoretic ones.

The values of the limit error for the selection mean ($\Delta \bar{x}$), taken into the computation of the minimum selection volume, were 2%, 5%, 10%, these values being determined in percentage from the computed means ($\Delta \bar{x} = p\bar{x}$) and shown in Table 2.

**Table 2**

*Value of the statistical parameters required for the computation of the minimum selection volume*

| Deposit | Average $\bar{x}$ (in %) | | | Dispersion $\sigma^2$ (in %) | | |
|---|---|---|---|---|---|---|
| | $Fe_2O_3$ | MnO | $SiO_2$ | $Fe_2O_3$ | MnO | $SiO_2$ |
| Sebeş I | 13.58 | 26.60 | 38.69 | 10.68 | 30.26 | 47.71 |
| Sebeş II | 12.55 | 25.68 | 41.66 | 6.96 | 34.79 | 42.37 |
| Delineşti | 12.71 | 24.98 | 38.56 | 8.94 | 39.96 | 56.86 |
| Iacobeni | 18.91 | 27.08 | 31.45 | 35.52 | 85.50 | 115.37 |

The results of the computations regarding the determination of the minimum selection volume for the deposits considered are shown in Table 3.

**Table 3**

| Ore type | Deposit | $N$ value | Minimum selection volume $n$, depending on the deviation value $\Delta \bar{x}$ | | | | | | | | | Minimum selection volume $n$ per deposit | | | Recommended value for $n$ by ore type | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MnO | | | $Fe_2O_3$ | | | $SiO_2$ | | | | | | | |
| | | | 2% | 5% | 10% | 2% | 5% | 10% | 2% | 5% | 10% | 2% | 5% | 10% | 5% | 10% |
| Manganiferous, siliceous | Iacobeni | 399 | — | 253 | 63 | 382 | 61 | 15 | — | 253 | 63 | — | 250 | 65 | 250 | 65 |
| Manganiferous, predominantly siliceous | Sebeş I | 462 | — | 93 | 23 | — | 126 | 31 | 437 | 69 | 17 | — | 130 | 30 | 140 | 35 |
| | Sebeş II | 130 | — | 114 | 29 | 60 | 96 | 24 | — | 53 | 13 | — | 120 | 30 | | |
| | Delineşti | 435 | — | 140 | 35 | 75 | 120 | 30 | — | 83 | 21 | — | 140 | 35 | | |

Table 4 is shown hereunder, with the values of Pearson's degree of variation ($v = \frac{\sigma}{\bar{x}} \times 100$) which points to the degree of non-uniformity, in our case to the chemical composition of the ores:

**Table 4**

| Ore type | Deposit | Value of variation degree $v$ | | |
|---|---|---|---|---|
| | | MnO | $Fe_2O_3$ | $SiO_2$ |
| Manganiferous, siliceous | Iacobeni | 34.2 | 31.5 | 34.2 |
| Manganiferous, predomiantly siliceous | Sebeș I | 20.7 | 24.1 | 17.9 |
| | Sebeș II | 22.9 | 21.0 | 15.6 |
| | Delinești | 25.3 | 23.5 | 19.6 |

One notices (tables 3 and 4) that between the values of the minimum selection volume $n$ and those of the variation degree $v$ there is a correspondence that is justified from the statistical viewpoint: to large values of the variation coefficient correspond larger minimum selection volumes and vice versa. This conclusion proves the rightness of the recommendations made regarding the minimum selection volume.

From the analysis of the tables that include the value of the minimum selection volume depending on various deviations there result the following:

a) for the type of predominantly siliceous manganiferous ore represented, mainly, by the deposits at Delinești, Sebeș I and Sebeș II, it is recommended for the minimum number of samples capable of indicating a representative chemical composition, to be, in a first approximation (admitting a 10% deviation) 35 samples, and for a more accurate estimation (the deviation being 5%) the minimum number of samples should be 140;

b) for the type of siliceous manganiferous ore represented by the Iacobeni deposit (in the present paper) and by those of Dadu, Dealul Rusului and Ciocănești it is recommended for the minimum number of samples to be 65 for a possible deviation of 10%, and 250 in case a more accurate estimation of the representative chemical composition of the ores investigated is required (5% possible deviation).

For such ores the normality of distribution will first be checked and then $\bar{x}$, $\sigma^2$, and $\Delta\bar{x}$ will be computed for a 0.98 probability. In case $\Delta\bar{x}$ ranges between acceptable limits, the technical-economical decision will be reached on basis of the mean computed values.

The aim of the present paper has been to recommend for each type of ore the minimum number of samples required to estimate the ore quality and its most probable chemical composition, starting from data regarding the chemical composition of the manganese deposits owing to work the carried out by the State Committee for Geology.

## REFERENCES


1. MILLER, R.L. and KAHN, J.S., *Statistical Analysis in the Geological Sciences*, John Wiley and Sons, Inc., New York, 1962.
2. KRUMBEIN, W.C., and GRAYBILL, F.A., *An Introduction to Statistical Models in Geology*, Mc. Graw — Hill Book Company, New York, 1965.
3. ШАРАПОВ, И.П. *Применение математической статистики в геологии*, Издательство Недра, Москва, 1965.
4. MATHERON, G., *Traité de géostatistique appliquée*. I, Memoires du Bureau de recherches géologiques et minières, Paris, 1962.
5. ЦАРОВСКИЙ, И.Д. *Применение изовариационных диаграм для разграничения математических и изверженных пород*, «Геохимия», № 4 1963.
6. VISTELUIS, A.B. *The Skew Frequency Distribution and the Fundamental Law of the Geochemical Processes*, "The Journal of Geology", 68. 1, 1—23, 1960.
7. IANOVICI, V. and DIMITRIU, Al., *Legi de distribuţie a concentraţiei elementelor chimice în roci carbonatice*, "Studii şi cercetări de geologie", vol. X, No. 1, pp. 129—159, 1965.
8. IANOVICI, V. and DIMITRIU, Al., *Legi de distribuţie a concentraţiei elementelor chimice în roci carbonatice. II. Dolomitele cristaline de la Buru (Munţii Apuseni)*, "Studii şi cercetări de geologie", No. 11, 1, 1966.
9. IANOVICI, V., DIMITRIU, Al. and IONESCU, C., *Studiul geologic şi geochimic al zăcămintelor de mangan Dadu şi Coşna (Carpaţii Orientali)*, "Studii şi cercetări de geologie", No. 11, 1, 1966.
10. IANOVICI, V., DIMITRIU, Al., CONSTANTINOF, D., DRĂGHICI, C. and IONESCU C., *Les caractères distinctifs chimico-minérologiques des minerais de manganèse de la République Socialiste de Roumanie*, "Proceedings of the 8th Congress of the Geologic Carpathian-Balkan Association, Belgrade, 1967".


# DETERMINATION DE CRITERES STATISTIQUES DANS LE BUT DE CONFIRMER CERTAINES CONCLUSIONS GEOLOGIQUES

Parmi les travaux géologiques les plus importants qui peuvent être rendus optimes au moyen de mét o es stat st ues — mathématiques, les auteurs ont abordé l'exploration géologique ces gisements de manganèse en vue d'évaluer leur composition chimique la plus probable et de déterminer également le nombre minimum d'échantillons.

Le caractère de la distribution des principaux composants chimiques du minerai de manganèse ($MnO$, $Fe_2O_3$, $SiO_2$), rapproché du caractère normal, a permis l'utilisation de la formule

$$n = \frac{t^2\sigma^2}{\Delta\bar{x}^2}$$

Les calculs ont été effectués pour une probabilité de 0,98 dans le cas de différentes valeurs de l'erreur limite de la moyenne ($\Delta\bar{x} = p\bar{x}$; $p = 0{,}02$; 0,05 et 0,10); on a considéré comme valeurs de référence, rapprochées des valeurs théoriques réelles, les valeurs de la moyenne arithmétique et de la dispersion calculées pour le cas de grandes collectivités $N$. Les résultats obtenus sont montrés, autant pour chaque gisement séparément, que pour les types de minerais étudiés et on démontre la possibilité d'obtenir une réduction importante des travaux d'exploration en vue d'évaluer la qualité la plus probable des minerais — dans le cas étudié, celle des minerais de manganèse. La concordance satisfaisante entre les valeurs $n$ et les valeurs du coefficient de variation $v$ sont à remarquer.

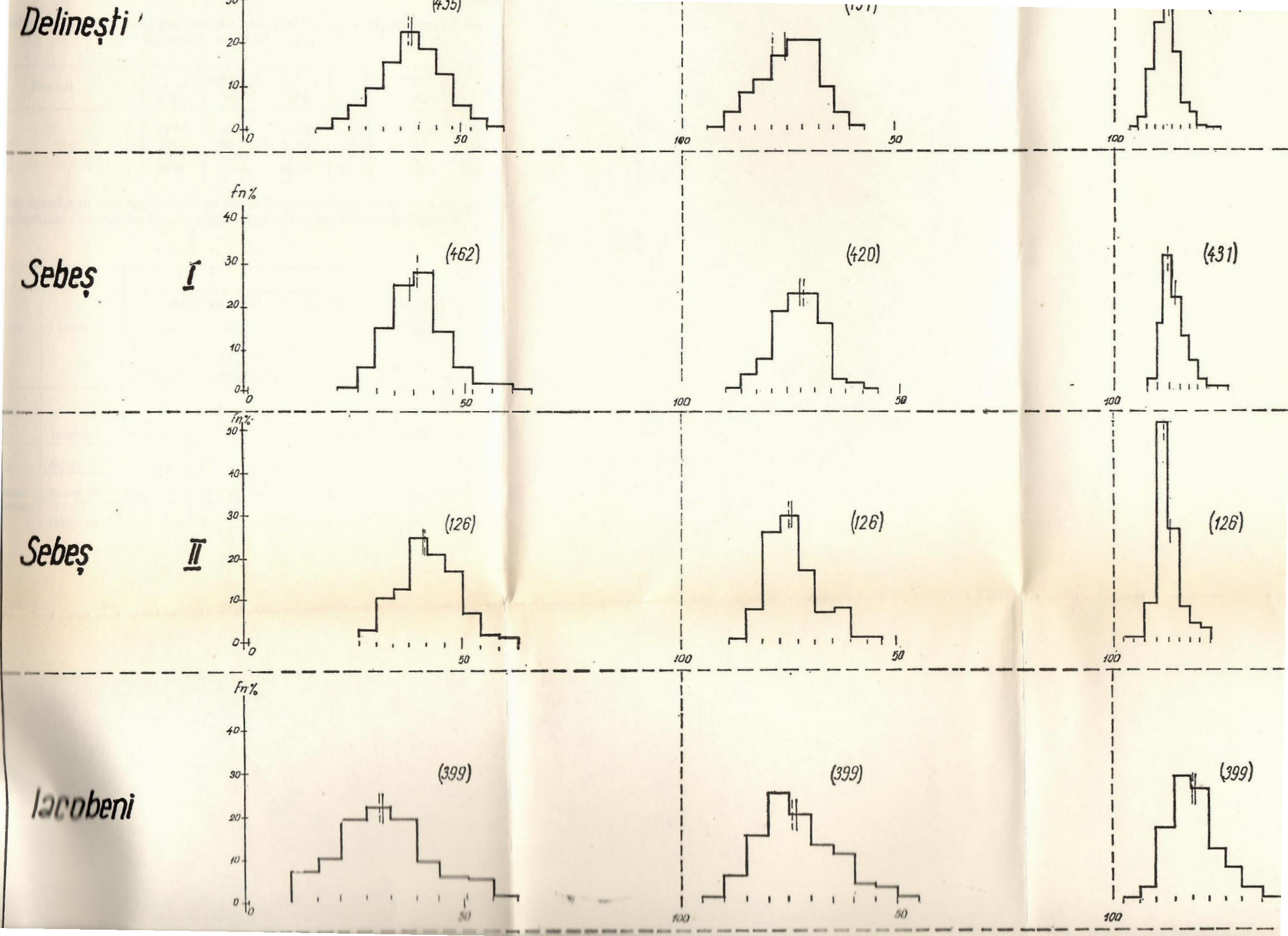
# УСТАНОВЛЕНИЕ СТАТИСТИЧЕСКИХ КРИТЕРИЕВ ДЛЯ ОБОСНОВАНИЯ РЯДА ГЕОЛОГИЧЕСКИХ ВЫВОДОВ

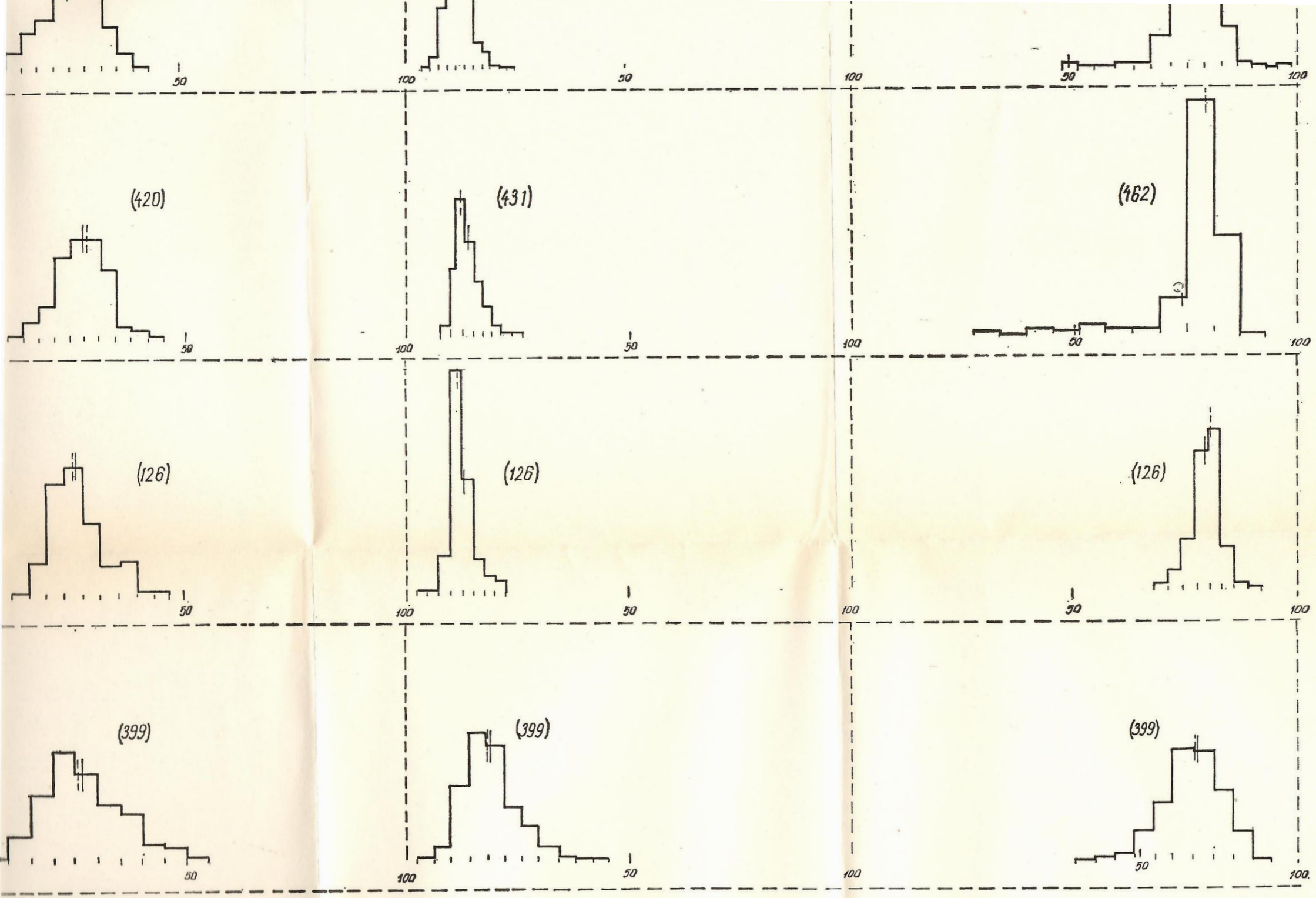
Из числа наиболее важных геологических работ, оптимизация которых может быть достигнута при помощи статистико-математического обоснования, авторы выбрали геологическую разведку залежей марганца с целью определения их наиболее вероятного химического состава и установления минимального числа проб.

Близкий к норме характер распределения главных химических компонентов (MnO, $Fe_2O_3$, $SiO_2$) позволил использовать формулу

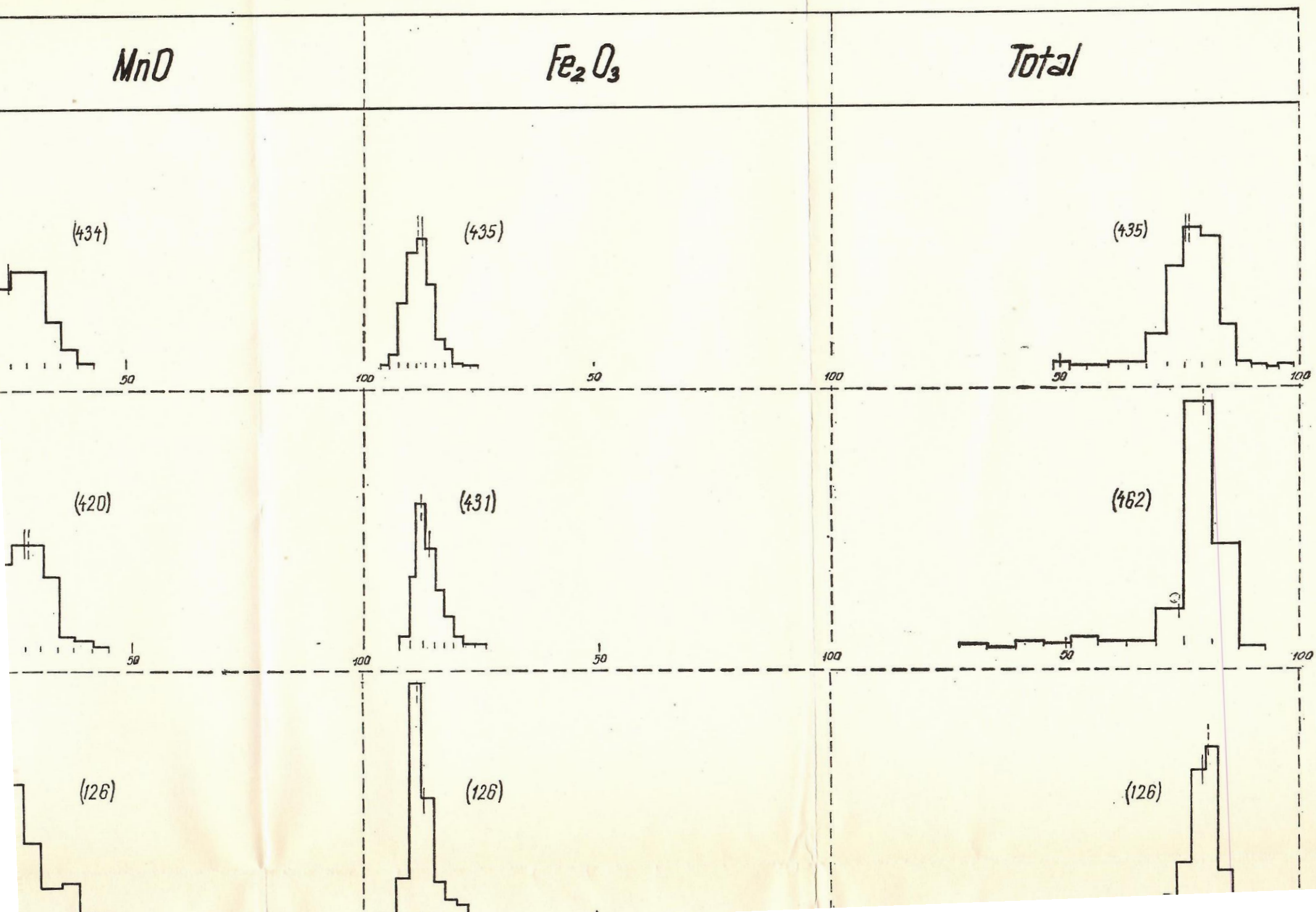
$$n = \frac{t^2\sigma^2}{\Delta\bar{x}^2}$$

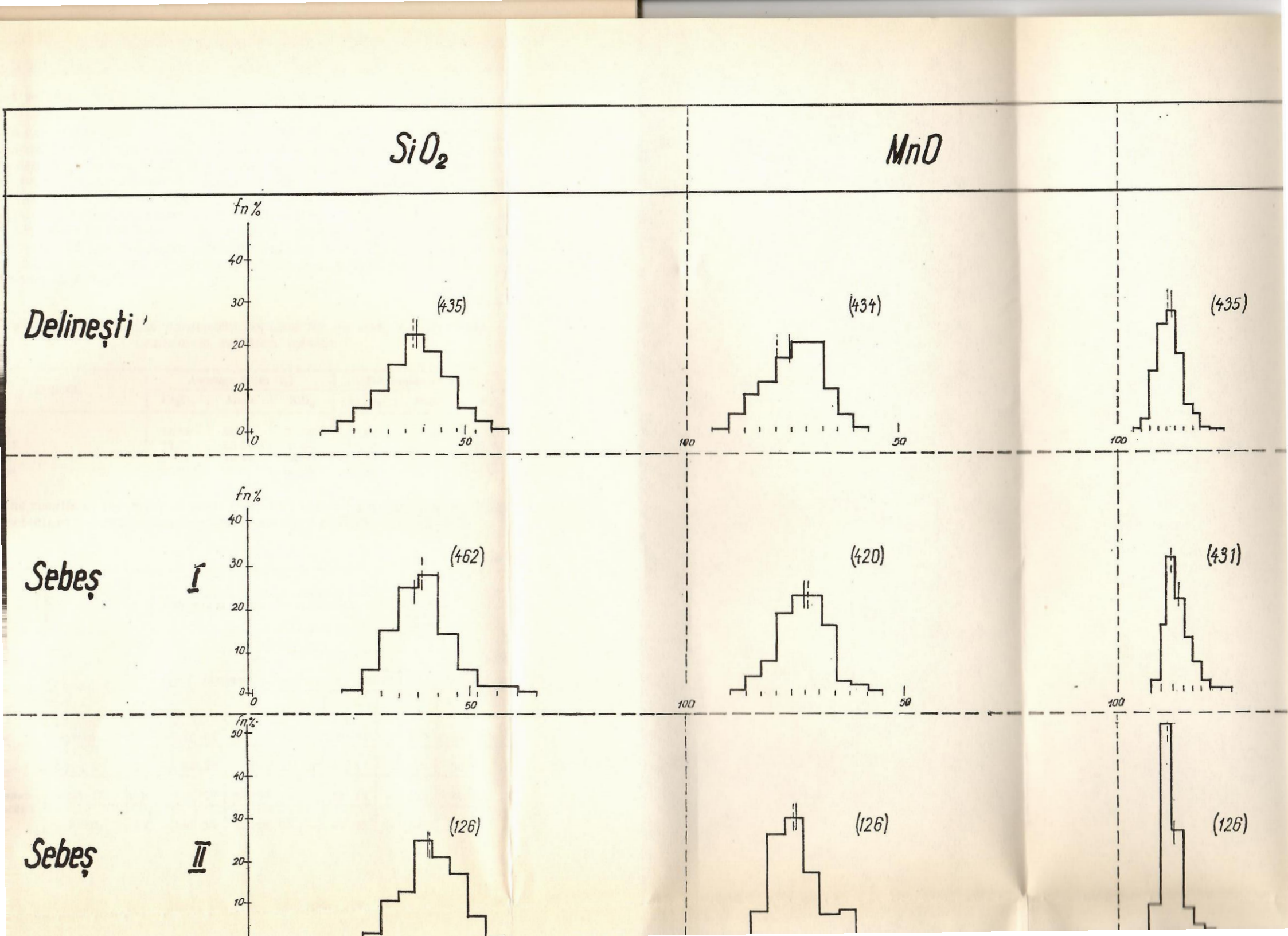
Вычисления производятся с точностью до 0,98 в случае различных значений средней допустимой погрешности ($\Delta\bar{x} = p\bar{x}$; $p = 0{,}02$; 0,05 и 0,10); значения арифметической средней и дисперсии, вычисленные в случае крупных коллективов $N$, были приняты за ориентировочные значения, приближающиеся к реальным теоретическим значениям. Полученные результаты представлены как для каждой залежи в отдельности, так и для изучаемых типов минерала, причем доказывается возможность значительно сократить разведовательные работы, целью которых является оценка наиболее вероятного качества минералов, — в данном случае марганцевой руды. Следует отметить соответствие между значениями $n$ и значениями коэффициента вариации $v$.


Delineşti
Sebeş I
Sebeş II
Iacobeni
fn%
(435)
(462)
(420)
(431)
(126)
(126)
(126)
(399)
(399)
(399)
0
10
20
30
40
50
100




Distribution of chemical elements in some *Mn* deposits in Romania.


MnO
Fe2O3
Total
(434)
(435)
(435)
50
100
50
100
50
100
(420)
(431)
(462)
50
100
50
100
50
100
(126)
(126)
(126)


SiO2
MnO
Delinești
Sebeș I
Sebeș II
fn %
(435)
(434)
(435)
(462)
(420)
(431)
(126)
(126)
(126)
0
50
100