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Point-Counting and its Errors
A Review

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With 3 figures, one plate and one table in the text

Zusammenfassung

Die Fehler der Punktzählanalyse und die Faktoren, die sie beeinflussen, werden diskutiert. Mehrere Autoren haben in der Vergangenheit theoretische oder empirische Formeln zur Berechnung derartiger Fehler vorgeschlagen. Diese Formeln werden in einheitlicher Form dargestellt und sind einem Nomogramm zugrunde gelegt, mit welchem der Analysenfehler vorausgesagt oder bei vorgeschriebenem Fehler die zeitsparendste Messanordnung gewählt werden kann. Das Nomogramm gilt aber streng genommen nur für äusserlich homogen erscheinende Messobjekte (z. B. Dünnschliffe mit mehr oder weniger zufälliger Verteilung der Mineralkörner).

Abstract

The errors in modal analysis by point-counting and the factors affecting them are discussed.

Error formulae derived by several authors for the point-counting of visually homogeneous rocks are compiled in uniform mode. Nomograms are worked out for a fast evaluation of such errors or for an optimum choice of the counting parameters if the errors are fixed.

INTRODUCTION

Delesse (1848) showed that the problem of determining the volumes of minerals in a rock may be reduced to the problem of measuring the area percentages of them in a thin or polished section. The following methods may be used for this purpose:

a) Enlarged reproduction of the thin or polished section (by hand or photographically) on a paper sheet. The latter is then cut along the grain bound-

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aries into fragments. The weight of the fragments of each mineral species is proportional to the area occupied by it on the sheet, if the sheet has a constant thickness (after DELESSE 1848).

b) The micrometric or ROSIWAL-SHAND (1898, 1916) method: measurement of the total length of the grain intercepts of each mineral species on lines of definite length over the section (e. g. by means of the integration stage of Leitz).

c) The point-counting method of GLAGOLEV-CHAYES (1933, 1949).

d) Area measurements by electronic optical means (e. g. Leitz Classimat, Zeiss Micro-Videomat, Wild Digiscan, etc.).

Method a) is simple but very long and complicated. Method d) is rapid and accurate but the technical equipment is very expensive and its applicability is restricted to minerals with distinctly different light absorption values. Methods b) and c) are less rapid and accurate than d) but they can be used for every area measurement problem. The technical equipment is less expensive than for method d).

CHAYES and FAIRBAIN (1951) demonstrated that the point-counting method is more convenient and more reproducible than the Rosiwal method. In fact it is now more frequently used than the Rosiwal method. It is therefore important for the petrologist to know within which limits point-counting results are reliable and how the measurement parameters must be set to obtain best results by this method.

EQUIPMENT FOR POINT-COUNTING ANALYSIS AND ERROR FACTORS

The point-counting analysis is performed as follows: A grid of observation points is projected onto the thin or polished section and at each point the analyst has to check the mineral on which this point falls. The sum of all the points lying on a mineral, multiplied by 100 and divided by the total number of the grid points gives an estimate of the volume percentage of this mineral.

In practice, two aids are used to produce such a grid on a microscopic scale:

a) The integration eyepiece (complemented by a counter).

b) The point-counter stage.

The choice of the one or the other of this equipment has no influence on the analytical error as far as the measurement parameters may be equally well adapted to the problem. The parameters involved in the modal analysis are:

A = grid area (counted area on the thin or polished section);

a = square root of the grid mesh area, $\sqrt{a_1 \cdot a_2}$[1]), where a_1 and a_2 are the point distances on the net lines;

n = A/a^2, the total number of counted grid points.

Two factors influencing the point-counting error cannot be changed by the analyst because they are given with the rock sample:

p = volume percentage of the mineral to be determined, and the grain size which may be expressed by values of i or d:

i = mean intercept length of the grains of a mineral in a section, calculated as $\sqrt{i_1 \cdot i_2}$[1]), where i_1 and i_2 are the means of all grain intercepts on the two sets of grid lines;

d = mean grain diameter of the mineral, which generally cannot be determined from a section. In the theoretical case of spherical or oval grains only, an unbiased estimation of the grain size is possible $d \simeq 3\,i$ (see HASOFER, 1963, p. 176).

THE ERRORS OF POINT-COUNTING ANALYSIS

If point-counting data from a thin or polished section are interpreted as volume proportions, two kinds of errors arise constituting the total or analytical error:

1. The error introduced because the areal proportions of the minerals found in a section are interpreted as volume proportions in the rock specimen. We call it the within specimen error[2]).

There are two components in this error depending

a) on the deviation of ideal random grain distribution within the rock sample and

b) on the ratio i^2/A (or d^2/A).

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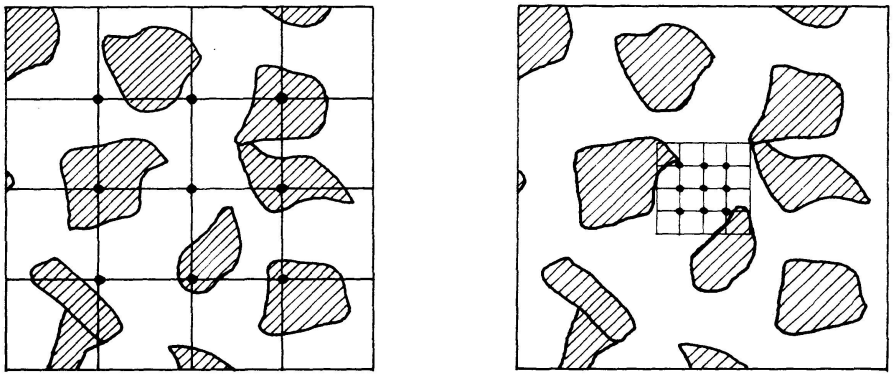
[1]) Multiplied by $\sqrt{\sin \alpha}$, α being the angle between the grid lines if the grid is not orthogonal.

[2]) Sampling error of BAYLY (1960). The sampling problem is very important for the modal analysis, but we can treat it here at the specimen level only. The interested reader will find more references in SCHRYVER (1968) and WHITTEN (1961). The first author studied the problem of sampling a gneiss for its modal analysis and the second proposes a sampling plan for effective quantitative estimates of the modal composition of a granitic complex.

If the grain distribution is random in a rock sample and we take some sections from it, fulfilling the condition that their areas are much greater than the mean grain area in the section ($i^2/A \to 0$, $d^2/A \to 0$), precise measurements of the areal proportions in every section should give the same results. In such rocks, the two components of the within specimen error are 0.

In a real rock sample, however, the mineral grains may not be distributed randomly and the error component a) may therefore be greater than 0. As this component is hardly controllable, the rock sample should be homogenous at least visually[3]). In this case component a) will be small. Our further treatment of errors deals mainly with such rocks.

If the thin section does not fulfil the condition $i^2/A \to 0$, $d^2/A \to 0$ (as in most practical cases), the second component of the within specimen error, b), arises, depending on the ratio i^2/A (d^2/A) only, if n is a constant (see fig. 1).



a b

Fig. 1. Demonstration that the within specimen error is enlarged if at the same number of counting points (9 in our example) the measurement area is reduced. The estimate of p of the shaded mineral is better in a than in b, where the measurement area is reduced to $^1/_{16}$.

2. Errors introduced if point-counting numbers are interpreted as areal proportions in a section. There are three different types of such errors:

a) The operator's error: misidentification of a mineral lying under a net point, or wrong assignment of this mineral to a mineral class. This error is insignificant compared with the counting and the within specimen errors if minerals easily misidentificated are not counted separately (see SOLOMON, 1963), and we shall disregard it in the following.

b) The counting error: it can be calculated as $\sqrt{p(100-p)/n}$, if the point distance is much greater than the mean diameter of the grains (d/a or

[3]) We define as visually homogeneous a rock whose grain distribution seems to be random in the rock specimen.

$i/a \to 0$). This follows from statistical (binomial) considerations (see CHAYES 1956).

But if the ratio d/a or i/a is greater than zero, this ratio enters as further parameter in the calculation of the counting error.

c) The error attributed to the "Holmes effect" (CHAYES, 1956). It must be taken into account for very small opaque mineral grains or small grains with a high refractive index which are observed in transmittant light. If the diameters of such minerals are in or below the range of the thickness of the thin section, their counting rates are higher than would be expected from their real volume relationship, because the minerals frequently will not fill the whole space between the surface and the bottom of the section, though they seem to do it. CHAYES (1956) gives the expression for a correction factor C, by which the counting numbers of such minerals are to be multiplied, on the assumption that the grains are spherical[4]). For a thickness k of the thin section, C is given by:

$$C = 2\,d/(2\,d+3\,k).$$

The Holmes effect may be taken into account by means of our nomogram of fig. 2.

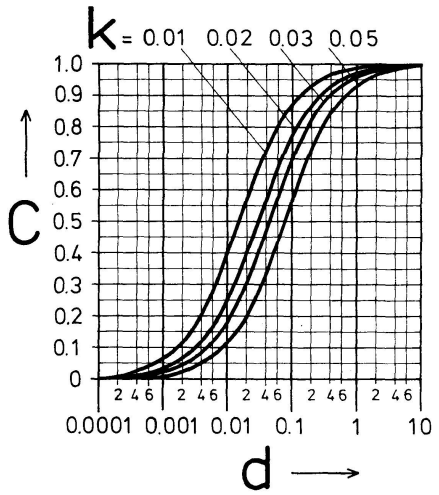


Fig. 2

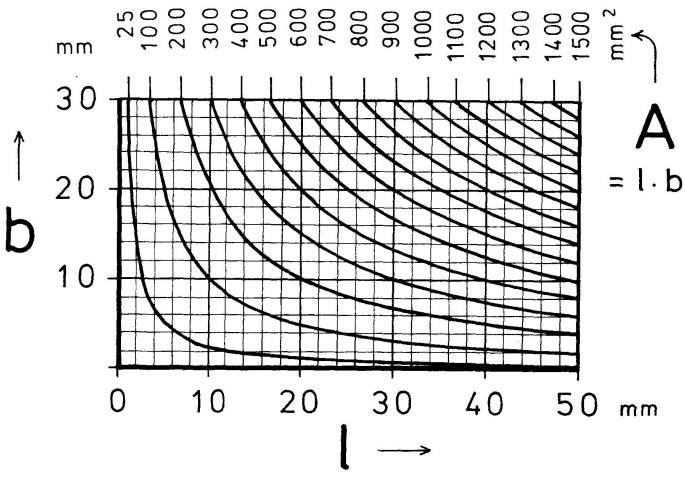


Fig. 3

Fig. 2. Nomogram for the determination of the correction factor C with which the counting number from opaque mineral grains in thin sections have to be multiplied, if the mean diameter d of these grains is in the order of or smaller than the thickness k of the thin section. The nomogram is valid in a strict sense only for spherical grains.

Fig. 3. Nomogram for the determination of rectangular measurement areas A in thin sections. The thin section is put on the nomogram in such a way that two edges of the rectangular measurement area lie on the abscissa l and on the ordinate b of the nomogram. The value A can be read off from the curve that lies under the right upper corner of the rectangle.

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[4]) Other correction factors for the Holmes effect were proposed by several authors, for example RITTMANN-VIGHI (1947), ELLIOTT (1951), and CAHN (1959).

The total or analytical error δp_3 is constituted of the counting error δp_1 and the sampling error δp_2 and, assuming that these two errors are uncorrelated, the total variance δp_3^2 is equal to the sum of the counting variance δp_1^2 and the within specimen variance δp_2^2:

$$\delta p_3^2 = \delta p_1^2 + \delta p_2^2.$$

ERROR FORMULAE

The question within which limits a point-counting analysis is reproducible, has been treated by many authors. The treatment of this problem is based upon statistical calculations on simplified models or on empirically derived formulae from experimental point-counting on natural rocks. In table 1

Table 1. *Compilations of expressions for* $X = \delta p^2 \cdot n/p$ *where* δp *is the counting, the within specimen or the total error, given as absolute values. The error* δp *indicates that in 68 % of all the cases the estimated value for* p *is within* $p \pm \delta p$, *in 95% of all the cases within* $p \pm 2\,\delta p$ *and in 99.7% of all the cases within* $p \pm 3\,\delta p$. $Q_i = i/a$, $Q_d = d/a$

$\delta p =$	grain distribution	grain shape and size	Q_i, Q_d	$X = \delta p^2 \cdot \frac{n}{p} =$	author
counting error	random	undetermined	$Q_d \to 0$	$\to 100 - p$	CHAYES (1956)
		MH[1])	$Q_d < 1$	$= 100$	HASOFER (1963)
		MH[1])	$Q_d > 1$	$\leqq 74/Q_d$	HASOFER (1963)
sampling error		undetermined	$Q_d \to 0$	$\to 0$	HASOFER (1963)
		MH[1])	$Q_d > 0$	$\leqq 63 \cdot Q_d^2$	HASOFER (1963)
	granites[2])		$Q_i \sim 0.2$ to 7	$3.52\, Q_i^2\,(100 - p)$	BAYLY (1960)
	granites[3])		$Q_i \sim 0.5$ to 0.7	$132 \cdot Q_i^2$	BAYLY (1965)
total error	random	undetermined	$Q_d \to 0$	$\to 100 - p$	
		MH[1])	$Q_d < 1$	$= 100$	HASOFER (1963)
		MH[1])	$Q_d > 1$	$\leqq 88/Q_d + 63\, Q_d^2$	HASOFER (1963)
	granites[2])		$Q_i \sim 0.2$ to 7	$\sim 100 - p + 3.52 \cdot Q_i^2\,(100 - p)$	BAYLY (1960)
	granites[3])		$Q_i \sim 0.5$ to 0.7	$\sim 100 - p + 132\, Q_i^2$	BAYLY (1965)

[1]) HASOFER model: spheres or oval grains of equal size. If the diameter varies, d in Q_d should be replaced either by $\bar{d} + \mathrm{S}\, d^2/\bar{d}$ ($\bar{d}$ = arithmetic mean of the diameters, Sd = standard deviation) or by the largest diameter.

[2]) Measurement parameters: $i = 0.29$ to 3.1 mm, $a = 0.49$ to 1.2 mm, $A = 160$ to 960 mm^2, $n = 660$ points, $p \cong 30\%$.

[3]) Measurement parameters: $i = 0.19$ to 1.9 mm, $a = 0.30$ to 2.7 mm, $A = 71$ to 1490 mm^2, $n = 700$ to 2016 points, $p = 9$ to 37%.

formulae calculating the counting error, the within specimen error and the total error are compiled. The total error formulae derived from experimental point-counting on natural rocks (granites) are based on data given by CHAYES (1956) and BAYLY (1965). They were calculated by BAYLY (1960, 1965) on the assumption that the counting and within specimen errors are not correlated (BAYLY, 1960) and that the within specimen error is enlarged by the counting error (BAYLY, 1965). In these formulae the fact that the ratio i/a (or d/a) also influences the counting error, is not respected.

HASOFER (1963) calculated the errors of point-counting analysis in sections taken from an idealized rock model. This model consists of a parallelepiped containing spheres or oval grains of fixed diameter, the centres of which are randomly distributed but in such a way that the spheres are entirely contained inside the parallelepiped (and in the investigated sections through it). Overlap of the spheres is freely allowed. The formulae calculated from this model have been tested by SOLOMON (1963) and CHATTERJEE (1965) on natural and artificial materials, and the results of both authors are in good agreement with the formulae though the errors calculated by HASOFER's formulae tend to overestimate the real values.

If d is approximated by $3\,i$ and if the ratio i/a is expressed by the symbol Q_i (or d/a by Q_d), a theoretical comparison of the formulae of the total error δp_3 calculated by HASOFER and BAYLY can be made for various parameters.

The discrepancy of the formulae is clearly seen on the uppermost fields (Q_d/X[5])) of plate I. Two regions may be distinguished there: a region with $Q_d > 1$ and one with $Q_d < 1$.

For $Q_d > 1$ the formula of HASOFER gives always a greater X value than the formulae of BAYLY, obviously because the HASOFER values represent upper limits of the error for $Q_d > 1$ (see table 1).

For $Q_d < 1$ and $p < 30\%$ the HASOFER values are either larger or smaller than those of BAYLY.

For $Q_d < 1$ and $p > 30\%$ HASOFER's values are always greater than those of BAYLY. This is the range where overlapping of the spheres in HASOFER's model becomes important. The HASOFER errors seem to be less realistic in this range and may be considered as upper limit values.

The formulae of BAYLY should give a good estimate of the error for granitic rocks and counting parameters similar to those employed by this author (see notes on table 1). For other rock types further experimental work has to be done to derive more reliable error formulae for them[6]). It is now possible to

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[5]) For the significance of X see table 1.

[6]) Some attempts to treat this problem have already been made for metamorphic (SHAW and HARRISON, 1955; SCHRYVER, 1968) and porphyric (NESBITT, 1964) rocks. The counting error in limestones has been calculated by DEMIRMEN (1971).

determine the counting error and especially the within specimen error more exactly as in former times when the electronic optical equipments for areal determinations were not yet available.

If some or all grain areas in a thin section are larger than the unit mesh of the point grid, some pairs or groups of points will fall on the same grain: They are correlated. Such a correlation increases the counting error to some extent over the value calculated by the expression $\delta p_1 = \sqrt{p\,(100-p)/n}$, because this expression is derived from a binomial model not taking into account the possibility of correlation. DEMIRMEN (1971) proposed to determine the counting error in such cases experimentally: The thin or polished section is divided into "cells" which are counted seperately. If for one of the minerals the evaluated volume percentage in cell j is p_j, and if m is the total number of cells, the counting variance for this mineral is

$$\delta p_1^2 = \sum_{j=1}^{m} (p_j - \bar{p})^2 / m\,(m-1), \text{ where } \bar{p} = \sum_{j=1}^{m} p_j / m.$$

THE DETERMINATION OF THE MEAN INTERCEPT LENGTH i

Looking at the formulas in table 1, it may be stated that Q_i (or Q_d) is a very important error factor. To evaluate it, the mean intercept length i must be determined for every mineral species. For this purpose, the section is shifted under the microscope lens parallel to the point-counting net lines. The grains crossing the centre of the eyepiece are counted for every mineral species separately. If the total shift lengths along the two net lines are l_1 and l_2 and the counting rates for a mineral species z_1 and z_2, the mean intercept length is

$$i = \frac{p}{100} \sqrt{\frac{l_1}{z_1} \cdot \frac{l_2}{z_2}},$$

where p is the volume percentage of the mineral in the rock (obtained from a previous rough determination by counting a few points, or estimated by eye). The measurement of the grain size (i in our case) may be a problem if the grains are of irregular shape, with concave boundaries, or if they contain inclusions. For this problem see DEMIRMEN (1971) and ROETHLISBERGER (1955).

THE CHOICE OF THE POINT-COUNTING PARAMETERS

The time necessary for a point-counting analysis depends on the total number of points counted. As every reduction of n enlarges the total error, Q_i or Q_d must be lowered in order to compensate this reduction, if a fixed

precision of the point-counting analysis is required. This means that a much larger measurement area A is needed.

While an enlargement of the measurement area is in most cases no problem (more thin sections from the rock sample may be analyzed) the enlargement of the parameter a to reduce Q_i or Q_d is limited by the point-counting device. As the greatest jump distance of the Swift point-counter for instance is $^1/_3$ mm only, and a very strong distortion of the counting net into the other direction is not advisable (because its effects on the analytical error may become uncontrollable), macro-point-counting devices and methods are to be used for an expedient analysis of coarse grained rocks. Details on the technique of macro-point-counting can be found in JACKSON and ROSS (1956), FITCH (1959), and SOLOMON and BROOKS (1966).

According to the HASOFER-formulae the total error is no longer reduced by a diminution of Q_d if Q_d becomes smaller than 1. But this is true in a strict sense for the HASOFER's model only and it must be assumed that in real rock samples without prefectly random distribution of regular shaped mineral grains a reduction of Q_d at a value to some extent under 1 yet affects the total error. Respecting this fact and to prevent an increase of the counting error by the correlation of points (see p. 26) a should always be choosen greater than the diameter of the largest grain to be counted. This statement may be taken as "the golden rule" for a most expedient point-counting analysis, especially if the rock sample is visually not wholly homogeneous.

If a once is fixed the total error will only be dependent on the total number of points to be counted and on the measurement area A, if the minerals are distributed randomly.

THE CHOICE OF THE ORIENTATION OF A SECTION IN AN ANISOTROPIC ROCK SAMPLE

Thin sections for the point-counting of anisotropic rocks containing minerals or mineral aggregates of preferred orientation should be cut perpendicular to the s-plane resp. b-axis because such sections show lowest i-values and give us therefore lowest total errors for a fixed number of counted points and a fixed measurement area.

The thin sections obtained from banded rocks should contain area percentages of the various types of bands equal to the real volume percentages of these bands in the rock. In the case of rocks with layers of equal thickness this is best performed if thin sections (measuring 3×5 cm) are cut perpendicular to the layers in such a way that their shorter edges are inclined against the layers at angles of ca. 16, 39, or 63° (CHAYES, 1956).

USE OF THE NOMOGRAMS

The use of the nomograms of plate I and fig. 3 may be best demonstrated by solving two practical problems of point-counting.

Problem 1:

A point-counting analysis of plagioclase in a thin section is performed; $n = 795$ points are counted with grid line distances $a_1 = 0.34$ mm and $a_2 = 0.34$ mm ($a = 0.34$ mm). The mean grain intersection length is $i = 0.3$ mm. 238 points fall on plagioclase, giving an estimate $p \cong 40\%$. What is the total error of the analysis?

a) Draw a horizontal line $a = 0.34$ through the nomogram of plate I.
b) Find the intersection with the line $i = 0.3$ and go down on a vertical line to find the value $Q_i = 0.85$.
c) Mark the value 0.85 on the Q_i axis of the two uppermost fields of the nomogram and draw horizontal lines to encounter the 40% curves for BAYLY 1960 and 1965 and for the HASOFER 1963 line. Mark these points and draw a vertical line for each of them.
d) Mark the value 795 on the n axis and draw a vertical line to encounter the 40% line in the p field (the intersection with the horizontal line $a = 0.34$ gives the value of $A = 80$ mm^2).
e) Draw a horizontal line from this point and mark the intersections with the three vertical lines of c) in the δp field.

The BAYLY 1960 line intersects at $\delta p \cong 3.1\%$, the BAYLY 1965 line at $\delta p \cong 2.8\%$ and the HASOFER 1963 line at $\delta p \cong 4.5\%$.

The HASOFER value approximates the upper limit of the analytical error and the 68% confidence interval for p is therefore $35.5\% \leqq p \leqq 44.5\%$[7]).

From our nomogram of plate I we can see that the error would have been smaller if the whole thin section area $A = 550$ mm^2 (measured with the nomogram of fig. 3) would have been counted with the same number of points but a grid spacing of $a = 0.8$ mm.

In this case $\delta p = 2.1\%$ for BAYLY 1960, $\delta p = 2.0\%$ for BAYLY 1965 and $\delta p = 2.8\%$ for HASOFER 1963.

Problem 2:

The volume amount of hornblende in a mafic rock is estimated by eye as $p \cong 60\%$, the median diameter as $d = 1.5$ mm. The point counter can be set in maximum to $a_1 = 1.0$ mm. a_2 is taken as 1.5 mm. How many thin sections with 600 mm^2 areas and how many points are to be counted to reach an analytical error (corresponding to the HASOFER formula) of 3%?

a) Draw a horizontal line $a^2 = 1.5$.
b) Find the intersection with the line $d = 1.5$ and go down to find the value $Q_d \cong 1.2$ on the $Q_{i,d}$ axis.
c) Mark the value 1.2 on the Q_d axis of one of the uppermost fields of the nomogram and draw a horizontal line to encounter the HASOFER curve.

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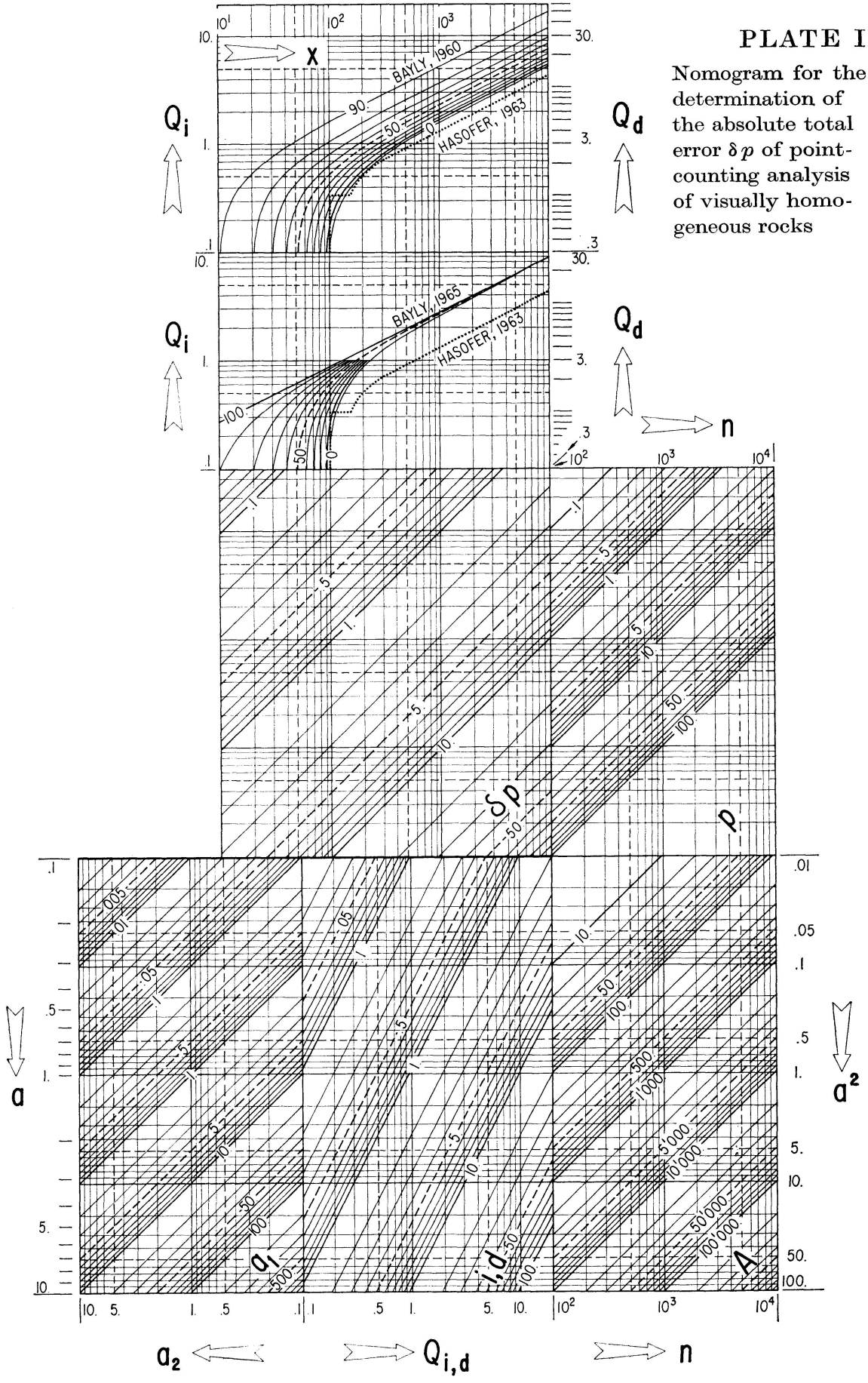
[7]) The values calculated from the formulae of table 1 are: BAYLY (1960): $\delta p_3 = 3.3\%$; BAYLY (1965): $\delta p_3 = 2.8\%$; HASOFER (1963): $\delta p_3 = 4.8\%$.

PLATE I

Nomogram for the determination of the absolute total error δp of point-counting analysis of visually homogeneous rocks



d) From the intersection point draw a vertical line to encounter the $\delta p = 3$ line.
e) Mark the point and draw a horizontal line. Find the intersection with the $p = 60\%$ line.
f) Draw a vertical line from this point and read the value of $A \simeq 1500$ mm^2 at the intersection with the horizontal $a^2 = 1.5$ line and the value of $n \simeq 1000$ at the intersection of the n axis. We need therefore three thin sections for our point-counting analysis.

The nomogram on plate I can be complemented by any further expression for the total error (for instance for metamorphic rocks) if this expression is based only on the parameters $Q_{i,d}$, p and n.

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