A SMALL SET OF GRIDS FOR THE DETERMINATION OF NON-OPAQUE MINERALS

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Determinative Scheme

The principle of the determinative grids has been described elsewhere[1] as a novelty. I have learned, however, through a review of that paper,[2] that my "invention" was proposed fifteen years ago by Gray,[3] a mining engineer in Johannesburg, South Africa. I take this opportunity to acknowledge his priority in the matter.

Not only the amateur mineralogist, but the professional as well, will agree that the determination of minerals is always a delicate, sometimes a baffling, problem. The main reason for this is that the available determinative tables are based on a certain number of distinguishing criteria, taken up in an imposed order. But, the specimen to be identified may or may not exhibit particularly well the properties on which the very first subdivisions are made. For instance, the excellent tables of Larsen and Berman require, at the outset, a knowledge of the optical character of the mineral, as biaxial positive, uniaxial negative. If no good interference figure can be obtained, it becomes extremely difficult to make use of the determinative data recorded in the tables. Any kind of table constructed on the dichotomous principle is similarly handicapped.

Every specimen shows certain properties better than others; they are those on which the determination should rest. The logical consequence of this is that one should have as many different tables as there are different orders in which the various properties of a mineral can be listed. If we were satisfied to use only twenty properties, the number of desirable tables would be equal to the number of permutations of 20, that is to say *factorial 20*, or more than two quintillion. No library in the

[1] Donnay, J. D. H., Système de grilles pour la détermination des minéraux: *Annales Soc. géol. Belgique*, vol. **59**, B, pp. 250–257, 1936.

[2] *Min. Abstr.*, vol. **6**, 431, 1937. In this review the principle of the grids is misunderstood, in that a hole is said to stand for a property ("A series of cards with perforations corresponding to various characters are superposed"), whereas it actually represents a mineral, and each grid corresponds to a property. This error has been repeated in another review (*N. Jb. Min.*, Ref. I, **1937**, p. 121).

[3] Gray, C. J., A new method of using the physical characteristics of minerals for their identification: *Trans. Geol. Soc. S. Africa*, vol. **23**, pp. 114–117, 1920 (1921). The set comprises 361 minerals, for which 66 grids are available.

A recent patentability search has revealed the existence of a patent, taken in 1915, by Horace Taylor of Brookline, Mass., describing an identical "Selective device" applied to the determination of birds (*added while in press*).

world could house such a collection of books. The set of grids enables one to construct at will and instantaneously any one of these multitudinous determinative tables.

In the small model recently placed on the market, a grid is a sheet of cardboard, about 7 by 3 inches, on which 45 vertical columns of 10 figures each (0 to 9) are printed, the columns being numbered from 1 to 45 along the lower margin of the card. Every one of the 450 figures stands for a mineral, which can be looked up in the index. For example: 0 in column 1 represents *acmite;* 0 in column 45, *barite;* 9 in column 38, *zircon.* Each card corresponds to a property; it is labelled accordingly, for instance *Red or reddish.* On that card all the figures that represent red or reddish minerals are punched out (hence the name "grid"). On superposing various grids, corresponding to several properties observed on a specimen, some holes will be left open: they indicate all the minerals that possess all these properties. After a sufficient number of properties have been determined (and it does not matter which ones), the number of holes left will be reduced to one (the one that stands for the mineral name sought) or to none (in which case the mineral is not among the 450 included in the grids, or a mistake has been made in the determination of the properties, or again there is an error in the construction of the grids). The punching of the cards is done mechanically so that perfect register is insured when the grids are stacked and held against the light.

The present model[4] has been designed to meet the needs of petrographers, mining engineers, oil geologists, students in mineralogy, and mineral collectors. It covers 450 non-opaque minerals, including all the common species, all the petrographically important minerals (igneous, metamorphic, and sedimentary) whether common or not, and about one hundred additional minerals carefully selected in order to give a comprehensive representation of the less common groups of non-opaque species.

Choice of Determinative Properties

The grids are numbered from 001 to 254. They are also labelled according to the properties they represent. The list of determinative properties is given in Table 1. Further grids will be prepared from time to time (extinction angle, twinning, etc.)

[4] A larger model, covering all (ca. 1250) non-opaque minerals, was exhibited at the Cincinnati meeting of the Geological Society of America (Donnay and Mélon, *Am. Mineral.*, vol. **22,** p. 218, 1937; abstract). It had 210 grids, 55 by 37 cm., which were hand-punched. Six copies of this set were made, and sold. No way was found of manufacturing it inexpensively and, unless a sufficient number of requests are received, further sets of this type will not be constructed.

Table 1. Determinative Properties

I. Occurrence

001. Rock forming minerals
002. River concentrates
003. Powdery minerals

II. Structure

004. Fibrous
005. Radiating
006. Micaceous or flaky
007. Lamellar or columnar

III. Crystal Habit

008. Equidimensional
009. Prismatic or acicular
010. Tabular
011. Pyramidal

IV. Hardness

012. H less than 1
013. H less than $1\frac{1}{2}$
014. H less than 2
015. H less than $2\frac{1}{2}$
016. H less than 3
017. H less than $3\frac{1}{2}$
018. H less than 4
019. H less than $4\frac{1}{2}$
020. H less than 5
021. H less than $5\frac{1}{2}$
022. H less than 6
023. H less than $6\frac{1}{2}$
024. H less than 7
025. H less than $7\frac{1}{2}$
026. H less than 8
027. H more than 1
028. H more than $1\frac{1}{2}$
029. H more than 2
030. H more than $2\frac{1}{2}$
031. H more than 3
032. H more than $3\frac{1}{2}$
033. H more than 4
034. H more than $4\frac{1}{2}$
035. H more than 5
036. H more than $5\frac{1}{2}$
037. H more than 6
038. H more than $6\frac{1}{2}$
039. H more than 7
040. H more than $7\frac{1}{2}$
041. H more than 8
042. Minerals whose hardness is given in the literature or could be estimated. (This grid eliminates all minerals whose hardness probably cannot be determined.)

V. Specific Gravity

043. G less than 2
044. G less than 2.5
045. G less than 2.9
046. G less than 3.33
047. G less than 4
048. G less than 4.5
049. G less than 5
050. G less than 6
051. G more than 2
052. G more than 2.5
053. G more than 2.9
054. G more than 3.33
055. G more than 4
056. G more than 4.5
057. G more than 5
058. G between 6 and 7
059. G between 7 and 8
060. G more than 8

VI. Reflected Color

061. Yellow, gold, or greenish yellow
062. Brown or brownish
063. Red or reddish
064. Orange
065. Yellow, orange, brown, or red
066. Green
067. Green, brown, or yellow
068. Blue
069. Green or blue
070. Violet or purple
071. Blue or violet
072. Colorless or white
073. Black
074. Gray

VII. Pleochroism

075. Nonpleochroic
076. Pleochroic

Remarks: (1) Always use one of these two grids jointly with grids indicating transmitted color (or colors).

(2) Faintly pleochroic minerals are recorded on both 075 and 076. The two grids may be superposed to indicate faint pleochroism.

VIII. Transmitted Colors

077. Yellow
078. Brown or brownish
079. Red or reddish
080. Orange
081. Yellow, orange, brown, or red
082. Green
083. Green, brown, or yellow
084. Blue
085. Green or blue
086. Violet
087. Blue or violet
088. Colorless
089. Black
090. Gray or neutral

IX. Cleavage

091. No distinct cleavage
092. Cleavage in at least 1 direction
093. Cleavage in at least 2 directions
094. Cleavage in at least 3 directions
095. Cleavage in at least 4 directions

X. Refractive Indices

At least one refractive index has the following value:

096. n less than 1.46
097. n less than 1.50
098. n less than balsam
099. n less than 1.60
100. n less than 1.66
101. n less than 1.70
102. n less than 1.74
103. n less than 1.78
104. n less than 1.88
105. n more than 1.46
106. n more than 1.50
107. n more than balsam
108. n more than 1.60
109. n more than 1.66
110. n more than 1.70
111. n more than 1.74
112. n more than 1.78
113. n more than 1.88

XI. Birefringence

114. Isotropic
115. Anisotropic

The maximum birefringence *B* of the mineral has the following value:

116. *B* less than .0035
117. *B* less than .0095
118. *B* less than .0185
119. *B* less than .0275
120. *B* less than .0365
121. *B* less than .0545
122. *B* less than .100
123. *B* less than .200

124. *B* more than .0035
125. *B* more than .0095
126. *B* more than .0185
127. *B* more than .0275
128. *B* more than .0365
129. *B* more than .0545
130. *B* more than .100
131. *B* more than .200

XII. Optical Sign

132. Uniaxial
133. Biaxial

134. Positive
135. Negative

XIII. Optic Angle 2*V*

136. 2*V* less than 30°
137. 2*V* between 30° and 60°
138. 2*V* more than 60°

139. Minerals for which 2*V* is given in literature. This grid eliminates all minerals for which 2*V* probably cannot be determined.

XIV. Dispersion

140. *r* smaller than *v*

141. *r* greater than *v*

142. No dispersion

XV. Crystallinity

143. Amorphous
144. Isometric system
145. Tetragonal system
146. Hexagonal system (sensu vasto)
147. One 3-fold rotation axis only

148. One 6-fold rotation axis
149. Orthorhombic system
150. Monoclinic system
150.1. Monoclinic or orthorhombic
151. Triclinic system

XVI. Fusibility

152. *F* less than 2
153. *F* less than 3
154. *F* less than 4
155. *F* less than 5
156. *F* less than 6
157. *F* less than 7 (still fusible)

158. *F* more than 1
159. *F* more than 2
160. *F* more than 3
161. *F* more than 4
162. *F* more than 5
163. *F* more than 6 (infusible)

XVII. Solubility

164. Soluble in water
165. Soluble in HCl, HNO_3, or aqua regia
166. Insoluble in these acids

XVIII. CHEMISTRY

Ag (167, 211)—Al (168, 212)—Arsenate (169, 213)—Arsenide, telluride or Se (170, 214)—Ba or Sr (171, 215)—Bi (172, 216)—Bo (173, 217)—Br, Cl, or I (178, 222)—C, in carbonate (174, 218)—C, not as CO_2 (175, 219)—Ca (176, 220)—Cd (177, 221)—Cl, Br, or I (178, 222)—Co or Ni (179, 223)—Cr (180, 224)—Cu (181, 225)—Cs, Rb, or Li (182, 226)—F (183, 227)—Fe (184, 228)—Fe, ferrous (185, 229)—Fe, ferric (186, 230)—H_2O in closed tube (187, 231)—Hg (188, 232)—I, Cl, or Br (178, 222)—K (189, 233)—Li, Cs, or Rb (182, 226)—Mg (190, 234)—Mn (191, 235)—Mo (192, 236)—N, in nitrate (193, 237)—Na (194, 238)—Nb or Ta (195, 239)—NH_4 (196, 240)—Ni or Co (179, 223)—P, in phosphate (197, 241)—Pb (198, 242)—Rare earths (199, 243)—Rb, Cs, or Li (182, 226)—S, in sulfate (200, 244)—S, in sulfide (non oxidized) (201, 245)—Sb (202, 246)—Se, arsenide, or telluride (170, 214)—Si, or Si in silicate (203, 247)—Sn (204, 248)—Sr or Ba (171, 215)—Telluride, arsenide, or Se (170, 214)—Ta or Nb (195, 239)—Ti (205, 249)—U (206, 250)—V (207, 251)—W (208, 252)—Zn (209, 253)—Zr (210, 254).

Remark—Positive test: first number. Negative test: second number.

A wide range of properties can be used, many of which serve only as confirmatory criteria in the usual determinative tables. They can be used in any order. The properties that show best should be given precedence. Any amount of information is of value. For instance, such properties as hardness, specific gravity, refractive index, birefringence, fusibility, can be determined with small or great accuracy; one may always "frame" the determined value between any two limits that will allow for the possible error. Example: *hardness less than 5 1/2* (grid 021) and *more than 2 1/2* (grid 030), or *hardness less than 4* (grid 018) and *more than 3* (grid 031). For chemical properties, negative as well as positive tests have a determinative value. Example: the mineral *contains aluminum* (use grid 168) or *does not contain aluminum* (use grid 212).

At any time during the determinative procedure, the number of possibilities left indicate the progress made. The grids are also a guide in the choice of further determinative tests. Example: in order to find out whether the knowledge of a certain additional property (say, the solubility in acids) would be useful for the progress of the determination, simply take the grid that corresponds to that property and place it on the stack already available; if the grid extinguishes many holes, it is advantageous to determine the property; if not, another grid may point to a more effective property.

Some grids should be used with caution. Example: *No distinct cleavage*. It is hard to say that a mineral has no cleavage from examining one specimen only. The cleavage may not show, or one may not succeed in producing it. The difficulty has been somewhat minimized by including minerals with imperfect cleavage in the grid, which is accordingly labelled "No *distinct* cleavage." Yet one must keep in mind that negative criteria are less certain than positive ones.

Colors in reflected light (in the hand specimen). Provision is made for indefinite colors (grids 065, 067, 069). Such grids do not have as much determinative value as the more specific ones. If you are able to detect a mixture of two colors in your specimen (say, bluish green or greenish blue) use both *blue* (grid 068) and *green* (grid 066) in order to make use of your observation to full advantage. Colors of streaks and powders are included.

Pleochroism and transmitted colors (in polarized light). Either the grid *Pleochroic* (076) or the grid *Non pleochroic* (075) should always be used in conjunction with grids for transmitted colors. Feebly pleochroic minerals have been included in both grids 075 and 076; if the pleochroism is obviously weak, the two grids can be used jointly. Similarly a mineral with a birefringence close to .0095 (quartz, e.g.) is entered on both grid 117 (*B less than .0095*) and grid 125 (*B more than .0095*). In all such cases, where the determined value of a property is on the border line between two grids, both may be used jointly, with circumspection, of course, since this practice implies a fairly accurate determination of the property in question.

Hardness and 2V. The grid *Hardness in literature* (042) may be used when the hardness is so easy to find that there is no doubt it has been determined by previous observers and recorded in the literature. This eliminates all minerals on which H never was determined. The same remark applies to grid 139 (*2V in literature*).

Dispersion. On the grid *No dispersion* only those minerals are "punched out" for which the absence of dispersion has been recorded in the literature. This grid shows that data on dispersion are lacking for a great many species; it is not safe to use it for determinative purposes.

Chemistry. Only the main constituents of the mineral are taken into account, namely those that are expressed by its chemical formula. Impurities that may occur in traces or in small amounts should be disregarded.

General recommendation. Do not feel obliged to use a property that does not show well; restrict your choice to reliable characters.

Examples of Determination

N.B.—The names of the minerals given as examples will be found in the appendix to this paper under their key numbers. Before looking them up try to identify the "unknowns" from the properties indicated.

Example I. The specimen is *blue* (grid 068), its *G is less than 2.9* (grid 045), its *H more than 7.5* (grid 040). Mineral 1-8.

Example II. *Blue* (068), *H less than 2.5* (015), *water in the closed tube* (187), *soluble in acids* (165), *ferrous iron* (185). Mineral 9-17.

Example III. If you suspect what the specimen is, you test for *P*, *in phosphate* (197), *ferrous Fe* (185), *H less than 2.5* (015). Mineral 9-17.

Example IV. *Amorphous* (143), *orange* (064), *G more than 5* (057). Mineral 8-23.

Example V. *Green* (066), *one 6-fold rotation axis of symmetry* (148), *G between 6 and 7* (058). Mineral 7-18.

Example VI. *Soluble in water* (164), *isotropic* (114), *n less than 1.50* (097). Mineral 8-30.

Example VII. *Isometric* (144), *red* (063), *H less than 4* (018), *F less than 4* (154), *F more than 2* (159). Mineral 2-24.

Example VIII. A mineral is *found in a rock* (001), it is *micaceous* (006), *green* (066), *hexagonal sensu vasto* (146), its *G is less than 2.5* (044). Mineral 1-20.

Example IX. A mineral may be determined by different sets of simultaneous properties. (a) *Isometric* (144), *H less than 5* (020), *rock forming mineral* (001). Or, (b) *Equidimensional* (008), *isotropic* (114), *n less than 1.46* (096), *contains Ca* (176). Or, (c) *H more than 3* (031), *cleavage in at least 4 directions* (095), *G less than 3.33* (046), *no water in closed tube* (231), *soluble in acids* (165), *contains F* (183). Mineral 3-29.

Example X. (a) The mineral is determined by optical methods. *Pleochroic* (076), *yellow* (077) and *colorless* (088) in transmitted light, *n more than 1.88* (113), *uniaxial* (132), *positive* (134). (b) The mineral occurs as a massive specimen. *H more than 6* (037), *H less than 7* (024), *G between 7 and 8* (059) and *G between 6 and 7* (058) (these two grids are used jointly because the G is very close to 7), *insoluble in acids* (166). (c) The unknown occurs in good crystals. *Rock forming mineral* (001) *tetragonal* (145), *black* (073), *no distinct cleavage* (091). (d) The mineral is a rounded pebble. A simple chemical test, found to be positive, permits you to use grid 204, which suffices to determine the mineral. In all four cases (a, b, c, d) the mineral is 1-31.

Example XI. This last example is given to show how it is possible to realize the progress of the determination as the grids are used. The unknown will be determined by three different methods.

(a) BY MEANS OF THE POLARIZING MISROSCOPE AND A PREPARATION IN CANADA BALSAM.

Pleochroic (Grid 076): there are 185 minerals that possess this property. Three distinct hues of pleochroism, *blue* (084), *violet* (086), *gray or neutral* (090): 10 minerals remain. The *refractive index* is *greater than that of*

Canada balsam (107): 9 possibilities remain. *At least one index* is *less than 1.70* (101): 8 minerals are left. *Anisotropic* (115): the 8 holes are left open. *Birefringence more than .0095* (125): 7 minerals left. *Birefringence less than .0275* (119): 6 minerals left. *Biaxial* (133): the 6 possibilities are unchanged. *Negative* (135): 5 minerals are left. *Angle of the optic axes between 30° and 60°* (137): 4 minerals now remain. *Dispersion, r smaller than v* (140): the same 4 possibilities are unchanged. They are: 2-13, 2-20, 3-3, 3-43.

(b) By Chemical Tests.

In this case a chemical determination would be quite laborious. Assuming that one has ascertained that the unknown is *insoluble in acids* (grid 166), that it is a *silicate* (grid 203), that it contains *Al* (grid 168), *Na* (194), *Mg* (190), *Fe* (184), and even *ferrous Fe* (185), which amounts to a rather complete qualitative analysis, all that information will still leave 17 possibilities open. A simple test, *no water in the closed tube* (grid 231), will help materially in the determination—closing all the 17 holes but 4. The choice is now limited to: 0-5, 1-1, 2-20, 3-43.

(c) By Simple Physical Tests.

As compared with the above determinations, let us try to identify the unknown by means of its macroscopic properties, with none but the simplest tests.

The mineral is blue-black. Use grids 068 (*blue*) and 073 (*black*). Its *H* is *less than 7* (grid 024) and *more than 6* (grid 037). These grids immediately restrict the choice to 3 minerals. If the specimen permits recognition of the crystal system (*monoclinic*, grid 150), the determination is completed. If one hesitates between monoclinic and orthorhombic, grid 150.1 (*Monoclinic or orthorhombic*) may be used and found just as effective. If the symmetry is not apparent, an approximate value for the specific gravity may be obtained (heavy liquids, balance, or sense of heft) and grid 046 (*G less than 3.33*) used. This also leads to the result. Or again, the fusibility (3) may be tested with the blowpipe; grids 154 (*F less than 4*) and 159 (*F more than 2*), added to the first four, make the determination complete. And if the fusibility is difficult to estimate, surely the intense yellow flame cannot be missed—then grid 194 (*Na*) will prove sufficient. Mineral 3-43.

Material Presentation

The grids are made of Manila cardboard, $7\frac{3}{8}$ by $3\frac{1}{4}$ inches. They are contained in a special filing box, $2\frac{1}{2}$ inches deep, made of cedar wood, with shellac finish, corners interlocked and glued, hinges and fastener nailed, lid cut obliquely to facilitate handling of cards. Twenty labelled guides (buff Bristol tabs) separate the groups of properties. The index of minerals is printed twice: on ten Manila cards, as permanent reference, and in tabular form, for desk use.

Acknowledgments

Most of the data recorded in the grids are taken from Larsen and Berman. Dana has been especially useful for the data on colors in reflected light. The limits adopted for the ranges in birefringence are those proposed by Winchell. A number of standard textbooks on mineralogy have been occasionally consulted and many references to the original descriptions had to be made.

It is a pleasure to tender my best thanks to Dr. J. Mélon, of the University of Liége, Belgium, who helped me prepare the data for the large model and gave many valuable suggestions as to the selection of determinative properties.

Appendix

Index To Minerals