THE PARAGENESIS OF MINERALS.

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INTRODUCTION.

The most interesting field in mineralogy at present, as well as the most promising one for the future, is probably that dealing with the occurrence, association, and origin of minerals. The mineralogist has too often been content with the measurement of crystals and the chemical analysis of a mineral, and has usually neglected to note the mode of occurrence and possible origin, except as they may be observed in the hand specimen. But as Lacroix¹ says: "Lorsque les propriétés physiques et chimiques d'un minéral sont définitivement établies, son histoire n'est pas complète. Il joue un certain rôle dans la nature; . . ."

Questions of occurrence and origin will more and more concern the mineralogist for the characters of minerals have been pretty thoroughly worked out, and in the future the occurrence, association, and origin will take equal rank with the characters themselves.

USE OF THE TERM PARAGENESIS.

In the discussion of the occurrence, association, and origin of minerals, the term *paragenesis* is often used and the fact that it is used in different senses by different writers is the principal reason for presenting this paper. The word *paragenesis* was coined by Breithaupt in 1849 and used as the title of his book, "Die Paragenesis der Mineralien."²

In the introduction (p. 1) of this work, Breithaupt defines *paragenesis*: "Unter der Paragenesis der Mineralien ist die mehr oder weniger ausgesprochene Weise des Zusammenvorkommens

¹ "Mineralogie de la France et de ses Colonies," Vol. I., p. vii, 1893.

² Pub. by J. G. Engelhart, Freiberg, 1849.

der Association derselben zu verstehen. Man hat dabei auf das relative Alter der Körper, da, wo eine Sukzession derselben zu erkennen ist, einen besondern Werth zu legen, weil in diesem Verhalten die meiste Belehrung liegt." Breithaupt emphasizes the order of succession, but his book is not confined to this topic. He discusses the occurrence and association of minerals in rocks and veins.

The following definitions of *paragenesis* are given:

Standard Dictionary: "... treats of the association and order of succession of mineral species in their formation."

International Dictionary: "The science which treats of minerals with special reference to their origin."

Century Dictionary: "The association of mineral species with each other with reference to the order and mode of their formation."

Rinne: "Das Zusammenvorkommen der Mineralien nennt man ihre Paragenesis."

Loewinson-Lessing: "Nennt Breithaupt die Gesetze der Association der Minerale in Gesteinen, Gängen, etc."

Kemp: "A general term for the order of formation of associated minerals in time succession one after another. To study the paragenesis is to trace out in a rock or vein the succession in which the minerals have developed."

Moses and Parsons: "The term *paragenesis* is used to express the relations between associated minerals."

A casual search of recent geological literature also shows great diversity in the use of the term *paragenesis*. I quote several illustrations:

Simpson:¹ "Recent studies in the order of formation or paragenesis of the metallic ore minerals . . ."

Palache,² speaking of powellite in Michigan, says: "It differed from the Idaho mineral in its paragenesis, occurring with native copper and epidote. . . ."

Clarke,³ speaking of zeolites, says: ". . . but they represent

¹ ECON. GEOL., Vol. 3, p. 628, 1908.

² Amer. Jour. Sci. (4), Vol. 7, p. 367, 1899.

³ Bull. 330, U. S. Geol. Surv., p. 350, 1908.

some paragenetic relations. Stilbite and heulandite seem, for example, to be derivatives of an unknown calcium-albite."

Knopf and Schaller:¹ "It is clear from the paragenesis of paigeite that it represents a fixation product of magmatic emissions rich in fluorine (and chlorine), boron and iron."

Rogers:² "In characters and paragenesis, the Kansas anhydrite resembles the foreign anhydrite."

Thus we have *paragenesis* used in the sense of (1) order of succession, (2) association, (3) origin, (4) association and occurrence giving a clue to the origin, and (5) a general term for the occurrence, association, and origin.

In the literature, the term *paragenesis* has perhaps been used more often in the sense of order of succession than in any other one sense. Breithaupt put great emphasis upon this phase of the association and probably thought that he had discovered important laws governing the order of succession, but we know that these are largely of only local importance. Yet many writers have put so much emphasis upon the order of succession that they use *paragenesis* as a synonym of order of succession. I protest against its use in this sense, for it is not only a limitation of Breithaupt's original meaning but substitutes the word *paragenesis* for the simpler and more definite phrase, *order of succession*.

I would define *paragenesis* as *the association of minerals with special reference to the occurrence and origin*. While it is not synonymous with *origin*, the idea of origin is involved etymologically. As Tschermak³ says: "Das Zusammenvorkommen drückt also zugleich das Nebeneinander- oder Nacheinanderstehen, zuweilen auch die Abstammung aus, daher die von Breithaupt eingeführte Bezeichnung Paragenesis glücklich gewählt erscheint."

The ideas of occurrence, association, order of succession, and origin are so bound together that I should like to see the term *paragenesis* expanded so as to cover all these ideas. We have the

¹ *Amer. Jour. Sci.* (4), Vol. 25, p. 325, 1908.

² *Amer. Jour. Sci.* (4), Vol. 29, p. 258, 1910.

³ "Lehrbuch der Mineralogie," 6th edit., p. 318, 1905.

separate terms enumerated but no single term except *paragenesis* which can be used in the sense indicated. At any rate, *paragenesis* means the relations between associated minerals, and not simply one phase of these relations.

PARAGENETIC VARIETIES.

The present tendency in mineralogy is to do away with varietal names, based upon trivial characters, and to emphasize the unity of a mineral or mineral species, based upon essential characters. The varietal names based upon crystal habit, structure, color, and slight differences in composition are gradually disappearing from mineralogical literature.

The present tendency is to base varieties upon occurrence, association, or origin, or, in short, upon paragenesis; hence, the term *paragenetic varieties* used in a recent text-book.¹

This term is perhaps better than genetic varieties, for the origin of a mineral can not always be determined, and it may also be desirable to distinguish several kinds of occurrence with the same origin; for example, a mineral found in two different kinds of igneous rocks with different associates, yet in each case a product of fusion.

Tschermak² proposes that all specimens with the same essential properties be called a genus (*Gattung*) and that all specimens of any genus with the same manner of formation (*gleiche Bildungsweise*) be called a species (*Art*). According to Tschermak, the manner of formation impresses the mineral with a characteristic form or texture. While there is often a correlation between the form or texture, and the kind of occurrence, yet I believe Tschermak attaches too much importance to it. As Miers³ says:

"The essential characters of a mineral, moreover, are quite independent of its source or previous history. . . ."

Tschermak establishes species (*Arten*) for several minerals (*Gattungen*). For example, there are five for magnetite, as follows:

¹ Rogers, "Introduction to the Study of Minerals," New York, 1912.

² "Lehrbuch der Mineralogie," 6th edit., p. 370, 1905.

³ "Mineralogy," p. v, 1902.

1. Attached (*sitzende*) crystals (in the clefts of crystalline schists).
2. Embedded (*schwebende*) crystals (in crystalline schists).
3. Small octahedra and grains as a constituent of igneous rocks.
4. Granular magnetite interbedded with schists.
5. Secondary deposits in the form of sand.

Tschermak establishes definite species (*Arten*) for only about three minerals. For calcite and dolomite he says that the species fall under three divisions (*Abteilungen*), crystallized, crystalline, and limestone; but he does not definitely state what the species are.

Klockmann,¹ in his "Lehrbuch der Mineralogie," gives a numbered list of paragenetic varieties for a large number of minerals, though he does not use the term *paragenetic*. This, I believe, marks a distinct advance in the science of mineralogy. Magnetite he lists under four kinds of occurrences:

1. As an original constituent of basic igneous rocks.
2. As layers and lenses in regionally metamorphic rocks.
3. As contact deposits.
4. As sand.

From the standpoint of origin, this is a better list than that of Tschermak, though it might be improved by several additions.

Lacroix, in his "Mineralogie de la France et de ses Colonies," which may well serve as a model for all future work in regional mineralogy, gives a detailed description of minerals not by localities primarily, but by geological mode of occurrence, numbering the kinds of occurrences. He considers magnetite, for example, under seven heads.

1. In eruptive rocks.
2. In the contacts of eruptive rocks.
3. In the metalliferous veins.
4. In the seams and clefts of various rocks.
5. In the crystalline schists.
6. In the sedimentary rocks.
7. In artificial products.

¹ 3d edition, 1903; 4th edition, 1907.

There are subdivisions under some of these. Although Lacroix does not use the terms paragenesis and paragenetic varieties, the varieties he establishes are based upon paragenesis rather than upon origin alone.

For the first time in an English book,¹ the writer has attempted to give the most important paragenetic varieties for the two hundred minerals treated, although doubtless there are mistakes of both omission and commission. To establish, or to attempt to establish, these varieties may seem an ambitious undertaking. But science is an orderly arrangement of facts, and there should be an attempt to make definite our knowledge of this interesting part of mineralogy, which is, perhaps, in the same condition that the classification of minerals was half a century ago. To be convinced of this fact, let one attempt to get an adequate conception of the occurrence and association of some of the common minerals from our mineralogical text-books and treatises.

Certain occurrences and associations are so characteristic that they should be emphasized by numbered varieties. The time has come for definiteness of statement of these things even at the sacrifice of accuracy and completeness.

TYPES OF MINERAL DEPOSITS OR OCCURRENCES.

The discussion² of the paragenesis of minerals involves a classification of mineral occurrences, including not only rocks but veins and other mineral deposits.

W. H. Emmons,³ in a paper entitled "A Genetic Classification of Minerals," amplifying an earlier paper of Lindgren's,⁴ lists eight kinds of occurrences as follows:

1. Igneous Rocks.

¹ "Introduction to the Study of Minerals," New York, 1912.

² There are chapters on this topic in the German text-books of Klockmann, von Kobell, Naumann-Zirkel and Tschermak, and in the English text-books of Moses and Parsons, and Rogers.

³ *ECON. GEOL.*, Vol. 3, p. 611, 1908.

⁴ "The Relation of Ore-Deposition to Physical Conditions," *ECON. GEOL.*, Vol. 2, p. 105, 1907.

2. Pegmatite Veins.
3. Contact Metamorphic Deposits.
4. Deep Vein Zones.
5. Deposits of Moderate and Shallow Depths. Igneous Rocks nearby.
6. Deposits of Moderate and Shallow Depths. No Igneous Rocks nearby.
7. Zone of Oxide and Sulphide Enrichment.
8. Products of Dynamo-Regional Metamorphism.

To make this list complete, I would add a number of others, for it has a broader aspect than the study of ore-deposits, important though that may be.

1. Igneous Rocks.
2. Meteorites.
3. Volcanic Sublimates.
4. Inclusions in Volcanic Rocks.
5. Pegmatites.
6. Pyroclastic Rocks
7. Sedimentary Rocks.
8. Sands and Gravels.
9. Organic Deposits.
10. Deep Veins.
11. Shallow Veins.
12. Oxidized Zone of Veins.
13. Zone of Secondary Sulphide Enrichment.
14. Saline Residues.
15. Contact Metamorphic Zones.
16. Regional Metamorphic Rocks.
17. Minerals of Recent Formation.

A UNIVERSITY COURSE IN THE PARAGENESIS OF MINERALS.

A university course in which minerals are studied from the standpoint of paragenesis is perhaps the most useful advanced course in mineralogy for most students. In an elementary course in mineralogy very little attention can be given to this subject, for it takes all of the student's time to master the char-

acters of minerals, especially if their sight identification is emphasized, as I believe it should be. As Miers¹ says:

"One important branch of scientific mineralogy is the study of the modes and places of occurrences of minerals, their origin, and the changes to which they are subject. This is to a large extent an entirely independent subject except in so far as it throws light upon the nature of minerals themselves; it is, moreover, a study which should succeed that of the essential properties of minerals, for the essential properties do not vary with the origin or the modes of occurrence."

A course of the kind should also be taken after elementary petrography, for it correlates the facts of mineralogy and petrography. It trains the student in observation, makes him familiar with important literature, and above all, makes definite his ideas concerning the association, occurrence, and origin of minerals. This course serves as an excellent introduction to the study of ore-deposits and may well be made a prerequisite to the economic geology course.

Such a course has been given by the writer at Stanford University for several years, though it is an optional course for advanced students and not a prerequisite for economic geology. A collection to illustrate the course is being gradually made. In this collection are assembled pseudomorphs, petrifications, alterations, artificial minerals, minerals of recent formation, and all available specimens illustrating any phase of the occurrence, association, or origin of minerals. There is one very instructive specimen from Cornwall, England. This specimen consists of galena and chalcopyrite in vein quartz, while the free surface consists of limonite with acicular crystals of cerussite. Here we have on a small scale a typical ore-deposit with gossan above and unaltered sulphides below. Such specimens cannot fail to interest and impress the student.

SUMMARY.

When the physical and chemical properties of a mineral are worked out, there yet remains the task of learning everything possible about its occurrence, association, and origin.

¹"Mineralogy," p. 5, 1902.

The term *paragenesis* has been used with various meanings, more often perhaps in the sense of *order of succession*. *Paragenesis* may be defined as *the association of minerals with special reference to their occurrence and origin*, but it seems advisable to expand the term so as to include the closely related ideas of occurrence, association, order of succession, and origin.

It is important to distinguish definite varieties of minerals based upon paragenesis, rather than upon origin alone. These may be called *paragenetic varieties*.

Seventeen types of mineral occurrences are enumerated. This is an expansion of the earlier list of Emmons.

A university course in the paragenesis of minerals is suggested as a useful advanced course. To be effective, it should be illustrated by a special collection of minerals.