THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 79. JULY, 1914. Vol. XVII.

The genetic classification of rocks and ore deposits.

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[Read January 27, 1914.]

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1. General Remarks.

During the last decade there has been no lack of controversy on the subject of rock classification, but the dispute has concerned igneous rocks almost entirely. Petrography has been threatened by an effort to reduce it to an independent science of igneous rocks, and in consequence of this there has been a tendency to neglect its wider aspects. Important as igneous rocks are, their formation is less well understood than is that of some other sub-groups of rocks; moreover, they constitute one only of some six or seven sub-groups, and it is the business of petrography as a science to deal with these rocks as a whole. The student of petrography should be encouraged to take this wider view. He should look at these different sub-groups of rocks in their proper geological perspective, and approach the study of the classification of igneous rocks with a knowledge of the principles that are applicable to the classification of rocks as a whole.

The discussion concerning the classification of ore deposits has proceeded on independent lines, and in a more well-balanced manner than has that of rocks. With ore deposits, as with rocks generally, genetic principles have triumphed; but the application of these principles to rocks long preceded their application to ore deposits. In recent years it has become apparent that the fundamental requirements for the classification of rocks and ore deposits are essentially the same; and in view of the identity of their interests, both subjects are treated in this paper.

The aims of this paper are: To define the basis of genetic classification; to give a brief historical account of classification on genetic-geological principles; to point out defects in the present system of arrangement; and to suggest an alternative scheme of grouping that is in closer accord with geological and genetic principles.

2. Rocks.

(a) *Historical Review.*

To understand the present situation as regards the genetic grouping of rocks it is helpful to note the growth of the ideas involved; and for that reason a brief historical sketch is here given. To begin this it is necessary to go back to the very beginnings of modern geology, for the study of the processes by which rocks are formed long preceded the detailed study of rock slices by means of the polarizing microscope.

James Hutton (1785).—To Werner and his school (the Neptunists), whose views dominated geology towards the end of the eighteenth century and at the beginning of the nineteenth, all rocks, with the exception of volcanic ejectamenta, were aqueous in origin; and rocks were grouped by them according to age. It was Hutton's statement of the Plutonist doctrine in his 'Theory of the Earth' (Trans. Roy. Soc., Edinburgh, 1788, vol. i; read in 1785) that laid the foundations of a study of crustal processes and rock genetics. In that work Hutton established conclusively the distinction in mode of origin between igneous and sedimentary rocks, and pointed clearly, though with some exaggeration of its significance, to the existence of a third great group of thermally altered rocks to which Lyell afterwards gave the name 'metamorphic'.

By this study of rocks in relation to crustal processes, Hutton instituted what we may call the genetic-geological basis, in place of the age basis, for the broad grouping of rocks; and it is therefore to his 'Theory of the Earth' that the initiation of the modern threefold grouping of rocks must be traced.

Sir Charles Lyell (1833).—By introducing the term metamorphic to describe those sedimentary rocks that had been reconstituted by thermodynamical changes, Lyell definitely established a group of metamorphic rocks. It is a rather singular fact, however, that in his notions concerning the broad grouping of rocks Lyell did not put the emphasis on processes. He attached much more importance to place of deposition than to mode of origin. This is shown by the fact that he grouped plutonic (not volcanic) rocks with metamorphic rocks under the name 'hypogene'; and he appears to have anticipated a much wider use for the term hypogene than for the term metamorphic, for he remarks: 'We divide the hypogene rocks then into unstratified or plutonic and the altered stratified. For these last the term "metamorphic" may be used. The last-mentioned name need not, however, be often resorted to, because we may speak of hypogene strata, hypogene limestone, hypogene schist; and this appellation will suffice to distinguish the formations so designated from the plutonic rocks' ('Principles of Geology,' 1833, and later editions). The same feature is illustrated by the fourfold division of rocks which he adopted, and in which plutonic and volcanic rocks are treated as independent groups ('Elements of Geology,' 1838, and later editions). It is thus noteworthy that Lyell's use of the term hypogene was not strictly genetic, for he used it only with reference to rocks and not with reference to processes.

In 'The Student's Lyell' Judd retains Lyell's broad grouping on the basis of place of formation, and adopts the term epigene (used previously by Geikie in application to surface processes) as a group name for volcanic and sedimentary rocks, thus:—

Epigene	Volcanic.
	Sedimentary.
Hypogene	Metamorphic.
	Plutonic.

Cordier, von Leonhard, Brongniart, and Naumann (1800-50).—It was during the early part of the nineteenth century that there developed the fashion—not yet quite extinct—of studying rocks as if they were minerals, independently of their connexion with the science of geology. The most notable of the early specialists in the study of rock specimens, the petrographers proper of some authors, were Cordier, von Leonhard, and Brongniart, to all of whom rocks, like minerals, were things to be studied *per se* and classified accordingly. To them, consequently, the mode of origin of a rock was a matter of no importance, and their classifications were based entirely on intrinsic characters.

It was natural enough that the study of rocks should at that time take such a turn, in order that a knowledge of their intrinsic characters should be acquired. Indeed, Wernerian ideas of rock origins were very much alive at that time, and the feelings developed in the famous controversy were so strong that the peace-loving petrographer, who was ambitious to know more concerning the composition of rocks, was left with no alternative but that of making his classification independent of genetic data.

Gradually, however, the Huttonian conception of rock origins won its way. Lyell's 'Principles' and 'Elements' had not yet appeared when von Leonhard issued his 'Charakteristik der Felsarten' in 1823, and Brongniart his 'Classification et caractères minéralogiques des roches' in 1827; but after the appearance of Lyell's books there can be no doubt as to the change they wrought, and by the middle of the century genetic ideas were again active in petrography. Thus Naumann, in his 'Lehrbuch der Geognosie' (1849), looked at rocks from a much wider standpoint, and dealt with petrogenesis, though his classification of rocks was not genetic.

H. Coquand (1857).—It was not until 1857 that there appeared a work devoted specially to petrography in which the genetic mode of grouping was followed. In that year Coquand issued his 'Traité des roches', in which he adopted a threefold division of rocks into igneous, aqueous, and metamorphic types, and his subdivision of these was as far as possible genetic. Coquand's 'Traité' stands out prominently as the first purely petrographic work in which an attempt is made to correlate rock groups with formative agents and processes, up to the limits of available knowledge concerning those processes, using other data such as mode of occurrence and intrinsic characters only where the genetic data are uncertain, or to distinguish rocks arising from one and the same process.

B. von Cotta (1862).—In the first edition of his 'Gesteinslehre', published in 1855, von Cotta classified rocks in fourteen groups on the basis of their intrinsic characters. When, however, in 1862, he issued the second edition of this work, he followed Coquand's example, and divided rocks into three broad genetic groups, viz. eruptive, sedimentary, and metamorphic. It was presumably Lawrence's translation into English of the second edition of von Cotta's 'Gesteinslehre' that established this mode of division among English petrologists, though doubtless the fact that it harmonized with the Huttonian traditions fostered by Lyell was not without its significance.

David Forbes[1] (1867).—In a paper entitled 'The Microscope in Geology' (Popular Science Review, 1867) Forbes adopted a twofold division of rocks into primary or eruptive and secondary or sedimentary. 'The terms *primary* and *secondary* are here used quite independently of geological chronology. Primary rocks (of all ages) might be called "ingenite or subnate rocks" (i.e. such as are born, bred, or created within or below), whilst the term "derivate rocks" would be appropriate for the latter, since directly or indirectly they are all derived from the destruction of the former' (op. cit., p. 358). In making this suggestion Forbes was evidently thinking of mode of origin rather than place of formation as the proper basis of his twofold division, but he did not deal logically with the metamorphic rocks, since he referred to these separately, and failed to indicate how they were to be classified. It is perhaps worth

[1] David Forbes was one of the pioneers of microscopical petrography. As early as 1852 he had begun his rock studies with the microscope, working at slices which were cut for him by Oschatz of Berlin, who appears to have entered this field of activity independently of Sorby. This was some ten years prior to the date when Sorby, sitting with Zirkel on the Drachenfels, explained to him the advantage of examining rock slices microscopically, and described to him how slices were prepared. It is not unfair to the memory of Sorby to say that, though he was perhaps without equal as a master of the technique of rock-slicing, he was no match for Forbes as a petrographer. It is indeed doubtful if, during the late fifties and early sixties, there was anywhere a worker who had made such a wide study of this subject as Forbes. He was a practised observer in this line of work, thanks almost entirely to his own foresight and enthusiasm, before Zirkel had realized its value. He did not limit his microscopical investigation to slices; for he tells us that 'thin splinters of rocks and powdered fragments, mounted in Canada balsam, may also be examined with advantage'. His paper on 'The Microscope in Geology' was indeed a valuable early scientific contribution to microscopical petrography, excellently illustrated with coloured and other drawings of rock slices, and embodying work done at a time when there was no literature on the subject bearing on the broad outlook which he entertained.

mentioning that Forbes used the term metamorphism in a wide sense, as Naumann had already used it, and as it has been used since by many writers, notably by Van Hise.

G. H. Kinahan (1873).—In his 'Handy Book of Rock Names', published in 1873, Kinahan developed the suggestion put forward by Forbes, and produced a more scientific twofold division of rocks. He adopted the terms 'ingenite' and 'derivate', using them much in the same senses as Forbes had indicated; but instead of treating metamorphic rocks as abnormal types, he put the thermo-dynamically metamorphosed sedimentary rocks with the eruptives under the 'Ingenite' group, and put all other rocks into the 'Derivate' group. It is evident enough, however, that Kinahan was led to do this by his geological instinct rather than by any logical principles of classification; for in dealing with the metamorphic rocks he writes: 'The metamorphic sedimentary rocks belong indeed to the Derivate order; but being compelled to make a selection, we place them under the Ingenite, as the arrangement seems to involve the least inconvenience. They are Ingenite rocks, as they have been in a certain sense *formed below*, yet their materials were previously derived from the destruction of other rocks.' Thus Kinahan, prompted by considerations of convenience (!) rather than by any definite principles of genetic grouping, chose a mode of grouping which in its broad features is in accordance with a scientific and geological grouping of processes. One exclaims at his considerations of convenience, because it is on these very grounds that others have regarded it necessary to make a threefold grouping, with metamorphics as an independent group. It is interesting to interpret Kinahan's twofold grouping in the light of Geikie's later twofold grouping of crustal processes. It is also interesting to compare it with the choice made by Kalkowsky, who adopted a twofold division but treated the metamorphosed sediments differently (see below).

Sir Archibald Geikie (1879).—In his article on Geology in the 'Encyclopaedia Britannica' (1879 and later editions), and in his 'Textbook of Geology' (1882 and later editions), Geikie adopts the usual threefold division of rocks into igneous, sedimentary, and metamorphic. On the other hand, he adopts a twofold division of crustal processes, namely: 'I, Hypogene or plutonic action—the changes within the earth, caused by original internal heat and by chemical action. II, Epigene or surface action—the changes produced on the superficial parts of the earth, chiefly by the circulation of air and water set in motion by the sun's heat' ('Text-book of Geology', 1903 edition, vol. i, p. 262).

We see, then, that whereas Lyell used the term hypogene for rocks which had assumed their characteristics below the surface or deep-seatedly and did not apply it to processes, Geikie uses it for processes and does not apply it to rocks. The difference between these two uses is a rather serious one, for, using the term as Geikie does, volcanic action is hypogene, from which we should infer that volcanic rocks are hypogene, although they assume their characteristics under surface conditions, and were for that very reason excluded by Lyell from his hypogene rocks.

The conclusion of this matter seems to be that it is necessary to distinguish between the mode of origin of a rock (i.e. the formative processes involved in the production of its chief characteristics) and the place of formation (i.e. the situation under which it has assumed those characteristics). It appears that neither of the terms hypogene and plutonic can legitimately be used in such a way as to cover volcanic action. Further, Geikie's definition of the term epigene does not allow of its application to volcanic rocks as Judd has applied it (see p. 57). It also appears that terms applied to processes according to their deep-seated or superficial origin ought to apply to rocks irrespective of the position in which their characteristics are developed.

E. Renevier (1880).—An interesting genetic scheme of classification was that proposed by Renevier[1] in a paper read before the Geologists' Association in London in 1880, descriptive of the arrangement adopted by him for the rock collection of the Lausanne Museum. According to Renevier, 'Ce qu'il y a d'essentiel dans les roches, c'est leur origine, ou leur mode de formation,' and he adopted five groups, as follows: (1) *Deuterogenous* rocks, or sediments of mechanical origin; (2) *Organogenous* rocks, or sediments of organic origin; (3) *Hydatogenous* rocks, or chemical deposits of aqueous origin, including vein deposits; (4) *Pyrogenous* or igneous rocks; and (5) *Cryptogenous* rocks, of doubtful origin, including crystalline schists.

K. A. Lossen (1884).—In his paper 'Ueber die Anforderungen der Geologie an die petrographische Systematik' (Jahrb. k. Preuss. Geol. Landesanst. u. Bergakad. for 1883, 1884), Lossen made a strong defence of the geological basis of classification, and advocated a twofold division of rocks on morphological data (see also Zeits. Deutsch. Geol. Gesell., 1872, vol. xxiv, pp. 784 and 785). The massive and stratified rocks, according to Lossen, constitute two distinct and natural types of deposit.

[1] E. Renevier, 'A petrographical (*sic*) classification of rocks,' Proc. Geol. Assoc., 1880, vol. vi, p. 426. For a fuller account see 'Classification pétrogénique,' Bull. Soc. Vaud., 1882, vol. xviii, p. 93.

No third type corresponding to metamorphic rocks exists; and since these were originally formed as either massive or stratified rocks, they were not allowed by Lossen to constitute an independent group. Much as Lossen protested against the genetic element in rock classification, however, it is clear from his reasoning that his conceptions of massive and stratified rocks, though expressed in morphological terms, are not free from the influence of genetic ideas. His twofold division is essentially the same as the primary and secondary or eruptive and sedimentary of certain older authors; and the slenderness of his case against genetic data can perhaps be best seen by a comparison of his divisions with those adopted by Kalkowsky (see below).

Lossen's views had great influence on Rosenbusch and other petrographers. In his 'Mikroskopische Physiographie der massigen Gesteine' (1877 and later editions), Rosenbusch followed Lossen. In this work he treats the metamorphic rocks imperfectly in connexion with the 'massive' rocks, not because they are 'massive' rocks, but because he regards it as convenient to deal with contact metamorphism when describing intrusive rocks. This is an obviously unscientific method of procedure, and it may be assumed that Rosenbusch himself recognized this fact, when, in his 'Elemente der Gesteinslehre' (1898 and later editions), he adopted the threefold division into eruptive rocks, stratified rocks, and crystalline schists.

E. Kalkowsky (1886).—In a work entitled 'Elemente der Lithologie', published in 1886, Kalkowsky proposed what he claimed to be a genetic division of rocks into 'anogene' and 'katogene' rocks (p. 29): 'Gesteine entstehen also entweder, indem das Material dazu sich von unten nach oben bewegt oder umgekehrt von oben nach unten; erstere Gesteine wollen wir anogene, die letzteren katogene nennen. Dieselben Gruppen der Gesteine hat man auch mit anderen Namen belegt, von denen eruptiv und sedimentär so ziemlich dasselbe bedeuten, aber nicht den Ursprung des Materiales, den Anlass zur Bildung, sondern nur die äusseren Vorgänge bei der Bildung andeuten.' The curious fact about this twofold grouping by Kalkowsky is its similarity in all except names to that of Lossen, who disclaims all recognition of the genetic basis of grouping. Kalkowsky follows Lossen in refusing to recognize a third group of metamorphic rocks. He regards the genetic basis as useful only for the purpose of making a main twofold division, and he puts metamorphic rocks in the 'katogene' group.

C. R. Van Hise (1904).—In his 'Treatise on Metamorphism' Van Hise deals elaborately with many aspects of rock genesis. He divides the earth's crust into (1) an outer 'katamorphic zone' in which metamorphism results in the disintegration of complex compounds to produce simpler ones; and (2) an inner 'anamorphic zone' in which the changes are characterized by the formation of complex minerals at the expense of simpler ones. The 'katamorphic zone' is subdivided into (*a*) an outer belt of weathering and (*b*) an inner belt of cementation, the ground-water level defining the limit between these two belts.

It is often useful, when dealing with metamorphism, to distinguish between anamorphic and katamorphic changes as defined by Van Hise. Much less real are the 'zones' in which these changes are supposed to take place; for anamorphic changes are not necessarily deep-seated, and katamorphic changes are not necessarily superficial. There appears to be no accordance between anamorphic and katamorphic changes and the operation of formative agents and processes geologically considered. Important as pressure is, it is much less significant than heat and solution effects as a cause of mineralogical changes among rocks as we know them. The paramount importance of igneous intrusions as agents of metamorphism, the effects of which are usually anamorphic but sometimes katamorphic, and the importance of thermal effects even in 'regional' metamorphism, are facts not readily accommodated by the zonal divisions of Van Hise.

It is by these considerations that we must explain the failure of his crustal zones to provide a basis for the geological or genetic classification of either rocks in general or metamorphic rocks in particular. It was, however, not for the study of rocks and their classification, but for the study of the changes they undergo, that Van Hise suggested this way of looking at the earth's crust; though its bearing on the broad features of rock origins makes a notice of it necessary in giving an historical review on the subject of genetic classification.

Conclusion.—From the foregoing review it is seen that the subject of the broad genetic grouping of rocks has been handled in a more or less incomplete manner by many authors. Place of deposition has been confused with mode of origin. Formative processes have been considered apart from their bearing on genetic classification, and genetic groupings of rocks have been made without recognition of the fact that such groupings should be based on a geological analysis of processes. There has been throughout no recognition of a definite genetic method, and there has been no satisfactory co-ordination of rock-grouping and process-grouping such as the broad facts of rock genesis distinctly suggest.

(b) The genetic-geological basis of classification.

The data available for the classification of rocks are of two sorts, namely (1) Intrinsic, i.e. the data that can be obtained from a study of the specimens themselves, without reference to the mutual relations of the masses which they represent, or to the conditions under which those masses have been formed; and (2) Extrinsic, i.e. the data that relate not merely to the characters observed in a study of specimens *per se*, but to the mutual relations and modes of origin of the masses which they represent. The intrinsic data comprise the mineral and chemical composition of specimens, and their textural characters. The extrinsic data comprise the modes of origin, relative ages, modes of occurrence, and morphological features of the masses which the specimens represent.

The most important differences of opinion among authorities on the subject of rock classification arise from differences in mental bias concerning the relative importance of these two kinds of data. On the one hand, there are those who have a mineralogical and chemical bias, and who, naturally enough, choose intrinsic data as the basis of grouping. This school aspires to the establishment of descriptive petrography as a separate branch of study, based not upon geological but upon physical and chemical principles. It is not to be wondered at that the extremists of this school should regard petrography as a sort of museum study, aiming chiefly at the cabinet-grouping of specimens on the most expedient basis, which basis may be as artificial as is necessary in the interests of expediency. On the other hand, there are those whose bias is geological, and to whom rocks, unlike minerals, are things to be grouped in accordance with geological principles, and not simply in accordance with chemical and physical principles. By this school it is considered necessary that petrography should be naturalistic in scope.

Those who select intrinsic data as the basis of grouping put forth two claims which it is necessary to examine. One of these is that a system of classification should be free from the influence of theories of origin. This claim is indeed made by all who are opposed to the genetic basis of classification. It was put forth by some of the earlier petrographers; it has been advocated in recent years by L. Fletcher, who has applied the mineral-textural basis to rocks as a whole ('An introduction to the study of rocks,' British Museum Guide-Book, 1895); and by W. Cross on behalf of the quantitative-chemical basis for igneous rocks (see 'Geological versus petrographical classification of rocks,' Journ. Geol., 1898, vol. vi. See also 'Review of the development of systematic petrography in the nineteenth century,' Journ. Geol., 1902, vol. x). Among geologists, the claim that 'classification should be as free as possible from a leading theory' was made by De la Beche, who divided rocks on a morphological basis into (1) stratified and (2) unstratified ('Geological Manual,' 3rd edition, 1833). It was also strongly advocated by Lossen (see p. 61), whose plea was for a geological basis of grouping, and whose two chief groups did not differ materially from those of De la Beche.

The second claim made in defence of the choice of intrinsic data is that made by Cross, namely, that in a study of rocks it is necessary to distinguish 'between the formal unit and the rock substance of that unit', which means that, for the purpose of classification, rocks should be treated like minerals and considered as specimens rather than as parts of the earth's crust. This view is, of course, inseparable from the choice of intrinsic data as the basis of classification, and Cross has pushed it to its logical issue. He claims candidly that petrography as a science is the study of specimens *per se*, and that a *petrographical* classification, based on intrinsic data, should be treated separately from a *petrological* classification based on extrinsic data. Until, however, it has been admitted that petrography as thus defined has any *raison d'être* as a separate science, it seems unnecessary to admit this distinction between the terms petrology and petrography.

Neither of the above claims can be substantiated on geological grounds; and the answer to them appears to be given adequately enough by a consideration of the proper definition of the term rock, and by the inference, arising out of that definition, that the scientific basis of petrography is geological.

The term rock, properly considered, embodies a geological concept. It is as the architectural elements of the earth's crust, rather than as aggregates of minerals or chemical constituents, that rocks are best and most fundamentally considered; and, unlike a mineral, a rock has no scientific significance except in so far as it can be regarded as representative of the mass from which it has been detached. The mere description and classification of rocks as specimens, apart from any consideration of their origin and occurrence, can scarcely be made to constitute a science, in however quantitative a manner this operation be carried out; and if petrography is to fulfil any scientific purpose, it is necessary that it should link itself on to some definite body of scientific principles.

Now petrography offers splendid scope for the application of chemical and physical principles, but practically none for their establishment or advancement. There is, indeed, little fear that chemists or physicists will ever claim petrography as a branch of their sciences. What a study of rocks does establish and advance, and that in a very substantial manner, is a knowledge of geological principles. The necessity of petrography for the elucidation of these principles, and its needlessness for the elucidation of any other body of scientific principles, affords one very good explanation of the inherent weakness and consequent failure of schemes of rock classification that are non-geological in character; for on looking back over the century or so of history that petrography has now made, one finds that no non-geological scheme of classification has been successful. It has proved to be impossible, on the basis of intrinsic data, to secure a grouping that will harmonize with geological principles. To obtain such a grouping, we have to appeal to extrinsic data.

As regards extrinsic data, it seems scarcely worth arguing that age relations are useless as a basis of petrographical classification. More significant are morphological features and modes of occurrence; but though these have played and still play an important part as a basis of grouping, it is chiefly as a makeshift that they are tolerated, and as soon as they can with any satisfaction be made to do so, they give place to data connected with the mode of origin of the rocks, i.e. genetic data. Of all the extrinsic data available for rock classification, it is the genetic that give fullest play to the geological principles concerned in rock studies; and it is presumably for this reason that genetic data have always maintained an important place in rock classification, though never more so than at the present day.

As already mentioned, however, there have been, and still are, those who oppose genetic data on the ground that the origins of rocks are to some extent matters of theory. The history of petrography affords very little encouragement to those who hold this view, and present tendencies afford still less. If the experience of the past and the tendencies of the present teach us anything at all about classification, they show clearly that no system can be useful and acceptable unless it helps, and accommodates itself to, the prevailing theories of rock origins. As far as possible, therefore, a system of rock classification should be genetic.

In this paper, genetic data are regarded as comprising only that portion of extrinsic data relating to the action of formative agents and processes. Some writers have used the term in a less definite way, as including also certain other extrinsic data. It is, moreover, assumed in this paper that, since a genetic classification is one based on a study of formative processes, it is desirable first of all to decide upon a scientific grouping of these processes, and then to make a corresponding grouping of rocks.

It should be noted that a system of classification can be geological without being genetic, and conversely, it can be genetic without being geological. But by expressing the genetic data in a geological way it is possible to secure a scheme of classification that is eminently suited to geological requirements, and one that satisfies the needs of both science and practical utility.

From these considerations, then, we arrive at the following conclusions, in which the features of chief importance in the classification of rocks may be briefly summarized:

(1) In accordance with the view that the term rock embodies a geological concept, the classification of rocks should be as broad-based and complete as possible; it should pass in review the whole of the accessible rocks (mineral deposits) of the earth's crust.

(2) The highest end to be attained in rock classification is the correlation of types with formative processes. The mode of grouping should therefore be genetic, and as far as possible in accordance with a scientific grouping of processes. Data other than genetic should only be used as a temporary arrangement, or to distinguish rocks arising from one and the same process.

(3) The mode of grouping should be geological as well as genetic; and for this purpose the grouping of the formative processes should be in accordance with their disposition and operation in the earth's crust.

(4) The supreme objection to the grouping of rocks on the basis of intrinsic data is, that such a mode of grouping cannot be made to accommodate the data of dynamical geology. On the other hand, the genetic method of classification does not dispose of the necessity for intrinsic data, but uses these data as a basis for defining types of rocks, and the different varieties of any particular type. Genetic classification, therefore, finds a place for all kinds of data, geological, mineralogical, and chemical; whilst it conforms to and accommodates the facts and theories of dynamical geology, and by so doing stimulates the growth of the science of which it forms a part. Only by a due recognition of this scientific function of petrography is it possible to explain the history and present tendencies of rock classification.

(c) *The conventional threefold grouping of rocks—its merits and defects.*

From the historical point of view, one of the most interesting facts about rock classification is the way in which the custom of making a threefold division into igneous, sedimentary, and metamorphic has persisted. This mode of grouping is based on extrinsic data. It was, as we have seen, adumbrated by Hutton, and it seems to be the only scheme that meets with favour at the present day. To the early geologists by whom it was fostered, rocks had no meaning except as tectonic masses. It was not adopted by the early petrographers, who strove to establish groupings on the basis of intrinsic data. In later years, and even after the institution of the practice of rock slicing, Zirkel, Lossen, Rosenbusch, and others opposed it, but to no purpose. Petrographers have thus adopted the threefold grouping, not because they like it, but apparently because necessity has forced it upon them.

The explanation of this fact seems to be that the conventional grouping of rocks as igneous sedimentary, and metamorphic possesses the two prime virtues required of a system of rock classification: it is geological and genetic. Though based on genetic-geological principles, however, it is not a scientific embodiment of those principles. It is, indeed, generally admitted that this mode of grouping is prompted more by convenience than by devotion to principles of classification. Not only is it unscientific in this respect. It is open to the still more serious objection that it does not allow of completeness of grouping, an objection which is specially applicable where the term 'metamorphic' is used in its restricted sense. Let us now look briefly at these defects of the conventional threefold grouping.

Igneous rocks.—Concerning igneous rocks, in so far as these are regarded as the congealed material of the magmas proper, and are treated independently of the exudation-products of these magmas, there can be no doubt that they constitute a distinct genetic sub-group.

Sedimentary rocks.—Strictly speaking, the term sediment should mean detrital sediment. It was probably for this reason that Lyell and other geologists applied the terms aqueous and sub-aqueous to rocks deposited in water. The term sedimentary is, however, now used to include deposits from surface solutions as well as detrital deposits. Inaccurate as this usage is, it does not cause any inconvenience unless we wish to make provision for subterranean solution deposits. It is then we realize that, when the solutions responsible for these deposits originate at the surface, they should be grouped genetically with surface solution deposits, leaving an independent sub-group for the mechanical sediments or detrital deposits.

Metamorphic rocks.—Lyell applied the term metamorphic to hypogenetically altered sedimentary rocks, i.e. those that had suffered a transformation of type under deep-seated conditions. Except for the extension of its meaning to igneous rocks that have been similarly altered, most authors have adhered to Lyell's restricted usage, in spite of the fact that this usage is at variance with the full literal significance of the term. The obvious inconvenience of this restricted use of the term is that it excludes or misplaces a number of important types of alteration products, and makes completeness of grouping on anything like a scientific basis practically impossible.

It is, therefore, not surprising that many authors have been unable to resist the temptation to use the term 'metamorphic' in a wider sense, including under it rocks that have suffered a transformation of type under the influence of atmospheric changes and descending solutions. Some of the older writers used the term in this wider sense, but of all writers it is Van Hise who, in his 'Treatise on Metamorphism', has given this wider usage its fullest scope. Unfortunately for the student of rocks, however, that author limits his study almost entirely to the nature of metamorphic changes from a physical and chemical standpoint, and says very little about the really petrographical aspect of the subject.

Van Hise defines metamorphism as any change in any kind of rock. His metamorphic rock is one that has been altered by any agency whatever. From the standpoint of those who wish to retain the conventional threefold grouping, the serious drawback of this sweeping definition is that it makes all rocks metamorphic; for all rocks, as we know them, have arisen from changes in the constitutions of pre-existing rocks. This definition, therefore, goes too far; but where is the line to be drawn? There has hitherto been no satisfactory definition of the term. Either it is made too incomplete or too comprehensive in its meaning, and it seems from this standpoint that the adoption of a separate group of metamorphic rocks, in the sense implied by the conventional threefold grouping, is undesirable.

There is another way in which this question as to the desirability of separate main groups of sedimentary and metamorphic rocks may be approached. The division of rocks into igneous, sedimentary, and metamorphic is essentially genetic. As already postulated, however, if a genetic system of classification is to be scientific, it must pre-suppose a logical classification of formative processes. The scheme in question does not correspond to any such logical grouping of processes; and from the genetic standpoint it is therefore unsatisfactory, even if, for the purpose of classification, some arbitrary definitions of the terms igneous, sedimentary, and metamorphic could be agreed upon that would give this mode of grouping the needed quality of completeness.

Whether, therefore, we approach the consideration of this threefold division of rocks from the standpoint of its incompleteness, or of the feasibility of suitable definitions, or from the standpoint of genetic principles, we arrive at the conclusion that it does not satisfy the requirements of a scientific system of rock classification. What is the alternative?

(d) The grouping of rocks in relation to processes.

Before dealing with the alternative, it is necessary to consider briefly how rock types should be grouped in relation to the processes that have influenced their characters. This consideration is made necessary by the fact that some authors have adopted a method of grouping in which metamorphic types are classified with the rocks from which they have been derived. On this principle, a mica schist should be classified as a shale, and a hornblende schist as a dolerite, where it is known that these rocks have been produced by the metamorphism of shale and dolerite respectively. In Kalkowsky's mode of grouping (see p. 62) this principle was adopted. Again, J. Walther (Compte rendu, Congrès géologique international, for 1897) regards rocks as possessing primary or original characters that were given to them when they were first formed, and secondary characters that have been developed by alteration. This idea is, of course, also involved in the conventional threefold grouping; but, like Lossen and others who preceded him, Walther suggests the abolition of the metamorphic group, and makes it one of his principles of classification that the altered rocks are to be grouped with their original types. He makes four groups of original rocks, as follows: I Mechanical, II Chemical, III Organic, and IV Volcanic rocks. It is perhaps noteworthy that these correspond to Renevier's first four groups (see p. 61).

This view, expressed in such definite terms by Walther, implies (1) that certain types are to be regarded as original, (2) that it is possible to ascertain in any given case what the original type was, and (3) that original types should be grouped in accordance with the processes that have determined their existing characteristics, whereas altered types should be grouped in accordance with processes that determined their characteristics in some pre-existing state. It is difficult to see how any of these propositions can be sustained on either a geological or a genetic or any other scientific basis of classification. At any rate, they seem to be quite at variance with sound genetic principles.

Now it cannot be denied that rocks owe their characteristics to the processes by which they have been formed. It is these processes that have conditioned the mineral composition and texture of rocks as we know them. The operation of these processes is more or less continual, and there is no such thing as permanent stability of type. From the genetic standpoint, therefore, every rock is to be regarded as the product of a series of changes, only the last term or two of which is known to us; and if so, which of the many processes that have influenced the type of the rock is to be regarded as of chief importance in connexion with its classification?

The only acceptable answer to this question seems to be that, in relation to any given rock, those processes are of chief importance that have developed its dominant characteristics, i.e. that have developed those intrinsic characters by a study of which, in relation to its origin, the type of the rock is ascertained. The interminable nature of the cycle of changes, by which the characteristics of rocks are affected, renders quite impracticable the suggestion that altered rocks should be classified according to their original condition. Indeed, all rocks arise from changes in pre-existing masses, and nowhere do we find them in their original condition. Hence the only practicable genetic method is that of grouping a rock according to the nature of the process that has stamped upon it the characteristics that mark it as a type.

(*e*) *An alternative grouping on a genetic-geological basis.*

On the basis laid down in the foregoing generalizations, we are now in a position to decide upon an alternative and more scientific grouping of rocks. The principles that should govern the arrangement are—(1) it must be made in accordance with a geological grouping of processes; (2) the grouping must be determined by the nature of the process that, in any given case, has conferred upon the rock its type characteristics. This brings us to consider how processes can be best classified.

If we look at the earth's crust as a whole, it is almost impossible, from a geological point of view, to avoid a twofold main grouping of processes; for these processes seem to divide naturally into (1) those that originate in internal causes, and operate deep-seatedly in the earth's crust or from within outwards; and (2) those of external origin, operating superficially or from without inwards. This division of processes is practically the same as that involved in the twofold division of rocks made by Kinahan, following a suggestion made by Forbes (see p. 60). The terms 'ingenite' and 'derivate', introduced by Forbes and used by Kinahan, are, however, obviously ill-formed and unsuitable for the two groups of processes referred to above.

It will be noticed that this twofold division of crustal processes is also much the same as that made by Geikie (see p. 60), but it seems inadvisable to apply the terms 'hypogene' and 'epigene' used by him. In the first place, Geikie's use of the term 'hypogene' is not the same as Lyell's, and it might very properly be urged that this term should be defined, as it is defined in Murray's Oxford Dictionary, with the meaning that Lyell intended it to carry. The terms 'epigene' and 'epigenetic' are in a still more serious predicament, since the latter has been, and still is, used antithetically to the term 'syngenetic' by writers on ore deposits, to describe a deposit the age of which is subsequent to that of the rocks in which it occurs. Indeed, its use in this sense with reference to ore deposits is now so extensive and popular that its previous geological usage as defined by Geikie (see also Murray's Dictionary) appears to have been almost lost sight of. Again, as we have already seen, the term 'epigene' has been used in a still different sense by Judd (see p. 57), who uses it antithetically to the term 'hypogene', using the latter term in the Lyellian sense, but using both terms in relation, not to processes, but to place of deposition.

Moreover, two good terms are available for the two groups of processes to which reference has been made, viz. *endogenetic* (originating within) and *exogenetic* (originating without). The terms 'endogene' and 'exogene' have long been used by German and French geologists, chiefly as the equivalents of 'eruptive' and 'sedimentary' respectively. They were used in these senses by some of the earlier geologists, notably by A. von Humboldt in his 'Cosmos' (1844). In the English edition of that work the terms 'endogenous' and 'exogenous' were used; and the use of these terms in this broad geological sense has thus priority over certain more limited usages now in vogue in petrology. As these terms are not required for use as equivalents of 'eruptive' and 'sedimentary', it seems permissible to use them as here required, in the forms *endogenetic* and *exogenetic*, firstly in application to the processes defined above, and secondly in application to the rocks produced by the operation of those processes, irrespective of place of deposition. The form *endogenetic* appears to be new, but *exogenetic* is already in use as here defined (see Murray's Oxford Dictionary).

Endogenetic processes fall into three natural subdivisions, viz. those associated with (1) fusion and the direct crystallization of the fused (igneous) masses, (2) exudations arising from the action of these fused intrusive masses, and (3) thermal and thermo-dynamic alterations unaccompanied by fusion and exudation effects. Some may choose to make an additional subdivision for purely dynamical processes that result in the formation of crush-breccias and other types in which texture is affected by simple crushing and trituration without any alteration in mineral constitution; but to others this will seem unnecessary, and it would appear to do no violence to the principles of genetic classification to group such types with their uncrushed equivalents.

Exogenetic processes are best subdivided, from a geological standpoint, with reference to the phenomena of weathering and denudation, and this mode of subdivision entails a distinction between weathering residues and transported materials. The transported materials are deposited in part mechanically and in part from solution, whilst deposition from solution is effected in part from surface waters and in part from waters descending into the crust. Subaerial plant accumulations and their products form an independent subdivision.

On the basis of the classification of processes thus outlined, we get the following corresponding scheme of rock classification:—

I. ENDOGENETIC ROCKS, formed by processes of internal origin, which processes operate deep-seatedly or from within outwards. High-temperature effects constitute the prevailing characteristic, and the water taking part as an agent is partly of magmatic origin.

1. IGNEOUS ROCKS.
2. IGNEOUS EXUDATION PRODUCTS:
   (*a*) Contact impregnations and metasomatized rocks, including pneumatolysized rocks.
   (*b*) Hydrothermal vein rocks.
   (*c*) Solfataric deposits.
3. THERMO-DYNAMICALLY ALTERED ROCKS, but unfused and unmodified by exudations.

II. EXOGENETIC ROCKS, formed by processes of external origin, which processes operate superficially or from without inwards. These rocks are formed at ordinary or comparatively low temperatures, and the water taking part in their formation is of atmospheric origin.

1. WEATHERING RESIDUES.
2. DETRITAL ROCKS, comprising aeolian, alluvial, and marine sediments, loose or cemented.

3. SOLUTION DEPOSITS, loose or cemented.
   (i) *Surface-solution deposits*:
      (a) Organic deposits.
      (b) Inorganic deposits.
   (ii) *Descending-solution deposits*:
      (a) Certain vein deposits.
      (b) Metasomatized rocks.
4. SUBAERIAL PLANT ACCUMULATIONS and their products.

A grouping of rocks on these lines has the advantage of completeness. It makes possible a complete survey of crustal processes, with a geological classification of which it is in harmony; and it has thus a sound genetic-geological basis. It is, perhaps, not quite so simple as the conventional threefold grouping; but it is more scientific, and it avoids many difficulties that confront us if we wish to retain sedimentary and metamorphic groups. Moreover, the scheme here proposed should not give any difficulty to a student who has taken as seriously as he should the study of formative processes which, in the shape of physical geology, usually precedes that of petrology.

There is, of course, ample scope for discussion as to the best way of subdividing the two main groups. It is impossible within the limits of this paper to consider the many points which such a discussion involves, or to enter into details. Two or three features of note, however, may be referred to.

There are strong genetic reasons at present for recognizing a sub-group of rocks characterized by the presence of exudation products, as distinct from the igneous rocks and their segregation products. These exudation products, in the form of gases, vapours and solutions arising from the action of a magma, produce important effects in the aureole of enclosing rock, and in the porous rocks and fissures through which they find their way towards the surface. Until the problem of the genetic grouping of igneous rocks has been satisfactorily solved, it seems best to make a separate sub-group for rocks characterized by these exudation products. Ultimately, however, it may be found preferable to group them more intimately with the igneous rocks, each distinctive type of magma being grouped together with the exudation products peculiar to it.

Connected with this question is that of the subdivision of the rocks styled 'metamorphic' in the restricted sense. The practice of distinguishing contact-metamorphosed and regionally metamorphosed rocks is one that has been widely adopted, but one for which, in the usually accepted sense of these terms, there is no warrant from a genetic standpoint. Contact metamorphism is in many cases merely a local and small-scale manifestation of the thermal or thermo-dynamical processes to the effects of which, on a wider scale, the name regional metamorphism is given. The only difference is that in the contact case the source of heat is visible in the shape of an intrusive mass, whereas in the regional case the source of heat is less obvious, and the effects more widespread. Of far greater importance is the distinction, not involved in the terms contact and regional as used by petrologists, between masses that have been substantially modified by exudation products and masses that have not been so modified; for except in so far as an invaded rock has borrowed material from the intrusive, there is no material difference between contact-metamorphosed and regionally metamorphosed types.

According to the arrangement here proposed, those contact-metamorphosed rocks characterized by the presence of exudation products form part of a special sub-group, and a third sub-group of endogenetic rocks comprises those in which thermal or thermo-dynamical alterations have taken place without fusion and without any substantial addition of new material.

As regards igneous rocks, it is not the writer's intention to enter into the question of their genetic classification in this paper. Moreover, it is as yet a matter of opinion whether there exists a sufficiently good theory concerning magmatic processes to serve as a substantial basis for the genetic grouping of igneous rocks; and attempts at such a grouping are perhaps undesirable until more conclusive evidence is available concerning the origin of magmas, the relative importance of differentiation and absorption as modifying factors, and the mechanism of intrusion.

Present tendencies, however, are towards the adoption of a genetic system, and it seems pretty certain that no system will prove satisfactory that is not genetic; for it is true of igneous rocks in particular, as it is of rocks in general, that their intrinsic characters have been conditioned by formative processes in such a way as to make these characters, considered alone and apart from their genetic bearings, unavailable as a basis of grouping consistent with geological requirements.

The quantitative basis of classification is clearly at variance with the genetic basis, and igneous rock affinities cannot be stated in terms of oxide percentages or of any conventions based thereon. In the opinion of the present writer nothing could be more decisively erroneous than the view, adopted by the school of quantitative-chemical classifiers, that the chemical composition of igneous rocks, as expressed by the analysis of specimens, is the most fundamental feature concerning them. The chemical composition of a specimen depends entirely on its mineral composition; and the relation between the mineral and the chemical composition is such that although the chemical composition can be inferred from a knowledge of the mineral composition, the converse is not true. That is why, in the quantitative-chemical system, it is impossible to codify analyses in terms of natural mineral composition. The 'norm' of this system is an unnatural expression of a chemical analysis of a rock specimen. It has no meaning apart from that specimen, and it cannot possibly be invested with a genetic significance.

The natural mineral composition of rocks, on the other hand, may be allowed to have a genetic significance, and when its relation to magmatic conditions is properly understood, the correlation of the natural mineral composition of igneous rocks and magmatic processes will be possible. It is these processes that are fundamental, and that, studied in relation to natural mineral composition, mode of occurrence, and texture, should be made the basis of grouping among igneous rocks.

Pending the establishment of such a genetic basis, there appears to be no legitimate alternative to a classification based on mode of occurrence and mineral-textural features, combining these naturalistic data in such a way as to secure the best advantage from the genetic-geological point of view.

3. Economic Mineral Deposits.

(a) *The study of ore genesis inseparable from that of rock genesis.*

Ore deposits are rock masses in which occur one or more metalliferous minerals in sufficient quantity to make them useful as sources of metals. This definition can be extended to deposits of economic minerals generally, i.e. an economic mineral deposit is a rock mass in which occur one or more useful minerals in such quantity that it is practicable to extract them for use in the arts. Any one who faces the facts fairly will find it impossible to escape from this petrological definition of an ore deposit.

In some instances an economic mineral in itself constitutes a rock. Masses and beds of iron ore, chromium ore, manganese ore, corundum, rock salt, apatite, and numerous other instances could be quoted. More commonly, however, the economic mineral is, from a quantitative standpoint, a comparatively insignificant constituent of the rock in which it occurs; but in all cases the deposit as a whole is essentially a rock. Indeed, there are all possible gradations between instances in which economic minerals in themselves form the chief part of a rock mass, and those in which they are disseminated through a large amount of useless rock matrix.

One important end is attained by this way of looking at ore deposits: it shows the fundamental value of petrology in a study of these deposits. If the recognition of this fact has been slow in growth, the petrographers are to blame; for had vein deposits and other types of economic mineral deposits received adequate scientific treatment at their hands, there would doubtless have been a quicker, and by this time a fuller recognition of the almost inseparable connexion that exists between rock genetics and ore genetics, and of the mutual aid that these studies can afford.

It is certainly unscientific to allow an igneous dyke to rank as a rock, and to deny that rank to a vein deposit, especially when we take into consideration the fact that a vein deposit is often of far greater dimensions than a dyke. The recognition of this fact by petrologists has at most been extremely feeble—witness the name *quartz rock* given to vein quartz, of hydrothermal origin, associated with granites; and also the admission of the hydrothermal origin of certain pegmatite veins. Even Weinschenk ('Grundzüge der Gesteinskunde,' 1902), who is comparatively liberal in these matters, tells us, after having dealt with the formation of pegmatites, that 'Die übrigen Neubildungen der postvulkanischen Perioden haben für die Gesteinskunde an sich weniger Interesse, ihre Besprechung gehört vielmehr in die Lagerstättenlehre.' (op. cit., 1. Teil, p. 114.)

Coupled with this point of view, there exists among certain petrographers an objectionable practice of naming as independent types every new combination of silicate minerals among igneous rocks, without any reference whatever to the scale of magnitude displayed by the occurrence. This practice is in itself perhaps not absurd, but it is made to appear so by the fact that, associated with the practice, there is a lack of any sense of proportion in rock studies. It is hardly likely that such an unscientific attitude of mind will prove permanent, and one may safely predict that petrography is destined to broaden its sympathies and rationalize its outlook.

Ore deposition is, indeed, even from the petrological standpoint, an important and not merely a trifling incident in the process of change that is continually affecting the rocks of the unstable earth's crust; and whether it has taken place *pari passu* with the formation of the more ordinary rock in which the ore deposit occurs, or subsequently, it is one of several causally related incidents that need to be considered together.

The origin of ore deposits is thus inseparably bound up with the origin of rocks. It almost follows as a matter of course that the best genetic grouping of ore deposits should correspond closely with that of rocks: and if, for reasons already stated, it is desirable to have a genetic-geological arrangement for rocks, it is for the same reasons also desirable to have a genetic-geological grouping of ore deposits.

(*b*) *Historical Review.*

We have seen that, from the beginning of modern geology, the broad grouping of rocks has been made on a genetic basis; and in spite of much opposition from those who have held the view that petrography and rock classification should be independent of geology, the genetic method of classification has gradually strengthened its position.

With ore deposits, the origins of which it has been, and still is, less easy to establish, the genetic mode of grouping has on the whole been less successful; and grouping according to morphological data has been more widely adopted. Here again, as in the case of rocks, those who have fostered the morphological point of view have done so on the plea that classification should be free from the influence of theories of origin.

Werner was deeply interested in both rock genesis and ore genesis, and the influence of his petrological ideas on his views concerning ore deposits is very obvious ('Neue Theorie von der Entstehung der Gänge,' 1791). Even in Werner's time, the terms 'Lager' and 'Gänge' had been long associated with German mining tradition; and consistently with his way of classifying rocks on the basis of relative age, Werner made a sharp distinction between ore deposits corresponding to 'Lager' which had originated contemporaneously with the enclosing rock, and those corresponding to 'Gänge', which had been formed later. 'Die Gänge müssen von einzelnen Schichten des Gesteins, von mehr und weniger mächtigen Lagern des Gebirges, von Flözzen, Fällen und Stökken,—die insgesamt mit der Gebirgsart, in der sie sich befinden, und zu der sie gehören, einerlei Lage haben,—wohl unterschieden werden.' (op. cit., p. 4). This point is perhaps worth emphasizing, because the distinction of ore deposits according to their contemporaneous or subsequent formation in relation to the enclosing rocks has dominated German views on the grouping of ore deposits down to the present day, and is still regarded by some as the most fundamental distinction that it is possible to make. It has indeed been declared by nearly all writers to be a genetic distinction. In fact, however, it is based on relative age of deposit and enclosing rock, and though it is non-morphological, and may perhaps be allowed to have had a genetic significance for the Wernerians, it can scarcely be allowed to have a definite genetic meaning to those who accept the Huttonian view that igneous rocks are of intrusive origin, and who believe that magmatic exudations are important agents in vein formation.

During the first half of the nineteenth century, the reaction against theoretical conceptions in the classification of ore deposits was even more pronounced than it was in the case of rocks. Von Cotta, who had been converted to the genetic view of grouping for rocks, resisted this view in the case of ore deposits, and adopted a morphological basis of grouping. He says: 'Ich theile aber alle Erzlagerstätten ihrer Form nach zunächst in regelmässige und unregelmässige. Die ersteren zerfallen wieder in Lager und Gänge, die letzteren in Stöcke und Impregnationen.' ('Die Lehre von den Erzlagerstätten,' 1859, part i, p. 2). His mode of grouping as (1) *Regular deposits* and (2) *Irregular deposits* is one that has had a considerable vogue. Another non-genetic mode of grouping of ore deposits that has been widely used is that adopted by J. D. Whitney ('Metallic wealth of the United States,' 1854), viz. (1) Superficial, (2) Stratified, and (3) Unstratified deposits. (See also 'A treatise on ore deposits,' by J. A. Phillips, 1884.) This arrangement is borrowed from geology, for it had been used much earlier by De la Beche and others in the classification of rocks.

Although these non-genetic schemes have enjoyed much favour, they have not altogether monopolized the field; and at the present time they have been largely ousted among serious students of ore deposits by genetic methods of grouping. The morphological basis of grouping was abandoned by von Groddeck (see 'Lehre von den Lagerstätten der Erze,' 1879; and Berg- u. Hütt. Zeit., 1885, p. 217). Von Groddeck's scheme is very interesting; in it he wedded the Wernerian conception of relative age for ore deposits to the Huttonian conception of rock grouping, thus: I, Deposits formed contemporaneously with the rocks in which they occur; (*a*) sedimentary, (*b*) eruptive. II, Deposits formed later than the rocks in which they occur; (*a*) those filling pre-existing spaces in rocks, (*b*) metamorphic deposits.

Divested of its main groups, this scheme of von Groddeck differs only from the threefold division into igneous, sedimentary, and metamorphic, which had already been adopted for rocks, by having an additional group for vein deposits, &c.[1]

[1] According to Pošepný, von Groddeck entertained the idea of a composite

Pošepný followed von Groddeck in the view that 'the principal genetic distinction is doubtless between deposits contemporaneous with the country rock and those subsequently formed in it' ('The Genesis of Ore Deposits,' Trans. Amer. Inst. Min. Eng., 1894 (for 1893), vol. xxiii, p. 205). Again, he states that 'we have two main groups of mineral aggregates: that of the rocks, and that which we will call comprehensively *the mineral deposits.* The minerals of the first group belong to it as native and original; those of the second are foreigners to the rock in which they occur. The two groups may therefore be designated as Idiogenous and Xenogenous respectively' (op. cit., p. 205). Later in the paper, however, he remarks: 'We distinguish, then, *Idiogenites*, or deposits contemporaneous in origin with the rock, from *Xenogenites*, the deposits of later origin, including not merely those of ores but mineral deposits in general; and to these we may add, in harmony with some older systems, the deposits of débris as a third class, *Hysterogenites* or latest formations' (op. cit., p. 211). Still later in his paper, when he comes to describe the different kinds of deposits, he groups them under four heads as follows: 1, Ore deposits in spaces of decission. 2, Ore deposits in soluble rocks. 3, Metamorphous deposits. 4, Hysteromorphous deposits.

It seems evident enough from these statements by Pošepný that his ideas on genetic classification were rather indefinite. His views are strongly reminiscent of von Groddeck's, but his scheme is less geological and decidedly less scientific. It does not correspond to any rational or definite grouping of processes, and it is not the strictly genetic system that it has been claimed to be.

Stelzner (see 'Die Erzlagerstätten,' by A. W. Stelzner and A. Bergeat, 1904) adopted a main grouping into primary and secondary deposits, a mode of grouping that was favoured by von Groddeck at first, but afterwards rejected by him. Stelzner also grouped the primary deposits into those formed contemporaneously with, and those formed subsequently to, the rocks in which they occur; and to these groups he applied the names 'syngenetic' and 'epigenetic' respectively. He was followed by R. Beck ('Lehre von den Erzlagerstätten,' 1901; see also 'The nature of ore deposits,' by R. Beck and W. H. Weed, 1905), and this mode of division, expressed in these terms, is now very widely adopted. Thus

classification in which 'he hoped to represent one standpoint by abscissae and the other by ordinates, so that the intersection would determine the type of deposit' (op. cit., infra, p. 201). This idea has been applied by F. H. Hatch in a semi-genetic scheme recently proposed by him (Presid. Address, Inst. Mining and Metall., London, March 1914).

Lindgren writes: 'Two genetic terms have, however, found general acceptance after their recent introduction by Stelzner and Beck. These terms are *syngenetic* and *epigenetic*' (Econ. Geol., 1907, vol. ii, p. 750).

This application of the terms 'syngenetic' and 'epigenetic' by Stelzner, Beck, and others, is a rather unfortunate one. The term 'epigenetic' had been already used in several different ways in geology, and it has now such a variety of meanings from a petrological standpoint that it seems inadvisable to use it unless some restriction of its meaning can be agreed upon. The term 'syngenetic' had also been used petrologically and in a different sense by von Gümbel before it appeared in connexion with the literature of ore deposits ('Geologie von Bayern; I. Grundzüge der Geologie,' by K. W. von Gümbel, 1884, p. 370).

A much more serious objection to the use of these terms in these senses is the fact that their significance is not truly genetic. Indeed, the use of the terms 'syngenetic' and 'epigenetic', as applied to the broad grouping of ore deposits by Stelzner and others, is a good example of the misuse of the term genetic. For instance, Beck and Weed, in adopting this mode of grouping, remark of their scheme that 'it entirely abandons form as a factor of importance, and is thus purely genetic' (op. cit., p. 3). Similar remarks, implying that the data of classification are necessarily either simply morphological or simply genetic, have been made by other authors.

We have seen, however, that *form* is not the only non-genetic factor that is made use of in classification. Contemporaneity or lack of contemporaneity in age of deposition between ore deposits and the rocks in which they occur, does not constitute genetic data. This factor, as already explained, has to do with relative age of deposit and enclosing rock, and is independent of the mode of origin or formative processes involved; for whether we consider the 'syngenetic' or the 'epigenetic' group, we find that each is necessarily made to include deposits arising from widely diverse processes. Thus ore deposits resulting from igneous activity may be either 'syngenetic' or 'epigenetic'; the 'syngenetic' group includes both igneous segregations and sedimentary deposits; and vein deposits are 'epigenetic' whatever may have been the origin of the solutions from which they have been deposited. One therefore demurs at the statement made very recently by W. Lindgren, that 'A convenient and fundamental classification divides mineral deposits into *syngenetic*, or those formed by processes similar to those which have formed the enclosing rock, and in general simultaneously with it, and *epigenetic*, or those introduced into a pre-existing rock' ('Mineral

Deposits', 1913, p. 140). Convenient it may be; whether it is fundamental or otherwise depends on the view one takes as to the proper basis of classification; but it is certainly not genetic; and it is quite time that the view involved in this mode of grouping, which has played such a conspicuous part in German schemes of classification, should be definitely recognized as Wernerian in origin, and should no longer be regarded as genetic.

Another scheme which has been described as genetic is that proposed by H. S. Munroe (see 'The Ore Deposits of the United States and Canada', by J. F. Kemp, 1900). Munroe divides deposits into those (1) *of surface origin, beds,* (*a*) mechanical, (*b*) chemical, (*c*) organic, (*d*) complex; and (2) *of subterranean origin,* (*a*) filling fissures and cavities formed mechanically, (*b*) filling interstitial places and replacing walls. His main divisions are thus essentially identical with the stratified and unstratified divisions of some other authors, and his scheme can scarcely be regarded as genetic, except in a very imperfect way.

Of the really genetic schemes of grouping, the more scientific are those proposed by Kemp, Weed, Van Hise, and Lindgren. Kemp (op. cit.) makes a threefold main division, viz.: I, Of igneous origin; II, Deposited from solution; and III, Deposited from suspension. He divides his solution deposits into (1) surface precipitations, and (2) disseminations in beds or sheets, the former having five and the latter eleven subdivisions.

W. Lindgren (see 'Mineral Deposits', 1913, p. 188) goes a step further than Kemp, and eliminates the geological factor altogether in making his main divisions, treating igneous bodies as solution deposits. His chief groups are as follows: I, Deposits produced by mechanical processes of concentration (temperature and pressure moderate); II, Deposits produced by chemical processes of concentration (temperature and pressure vary between wide limits)—(*a*) in bodies of surface water, (*b*) in bodies of rocks, (*c*) in magmas, by processes of differentiation.

W. H. Weed (Engineering and Mining Journal, 1903, vol. lxxv, p. 256) adopts five divisions, as follows: (1) Igneous, (2) Pneumatolytic, (3) Fumarolic, (4) Gas-aqueous deposits, (5) Meteoric waters, and these he subdivides elaborately.

These schemes proposed by Kemp, Weed, and Lindgren all fail to attach sufficient importance to the geological basis of grouping, though in this respect perhaps Weed's scheme errs least. None of them succeeds in securing, what it appears necessary to secure for ore deposits, a scheme of classification that will harmonize with the scheme adopted for rocks. Petrological considerations would appear to furnish a safe control in these matters, and a genetic scheme for economic mineral deposits should, in its main features, hold for rocks generally. If we apply this test, the schemes of Kemp, Weed, and Lindgren are seen to be unsatisfactory.

More satisfying from the petrological point of view was the suggestion made by Van Hise (op. cit.), to group ore deposits simply as igneous, sedimentary, and metamorphic. If one takes the view emphasized in this paper, that ore deposits, and economic mineral deposits generally, are rocks, and that the study of these deposits has an essentially petrological basis, it seems inevitable that one should adopt a geological rather than a physico-chemical setting for the genetic data of classification in grouping ore deposits. The only question to be settled is, whether the threefold division, with a recognition of sedimentary and metamorphic groups, meets the requirements of the case.

(c) *An alternative grouping on a genetic-geological basis.*

The arguments already advanced against the recognition of sedimentary and metamorphic rocks as separate genetic groups, apply with added force in the case of ore deposits; and it is doubtless this fact that has prevented many from grouping these deposits in the same way as they group rocks.

Deposits arising from solutions of surface origin, as products of metasomatism due to descending solutions, and as precipitations in streams, lakes, and seas, have a much closer genetic affinity with one another than they have with detrital deposits. Further, from the standpoint of ore genesis it is difficult to avoid using the term metamorphism in a wide sense; but for genetic reasons products arising from the metamorphic action of solutions of surface origin cannot logically be grouped together with metamorphic products arising from the action of igneous intrusions. Again, the division into igneous, sedimentary, and metamorphic groups fails in the case of ore deposits, as it does with rocks, to make suitable provision for all types, and makes necessary the clumsy expedient of a miscellaneous group in which are placed such types of deposits as cannot conveniently be treated in any other way.

In brief, a threefold division of ore deposits into igneous, sedimentary, and metamorphic does not correspond to any logical grouping of formative processes, and both from the geological and genetic point of view it is unsatisfactory. The only geological way out of the difficulty appears to be that of adopting a twofold grouping into *endogenetic* and *exogenetic* deposits, on the lines already outlined for rocks as a whole. The subdivisions of these two groups in the case of ore deposits, or economic mineral deposits generally, will necessarily follow pretty closely that already given for rocks, as for example in the following table:—

I. ENDOGENETIC DEPOSITS:
- 1. IGNEOUS SEGREGATIONS.
- 2. IGNEOUS EXUDATIONS:
  - (*a*) Contact impregnations and metasomatic effects, including pneumatolytic deposits.
  - (*b*) Hydrothermal vein deposits.
  - (*c*) Solfataric deposits.
- 3. DEPOSITS IN THERMO-DYNAMICALLY ALTERED ROCKS (UNFUSED AND UNIMPREGNATED).

II. EXOGENETIC DEPOSITS:
- 1. WEATHERING RESIDUES.
- 2. DETRITAL DEPOSITS (including placer deposits).
- 3. SOLUTION DEPOSITS:
  - (i) *Surface solutions:*
    - (*a*) Organic deposits.
    - (*b*) Inorganic deposits.
  - (ii) *Descending solutions:*
    - (*a*) Certain vein deposits and other cavity infillings.
    - (*b*) Metasomatic and secondary enrichment deposits.
- 4. SUBAERIAL PLANT ACCUMULATIONS AND THEIR PRODUCTS.

4. SUMMARY.

In this paper economic mineral deposits are regarded as rocks, a view which makes unavoidable the inference that ore genesis is a part of petrology, and that any scientific system of genetic classification that applies to rocks should apply also to economic mineral deposits.

A consideration of fundamental principles shows that petrography has its scientific basis in dynamical geology, and that any genetic scheme of classification for rocks should also be a geological scheme. An appeal to historical considerations likewise shows that the requirements of science, as regards the classification of rocks, seem to lie in the direction of a scheme based on what may be called genetic-geological principles.

A scientific classification in accordance with these principles presupposes the possibility of a geological classification of formative agents

and processes. These processes fall into certain natural groups and sub-groups according to the way in which they operate on and modify the rocks of the earth's crust. Having decided on a definite geological grouping of formative processes in this way, the grouping of rocks with reference to the processes that have determined their type characteristics becomes possible, the rock-groups corresponding to process-groups.

The genetic classification of rocks and economic mineral deposits is thus essentially a classification of formative processes, and a correlation of these processes with the rock types the intrinsic characteristics of which they have developed. The use of intrinsic data and other non-genetic data in petrography finds its place in the definitions of rock types, but these definitions should be controlled by genetic and geological considerations.

Petrologists have for the sake of convenience, but with lack of wisdom, refused to regard most economic mineral deposits as rocks. This attitude on their part made possible, at a comparatively early date, an approximation to a sound genetic-geological scheme of grouping for rocks. The adoption of such a scheme for ore deposits was prevented by uncertainty as to the origin of subterranean solution deposits which fill an important place in ore genetics.

It has been known for a long time among petrologists that certain metalliferous vein deposits are genetically connected with igneous intrusions. The studies of recent years in ore genesis have largely extended the significance of solutions of deep-seated origin in connexion with ore deposition. There are, nevertheless, certain vein types which are known to arise from solutions of surface origin; and although the criteria for determining the origin of vein deposits are not fully established for all types, it seems permissible to adopt a genetic scheme in which processes are grouped geodynamically in two broad groups according to their internal or external origin in relation to the earth's crust. Such a scheme of division into *endogenetic* and *exogenetic* processes is adopted in this paper, and the subdivision is made in accordance with the geological action of the processes concerned.

The corresponding scheme for rocks may claim to be scientific. It is based on a well-defined genetic method. It comprehends all rock-forming processes, and finds a place for all types of rocks. The fact that uncertainty exists as to the nature of certain processes and the origin of certain types should be no bar to the adoption of such a scheme up to the limits of known facts and well-established theories, since it is one that will adapt itself to the progress of petrology.