THE NEW PETROLOGY

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I suppose that one is not far wrong in saying that Petrology is the science of rocks. But we have not made ourselves very clear by saying it. To the average student of the subject who must judge from what he is taught, and from what he can find in texts, petrology looks like a very complicated lot of methods of discrimination, coupled with still more complicated schemes of classification, by means of which one sometimes succeeds in finding a sufficiently mystifying name for a very innocent looking fragment of rock, to satisfy a perfectly natural craving for worthwhileness.

But this is not petrology—the real petrology that ought to be—no matter how elaborate it is, or however minutely every little detail may be described. It is one kind of rock study,—one form of petrology. The description of rocks is a form that no doubt has served a very good purpose in collecting and recording and classifying data; but there are other things to be done.

After the first steps in a new scientific field are taken, it is not sufficient to present simply long lists of names and descriptions and descriptive terms and tabulations of facts and classification schemes. Such data alone do not satisfy the legitimate demands for an explanation of some kind. Such natural grouping of rocks as has been attempted, is a first step toward meeting this demand, but it has not gone far enough in petrology.

THE FIELD

It is easy to assume or to adopt too simple a conception of the term, *rock*. It is clearly in the interest of beginners for them to think of a rock as a mineral aggregate, representative of a structural unit of considerable magnitude, and as a very definite and constant and reliable thing. But this is no great advantage to the investigator; and to insist on its magnitude and constancy may be very misleading indeed.

Petrology by rights includes the whole range of natural products of definite mineral make-up, all kinds of mineral aggregates, all kinds of origin, and all sorts of conditions.

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In actual investigation, it is a mistake to be content with the types of material representing only the more apparent large physical units. Some insignificant-looking portion, usually too unimportant-looking to be regarded as a rock-type at all, may carry more readable meaning than all the rest of the surrounding material. An ore, or a vein-matter, or a contact product, are as suitable material for the petrographer as are the igneous rocks or the sediments.

For this kind of petrology the term rock requires a revised definition.

A rock is a natural mineral aggregate of sufficiently definite composition and character to be representative of some structural unit, or of some process or condition, to justify separate consideration in arriving at a working understanding of the life-history and meaning of the physical unit to which it belongs.

How large these units may be, or how small, depends on the detail of the study, and the significance of the material in contributing to the solution of the problem involved.

Any petrographer, who has tried to make practical use of his petrology and of his own skill in any more systematic or connected way than that of simply naming or classifying separate fragments of rock, knows that it is very easy indeed to over-state the requirements of constancy of mineral makeup. Two pieces taken from the same physical unit in close proximity, often vary enough to require classification as quite different rocks. In many comparatively simple igneous bodies, this variation is in many cases still greater, and a whole series of different types could be recorded. If one is content with classification—such classification as we now have—such conditions may easily lead to confusion. There is no indication, in the terms usually used, of the fact that these varieties are all one geological unit of a very simple history and meaning. Emphasis on these classification-differences, therefore, may be very misleading. Many difficulties have arisen where the geologist or the engineer tried to find in the field as many structural units, as the petrographer, who described the rocks, called for.

The fault has been, in the past at least, that the petrographer dealt largely with mechanical distinctions, whereas the field man had to deal with genetic relations. The time has come now, surely, when a real petrographer must also be a field geologist, or he must at least appreciate the point of view of a field investigator.

THE OBJECT.

In the past our best petrographers have lent the weight of their influence and the fruits of their labors to the field of tabulated detail, and to niceties of discrimination, and to schemes of classification, as if the chief aim were to divide and subdivide, and to discover still more intricate or arbitrary bases of further subdivision. Description has been recognized as a more or less necessary accompaniment, but this usually covered chiefly the features useful in the scheme of classification. Otherwise it became a more or less rambling account of every thing that could be seen.

Thus to be able to describe and classify rocks, marked one as an accomplished petrographer; and to have discovered a slightly different or new mineral proportion, or a slightly different chemical proportion from anything previously described, and to be thoughtful enough to give it a new name, marked one as an active contributor to the science.

In the effort to reach the last word in this direction of intimate discrimination, some of the foremost petrographers of our own day have gone so far as to wholly destroy the actual rock by a complete chemical analysis, before even beginning the task of classification. Sometimes, by this method, mineral constituents were listed in the recast of this analysis, and taken into serious account, that never occurred at all in the live rock itself, whereas the much more suggestive constituents and structures that it did have, were largely disregarded.

The most serious offender in this respect is the so-called quantitative system of rock classification, originated by four eminent American petrographers. In saying these things, there is no wish to be understood as attempting to belittle any of this pioneer work. Much of it, doubtless, had to be done, to lay the foundation of critical inspection, discrimination, and comparison. The quantitative principle was a good one to emphasize. The principle itself has come to stay; but a classification as mechanical as the quantitative system, can be at best only a side-issue in the real petrology that is already coming.

Much as we must value the contributions that have been made by the systematic petrographers and the chemical petrographers, through their nice points of discrimination, and the increased appreciation of sound chemistry, and their rigid requirements of quantitative thinking, I am quite convinced that the apparent object in view is not a sufficiently high goal for the present stage of development of geologic science. This is not the chief or the most promising aim of rock study.

To classify and describe rocks on any system now in use is at best only a first step toward a more rational petrology, just as learning to distinguish and recognize words is a first step toward reading. There is, to my best belief, no such thing as a rational science of petrology wholly apart from the great science of Geology. Whatever of significance attaches to a rock, is largely gathered to it from the processes and agents and forces and conditions of its own geologic setting and history. Practically all of petrology's own contributions, if their meanings can be read, return to geology again to enrich the knowledge of that great field—the field of geologic history.

In so far as a nice discrimination and a true sense of proportion serve in detecting evidence of former conditions, or processes, or changes, or sources, they play directly toward the new aim. It is of course appreciated, that methods of discrimination and classification may have immense disciplinary and training value in education, quite apart from the chief aim of a science itself, but then it should be frankly recognized as an educational objective. For the science itself, discrimination for discrimination's sake alone, is not enough.

Meaning and History are higher aims. Interpretation is the objective of the new school in petrology, just as it is in the general science of geology.

The reading of the life-history of a rock is a much higher accomplishment than the ability to classify or describe it. It is the main objective of the New Petrology.

The steps in the determination of the origin and successive modifications of an ore, are as proper a petrographic study, as is the life-history of an igneous rock or a sediment.

Whether or not a rock has been much modified since its original deposition, whether or not some of its present make-up has been added to it since that time, or, whether or not it records some peculiar reversal in the course of development along which it first started, may be of immensely more importance than its name or its mineral proportions, or any amount of minute description, or even a complete chemical analysis with all sorts of formal recasts of its elements.

Practical work, covering many years, and touching a very wide range of materials and problems, has convinced the writer that the new aim is practicable, and that the greatest usefulness of petrology is in some way involved in unraveling the origin and life-history of rocks. The principal field of this kind of petrology lies in the reading of obscure history. Its chief claim to distinction lies in the antiquity of its materials, and the minuteness of its discriminations, and the refinement of the methods, out of which, and by means of which, these histories are read.

Any methods and any criteria and any nomenclatures that serve these ends, are the legitimate equipment and instruments and media of the petrologist. But he himself is first of all a geologist, helping in his own way to unravel the history of the earth, or else he is not in this class.

The petrology of the past has been developed and advanced in considerable part by men who were first of all mineralogists; and it is not at all surprising, therefore, that something of the point of view of the mineralogist should have dominated in this intermediate field. Under this leadership the mineralogy of rocks, comparison of rocks by means of mineral differences, and classifications emphasizing mineral proportions, were perfectly natural growths. Thus geologic principles at first did not make much of an appeal. Other interests of petrology have been brought forward more recently and almost wholly by geologists—applied and economic geologists—rather than by professional petrographers. This has been forced by an attempt to use the methods of petrography as geologic aids. These attempts are not new, but to regard them as belonging to the true field of petrology is new, and no systematic presentation of this kind of petrology has ever been made.

METHODS AND CRITERIA.

Every refinement of method that can promise any new insight into the obscure features of rocks must be resorted to, for rock-interpretation requires all the skill of discrimination that can be brought to bear. The difference, however, between the new and the older use of them lies in the purpose. The new effort is not only to detect differences, but to see meaning in them in terms of life history, or in terms of any other claim that a given special problem may present.

Much attention is given to structure,—quite as much as to composition. Structural features are much more likely to have genetic and historical significance than are mineral proportion or composition.

As an equipment one must have a sound appreciation of the working of geologic processes, the complex interplay of chemical changes under varying physical conditions, and the influence of the forces and agents that make and modify rocks. One must assemble the supposed criteria and learn how to use them. One must discover, or learn how to apply, new criteria—the criteria that aid in interpretation.

How shall I determine that a rock is igneous in origin, if I do not know that already from some other circumstance or relation? It is not an easy thing to do—yet most petrographic work starts with that as an assumption.

How shall I determine that the minerals that I now see in the make-up of the rock, have been, in part at least, introduced long since the rock was first made? It is not an easy thing to do, but it may well be the most important thing about the whole history.

How shall I determine that the ore values that I can see in a porphyry copper ore, are primary or secondary? And, if they are mixed, as they well may be, what are the evidences of their distribution?

How shall I determine that a specimen of rock has come from a formation that has been deformed and recrystallized and invaded by igneous material, and subsequently mineralized and secondarily enriched, until it is a workable ore? This is much more important than its name.

How shall I determine that the former constituents have been replaced, that the composition which the rock now has, is wholly new; and if I can determine that, how shall I ever find out what the original was?

In an historical direction, and for practical and applied purposes, these are some of the things that one must find ways of doing. These and many other questions one will sometimes solve. These and many others one will many times fail to solve. Sometimes, no doubt, the fault or cause of failure is lack of sufficient critical training in observation; sometimes it is an incomplete command of the principles of geologic processes; sometimes it is little facility in geologic reasoning or too great facility in loose reasoning; and sometimes it is a lack of properly standardized criteria.

Perhaps therefore a word about these needs would not be out of place. The last of these reasons,—the lack of properly standardized criteria—is a strictly petrographic question, while the others are in large part individual and personal.

DIFFICULTIES AND NEEDS.

I suppose that every rock has impressed on it, and to some degree preserves, traces of its origin and of every subsequent stage in its history. The difficulty is in reading these traces and interpreting them. Doubtless many of them are too obscure to be detected by any method that we know how to use. Doubtless, also, the effects of the later happenings tend to obliterate or obscure those that existed before. It may even be, that beyond a certain period, every thing is lost because of the very violence or completeness of the revolution. Such is the case where a rock suffers igneous fusion; or, again, where there is complete reconstruction,—as in some forms of metamorphism.

These difficulties, and the severe limitations set by the nature of the forces and changes that one has to deal with, however, do not furnish sufficient excuse for avoiding the problem. The same kind of limitations surround all branches of geologic research. The inherent difficulties do not remove the problem, they simply emphasize the peculiar nature of the problems of the science.

The great needs are *standardized criteria*. One must now assemble his own; and a little experience in assembling them, will soon show how very scattering are the observations and comments, that serve as reliable source records, and how much of a task it really is, to organize a working scheme along any line of petrographic interpretation.

For example one needs *criteria of origin*, and for *source* of original material, and for the *order* of appearance of the different constitutuents, for *deformation* and *recrystallization*, for introduced *mineralization*, for *hydrothermal influences*, for *pneumatolitic action*, for *deep-seated alteration* as contrasted with *weathering* or supergene changes, for *deuteric effects*, or end product changes as contrasted with entirely independent subsequent modifications, for *secondary enrichment*, for *primary* as contrasted with *secondary* constituents, for *high-pressure-temperature* as contrasted with *low-pressure-temperature* conditions, for *silication*, for *carbonation*, for *replacement* or *metasomatism*, for *metamorphism*, or any other geologic process in its effects on rocks, or for any *quality* or *condition* that might make them more readable and better understood.

For a good many years the writer and his students and associates have been slowly assembling and trying out such criteria, and have been attempting to interpret rocks. Even the imperfect standards that have been used show beyond doubt that the results are serviceable. But there is a long way to go, to perfect a working scheme of criteria.

ITS SERVICE.

This kind of petrology has already earned a place for itself in studies of ore deposits. It is more readily appreciated in that field, than in most others, that origin and subsequent changes and present exact condition of the material are vital matters. On an understanding of these factors, dependent as they are on perfectly normal geologic processes, depends also the extent and quality and distribution of the ore, as well as its changes in quality or value in depth or distance. No other methods than those of the new petrology have ever been successful in determining any of these fundamental factors.

In that branch of the science of geology, where great financial interests are often dependent on correct interpretation of conditions and origin, it is comparatively easy to show the practical value of methods that serve these ends. But as a matter of fact, wherever a better understanding of the life-history and the causes of the present condition of rock material is needed, there the new petrology—the interpretative method of rock study—is of real service.

That kind of service is as broad as are the wants of geologic history. It is probable, indeed, that by petrographic methods designed to this end, one could pry much further into the obscure secrets of many phases of geologic history than by any other means. It will do for structural history what paleontology does for stratigraphic history and what physiography does for the surficial history of the earth.

It would be easy to illustrate some of these forms of service by a variety of practical problems in which such methods have been used. Two or three certainly will suffice.

1. It appears that a good zinc ore was being worked, and questions arose about its extent and probable distribution as a basis for future development. The field indications, thus far, had not been clear, and there were several alternative possibilities. The ore was a mixture, and occurred in limestone. It might be (a) essentially primary, or (b) simply an altered primary constituent in place, or it might (c) be introduced, or (d) altered introduced material. In the latter case the distribution of the original introduced mineral, and its origin, would be an important link in the history. It was a strictly practical interpretation problem. One needed only a working knowledge of the criteria of sedimentary and organic rock origin, of metallic mineralization, of replacement, and of mineral alteration. It could be shown then that the ore in question was nearly all secondary; that it had been transformed by supergene (weathering) agencies from a sulphide lead-zinc-bearing ore which was the original; that this original ore had been itself introduced into the limestone subsequent to its own formation and deformation; and that the principal present ore values did not occupy the place of the original sulphide minerals, but, instead, had themselves replaced portions of the limestone, and that there was some selective distribution. The ore was strictly a superficial or near-surface deposit and had no chance of continuing in depth below the oxidized zone.

2. An old silver mine in Mexico, said to have been abandoned after reaching a certain level, not because of any fault with the ore, had been examined by competent mining engineers and sampled. Because, however, of difficult conditions at that time in Mexico, all of their shipped samples had been lost or destroyed, only a handfull of small chips remaining which one of the engineers had with some forethought carried out in his pocket.

The question they wished answered was a very direct one, i.e., has the mine been worked out? Or is there real evidence to show that the ore still continues at the bottom much like that at higher levels, so that additional work might hope to find workable values at still greater depth?

It is a perfectly good petrographic problem. The conditions are unusual and discouraging; but it can be solved by those methods or else it cannot be solved at all. One must have a working knowledge of the origin of ores of that kind, and of the principles of alteration and secondary enrichment, with their influence on distribution. One must be told about the relative distribution of these samples taken from the old mine and something of the structural facts. Then if one can read the criteria and interpret the data, he can venture an opinion based on real facts even in such an extreme case as this.

3. Several years ago the auther published a short description of the "Bluestone" of New York, making the study chiefly one of composition and micro-structural conditions. It was not by any means well done in one respect at least, and that was its interpretation. It was noticed that most of the original grains are now made up of aggregates, but it was then thought that these aggregates were secondary, resulting from the alteration of original, simple mineral grains. This interpretation is certainly wrong. These grains were originally aggregates, and are not at all due to subsequent alteration. It is certain also that some of these grains, perhaps nearly all of them, were disintegration products from older formations, which were themselves fine-grained aggregates in make-up, such as the slates or argillites.

Such an interpretation is supported also by the fact that older formations were certainly available to furnish the supply. The bluestone is of Devonian age, and beneath strata of that age, and beneath an unconformity, lies the so-called Hudson River Series, which is made up wholly of slates and graywackes and closely related varieties of sediments.

As far as the bluestone itself is concerned, the story could end here; but the similarity of the graywackes of Hudson River age, to the bluestone of much later origin, challenges an examination of it by the same methods. When this is done, it is discovered that the older graywacke of the Hudson River Series is also made up of original aggregate grains. In other words, it is made up, in like manner, chiefly of complex aggregate grains most of which must have been derived from a still older, fine-grained rock series, not very unlike itself.

But when one looks below the next unconformity for a corresponding rock series, a real difficulty is encountered. Apparently the next underlying series consists of the ancient crystalline gneisses and schists of the Highlands of the Lower Hudson, and no rocks similar to the grains in the graywacke occur at all.

On the south side of the Highlands, however, there is a crystalline series of disputed age, which was originally, before its extensive metamorphism, and is still in those parts which are not so completely metamorphosed, very like the required quality of material. If, therefore, this crystalline series, the so-called Manhattan schist-Inwood limestone-Lowerre quartzite series, is really older than the Hudson River slate-Wappinger limestone-Poughquag quartzite series, it could furnish the required material. Nothing else is known that could.

In so far, therefore, as this line of reasoning goes, it supports the contention that these two series of rocks are really of very different ages, and not one the metamorphosed representative of the other, as has sometimes been thought. Thus interpretative petrography may throw real light on a problem which is quite outside of the usual field covered by petrographic description.

4. It is usually considered comparatively easy to distinguish between a quartzite and a limestone, yet even this may become a very difficult thing to do. The writer has had occasion to work with material of this kind in which a microscopic determination of the relative amounts of silica would not suffice. The only method left, was that of petrographic interpretation, on the basis of origin and subsequent modification, including contact metamorphism, replacement, silication, silicification, carbonation and metallic mineralization Without discovering criteria by which rock-material of this history, i.e., original limestones, sandy limestones, and sandstones, could be distinguished one from the other, the determinations could not be done at all. With extreme caution such criteria can usually be discovered and used, as was done in this case. Even in samples, where a rock, that was originally a limestone, now carries as much free quartz as is usual in a quartzite, it was generally possible to distinguish the original limestone representative from the quartzite; and, incidentally, help to solve important, practical stratigraphic and economic problems.

ITS DISCOVERIES.

The chief discoveries of the new petrology are:

1st, that it is both practicable and very practical.

2nd, that it is very much more interesting and attractive as an instruction subject than is the old form.

3rd, That it yields beautifully to the application and teaching of research methods under simple and controllable circumstances.

4th, that petrographic nomenclature is sadly deficient in descriptive terms and names for this particular kind of rock description.

The first three items require no additional comment, but perhaps the last one does. It is the chief direction, in addition to the establishing of reliable criteria, for important contributions.

In the new view *genesis and history*, or *origin and subsequent changes* are fundamental factors. In some way they must be kept in the foreground, both in description and in classification. Other features need not be neglected but are, for this purpose at least, of secondary rank. The larger groupings must be on these more important factors where the greater significance lies.

When one tries to apply these revised ideas to his own work, it is discovered, in the course of time, that there are very many rock types and rock conditions and process effects, for which there are no corresponding petrographic terms at all.

Petrology is a branch of science which is thought by many to have too great an abundance of names and terms now, and with this criticism we may all agree in principle. Many of the terms are too mechanical in their conception and too unproductive in their significance. Yet this can scarcely be counted against new ones if they can demonstrate their usefulness.

My only purpose is to point out a few discoveries of this kind, and to venture the opinion, that within a very few years, suitable terms will be in use among petrographers for many more such processes and effects; and that, by and by, a whole new system of classification will be worked out, designed to emphasize these principles.

EXAMPLES.

1. Geologists speak of the residue left by the evaporation of a solution as a *precipitate;* but there is no name for the product of the reaction between two mixing solutions such as seems to have produced some of our ores. To a petrographer or a chemist the latter is the better precipitate, but he would like at least to distinguish between them. The genetic idea is carried better if the product of evaporation were called an *evaporate* as Dr. Grabau does in his work on Salt Deposits, and the product of reaction by mixing were called a *reactionate*. Perhaps one could write them *evaporite* and *reactionite*.

2. These are still different again from the product of simple reduction of temperature or pressure in an ascending saturated solution for which there is no name is it to be a *saturite?* And for the product of reaction between a solution and a rock-wall, resulting in precipitation from the solution, there is also no name.

3 These are all very different genetically from the product of reaction between solution and rock-wall or host, when the reaction causes reorganization of portions of the rock itself, taking something out of the solution to add to its own constituents. It is a form of *reactionite* also but very different indeed from either of the others. There must be a whole family of *reactionites* differing in various, quite fundamental, ways one from another, and altogether producing a most interesting and important lot of petrographic materials encountered in many practical problems.

If one has worked little with ores and their relations, these needs would not necessarily have been felt; but if one has followed applied petrology with mining engineers, he will have discovered that there are no names for a very great many of his perfectly typical things. But one does not need to invade that field, however, to feel this poverty of nomenclature. The fact is that geology as related to petrogenesis has outstripped petrology as a separate, descriptive branch, and there are now many perfectly clear concepts of processes and products for which there are no petrographic terms.

4. Sometimes one substance completely replaces another, or certain ones completely replace others, producing an entirely new composition.

There must be a whole family of these types. I suppose we can call them *exchangites* or *replacites* or *metasomatites*, and if we do, we shall be easily understood, but there not any such words in petrography.

5. What term shall one use for an ash that has been completely silicified? I know that one form of it has been called novaculite;—but not at all because of its origin. And on that very account the term would hardly serve for a rock that had a coarse structure. There simply isn't any adequate term.

This is not a rare thing. There is much more of this type of rock in the ground than there is of Jacupirangite, or of Luxullianite, or many others that could be named.

6. What constitutes a quartzite? And why should not one distinguish between a quartz rock that is still in its original unmodified condition, and one that has been indurated with silica, and yet again one that has been deformed There are immense differences historically, and all types are very abundant indeed.

In the field of katamorphism there are whole groups of products of immense importance to the practical petrographer, for which there are no classification terms, although there are geologic terms descriptive of the major processes.

7. For example, how shall one designate the average product of simple disintegration? Is it a *disintegrationite?*

8. What shall one call the products of leaching? Shall we call them all *laterites* or *leachites?* Is laterite an extreme condition represented less perfectly by all of the leachites?

9. Or, again, what shall one call the product of simple oxidation? I know that "*gossan*" is an oxidation-product from sulphides;—but are they all to be called *gossans?* There ought to be a better name for the whole family of *oxidationites*.

10. Or, how shall one indicate in simple terms, or by a suitable name, that a rock is a carbonation-product, when the original was not a carbonate rock at all? One has had little experience who has not seen such rocks and wondered how to classify them.

11. Hydration is one of the commonest processes active in the alteration of rocks. Serpentines are of such origin, derived from anhydrous silicate originals. But there is no name for the whole family of *hydrationites*.

12. A sandstone in which carbonate occurs is usually called a calcareous sandstone; but there is a great difference in meaning, whether the carbonate is original with the rest of the rock, or was introduced as an induration effect, or was traded in a process of replacement for parts of the same that have disappeard. How shall one designate these conditions?

13. A belief in recrystallization has come to stay. Recrystallization does not presuppose any particular composition or particular structure. Shall we call the group of such products the *recrystallizationites?*

Fundamentally there are two divisions of this group, the massive ones and the foliated or stretched ones, but we have no clearly recognized names for them.

If I call the latter *foliates* as Miller does in his reclassification of metamorphic terms, in what way shall we distinguish the primary foliated rocks of both igneous and sedimentary origin?

There is, of course, no object in pressing these questions further. They have been used only to indicate at how many points the terminology and classification schemes of petrography fall short of the working conceptions of applied geologist. If it is true, as it seems to me to be, that the rightful field of petrology is rock interpretation, and that its greatest service lies in its contribution to geologic history, then, sooner or later, a considerable modification in terminology is sure to come in petrography itself.

Petrologists of the new school will have to be, first of all, geologists, both in fundamental training and in thinking habit, rather than mineralogists, because their subject is an intimate part of the field of geologic history, and their science is but a branch of the science of geology.

Petrogenesis, the life history of rocks—geologic history hid in the obscure inner recesses of the rocks themselves—these are the chief interests of the new petrology and these objectives map out its major service.