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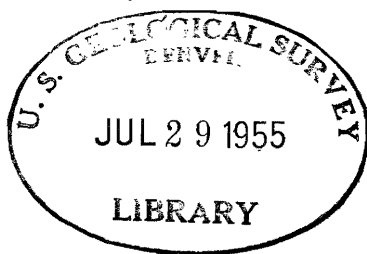
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Methods of Geologic Cartography in use by the United States Geological Survey.

(Presented, on behalf of the Director of the Survey, Major
J. W. Powell, by **W. J. McGee**, U. S. Geologist.)

Introduction.

By virtue of the specific terms of the law establishing it, it is made a principal and ultimate function of the United States Geological Survey to construct a geologic map of the dominion of the United States.

The area of the United States is vast; and while enough has long been known of its geography and its rocks to indicate the general geologic structure of its three and a half million square miles of territory, by far the greater portion has not yet been surveyed with such accuracy as to warrant final cartography. The preliminary reconnoissance has been made; but the survey proper has yet to be executed, and that duty has been assigned to the official Survey.

It is known that the country is geographically and geologically diverse in its different portions: There are the broad interior plains, in which the structure is simple, the formations attenuated and conformable, and the strata undisturbed; there is the Appalachian region, in which the same formations are thick, in which there are great unconformities, and in which the strata are extensively and characteristically corrugated and implicated; there is the structurally complex Rocky Mountain region, in which the formations are in places enormously thick and elsewhere attenuated, here conformable and there unconformable, now undisturbed and again displaced by flexure and fracture in all of their phases; there are the lava fields of the Cascades, unparalleled in extent and thickness; and there are the vast drift plains of the north, extending from the Atlantic nearly

to the Pacific. In no other single country are the various types of geologic structure exhibited on so grand a scale.

It is noteworthy that the entire series of rock groups recognized by geology is typically represented in the United States: There are broad Archean tracts in New England, in the Adirondacks, in the Piedmont division of the Appalachians, and in the Lake Superior region — the nuclei about which were wrapped the sediments of the nascent continent, — and there are many scarcely narrower belts which have been brought to the surface by orogenic movements in the far West. There are typical occurrences of the basal Paleozoics — the Cambrians — in numerous localities from Maine to California and from Minnesota to Texas, which include not only miles of strata but unconformities representing miles of erosion. The Silurians are now here more extensively and characteristically developed than in New York (where, thanks to an eminent American member of this body, Professor James Hall, they have formed the basis of American geologic classification), the Appalachian mountains, and the upper Mississippi valley. The American equivalents of the rocks of Devon put on a protean aspect, and, in different portions of their interoceanic extent, exhibit successional resemblances and diversities unknown elsewhere, which at the same time tax the systematist and test his systematization, and which can not fail to enlarge prevailing ideas of chorologic relation and the value of fossils as criteria for the correlation of the rocks of the earth. In its half million square miles of area and its two miles of thickness the Carboniferous includes a multitude of formations each of great economic importance and each indicating special conditions of genesis. The European Trias and the rocks of the Jura find stratigraphic and chronologic equivalents in the United States, with volume, geographic extent, and structural diversity entitling them to rank among the grander divisions of the geologic section in the new world as they do in the old. The Cretaceous terrane stretches from ocean to ocean and comprises a multitude of formations, already fairly discriminated in the United States and Canada, which, by their physical character and attitude, definitively record successive stages in the growth of the continent and enable the geologist to delineate approximately the geography of North America during the different epochs of the Mesozoic. The Cenozoic sedimentaries have wide geographic range and great thickness in the United States, and here, perhaps more clearly than elsewhere, illustrate the influence of geographic, climatic, and biotic conditions in determining the character first of the rock and finally

of the continent — i. e., the relation between the formation — the geologic unit — and the sum of conditions and activities constituting nature.

Despite the large number, the great diversity, and the marvellous displacements of the rock-masses of North America, all belong, as Dana has admirably shown in his classic Manual, to a single grand system marking successive steps in the evolution of a continent unique in its symmetry and morphologic simplicity, a clearly segregated geotectonic unit on which the various stages of world-growth are inscribed in easily interpreted phenomena. In no other quarter of the globe are the inter-relations of the rock-masses and their relations to the cosmos so clearly determinate as in the half of the North American continent now under investigation by the United States Geological Survey; and thus, since geologic cartography implies interpretation of geologic phenomena, this half-continent is, *par excellence*, the field for the development of comprehensive systems of geologic cartology; and the terms of less comprehensive systems will not adequately express the entire range of American phenomena and their significance.

Thus, by legal enactment as well as by the requirements of geologic science, and pre-eminently by the character of the country over which he has jurisdiction, the Director of this Survey and his associates have been compelled to devote much thought to methods of geologic cartography and the conventions involved therein.

When this distinguished body met in Bologna in 1881, the Director had the honor to present a statement of the system of classification of rocks and the method of geologic cartography then in use by the Survey. Subsequent experience has shown that these require some expansion and modification; and such expansion and modification have been made from time to time. No final cartologic system has yet been adopted; and the Director awaits with great interest the results of the deliberations of this Congress, which, it is hoped, may at least pave the way for the ultimate adoption of common conventional language for the expression of common phenomena.

Meantime, he begs permission to again lay before this body a brief statement of the methods now in use, together with some of the considerations which have led to the tentative adoption of these methods, and which, in his judgment, should not be neglected in discussions looking toward the unification of geologic conventions.

The geographic bases.

Since the greater part of the area of the United States is not yet represented upon maps suitable for the use of the geologist, the Geological Survey is compelled to construct geographic maps as a basis for the geologic cartography; and about onethird of the annual appropriations is expended in making the necessary geographic surveys. These surveys are now prosecuted on a plan which contemplates an atlas of the whole country comprising about 2600 sheets of nearly uniform dimensions, viz., 17 by 22 inches for single sheets, and 22 by 32 inches for double sheets.

The primary purpose for which the geographic base is constructed is the representation of the areal geology of the country, and the map is accordingly constructed on such scales and represents such geographic features as are important to the geologist; but while in its construction the primary purpose of the map is thus considered, it is constantly borne in mind that it will inevitably be made to subserve other important ends. When drawn and engraved the plate will serve for new editions from time to time, which may be used for a great variety of purposes, some of which are subsidiary to or indirectly connected with geology, and some of which are independent of its requirements; e. g., in the study of drainage systems; in the study of the regimen of rivers; in the study of the great and growing subject of irrigation; in the study of the distribution forests; in the study of Artesian wells and basins; in the study of catchment areas for the supply of water to cities; in the study of drainage of swamps and lands subject to inundation; in the study of soils and the classification of land for agricultural purposes; in the study of the relations of rainfall and climate to topography; in the study of geographic and hypsometric distribution of organisms; in the study of the vestiges of pre-historic man; in the study of the distribution of existing and decadent races, and their relations to the natural features of the earth; in the laying out of railways, highways, and canals; and for many other purposes of which some only are now recognized while some will be developed with future progress. The users of topographic maps are many, but the geologist is the most exacting in his demands; and if properly made to meet his wants they will serve the purposes of the naturalist, the civil engineer, the agriculturist, the military engineer, and other users of accurate maps. It is believed that the topographic survey inaugurated and the topographic maps contem-

plated by the United States Geological Survey will meet the wants of all classes of people.

The basis of the contemplated topographic maps is a trigonometric survey executed with only sufficient refinement for map making purposes, and not directly useful in geodesy. After (or, in certain rare cases, before) the completion of the triangulation the topographic survey per se is executed by various methods adapted to the peculiar conditions found in different portions of the country — by the plane-table (which, in the hands of the topographers of the United States Geological Survey, is not simply a portable drafting table, but an instrument of precision, by which minor positions of the topographic elements are determined by trigonometric construction) in open country or regions of sharp contours; by traverse lines showing vertical as well as horizontal angles, supplemented by notes with sketches, in tracts covered by forest and characterized by low and smooth relief; by measured co-ordinates accompanied by notes of topographic detail where the surveys of the General Land Office are utilized; etc., etc. The hypsometry is based on the levels of the railways intersecting the country in all directions. The profiles of these railways have been established with reasonable accuracy, and, since they cross each other in a multiplicity of points, a system of checks is afforded whereby the railroad surface of the country can be determined with all the accuracy necessary for the most refined and elaborate topographic maps. From this hypsometric basis the local reliefs are determined by level lines, by trigonometric construction, and, in mountainous regions, by barometric observations.

The scales for the atlas-sheets differ in different sections of the country, and are determined by, *first*, present and prospective density of population; *second*, the economic importance of the completed map; *third*, the complexity of geologic structure; and *fourth*, the degree of detail in topographic configuration. It is the design to map most of the northeastern portion of the country on a scale 1 : 62 500 or approximately one mile to the inch; the central and southern portion of the country and the Pacific slope will be mapped on a scale of 1 : 125 000, or about two miles to the inch; while the arid and thinly settled regions constituting the great basin, the Rocky Mountains, the high Sierras, and the plateau country drained by the Colorado river are being mapped on a scale of 1 : 250 000, or nearly four miles to the inch.

The topographic map will be engraved and published in atlas-sheets of which the unit is the square degree; i. e., one degree in

latitude by one degree in longitude. On the four mile scale each square degree forms a sheet; on the two mile scale it forms four sheets; and on the one mile scale the same unit forms sixteen sheets. The sheets are designated by their geographic position expressed in terms of the astronomic co-ordinates: — Thus, sheet »40—100« denotes the sheet which covers the square degree immediately north of latitude 40° and west of longitude 100° . The two mile sheets are designated in the same way with the addition of the further description, »S. E. $\frac{1}{4}$ «, »N. W. $\frac{1}{4}$ « etc. In like manner one mile sheets are designated by the numbers representing the latitude and longitude of the degree with the addition of the requisite fractional designation, »S. E. $\frac{1}{4}$ of the S. E. $\frac{1}{4}$ «, »N. W. $\frac{1}{4}$ of the N. E. $\frac{1}{4}$ « etc.

The sheets are engraved on copper, three plates being required for each.

On the first plate there is engraved the hydrography, including the coast lines, interior lakes, ponds, rivers, and, on large scale sheets, all springs and running streams. The hydrography is printed in blue.

On the second plate is delineated the hypsography — the relief of the surface. Since the accurate representation of relief is of prime importance to the geologist, great care is exercised in determining its value; and much consideration has been given to the different methods of representing this condition of the terrestrial surface. The method of representing relief by hachures has been long in vogue in this country, and brush shading has recently been employed for the same purpose to some extent; but while these devices possess the merit of producing artistic and attractive maps, they express relief only qualitatively, and are seriously affected by the personal equation of the draftsman. Contours — or grade curves — on the other hand express the relief quantitatively in terms of absolute measure. It has accordingly been decided to construct the maps in contours, and to reserve hachures and brush-shading for pictorial effect in certain special cases and for the representation of minor topographic details falling between adjacent contours. The contour-interval ranges from 10 feet in level country and upon maps of the larger scales to 200 feet in the smallest scale maps and among the high mountains of the West. (In a few maps adopted from other surveys the interval is 250 feet.) The hypsography is printed in brown.

On the third plate there are engraved the projection lines, the lettering, public culture, marginal lines, legend, title, etc. Private culture is excluded from this atlas. The distinction between »public

culture« and »private culture« is a valid one and easily made in practice. »Culture«, or the real and conventional features of the earth's surface due to human activities, is naturally divisible into that which pertains to communities and that which has relation only to individuals. Thus, boundaries of civil divisions, railways, canals, public works, towns, villages, etc., pertain to man (or communities of men) and constitute »public culture«. Boundaries of estates, private roads, single houses, fences, the features due to cultivation, etc., on the other hand, pertain to men individually, and constitute »private culture«. It is not represented for several reasons: *First*, it is not of sufficient general importance to demand delineation upon maps designed for general use; *second*, the time and expense involved in making the necessary surveys would add greatly to the cost of the maps; *third*, it changes so rapidly that the accuracy of maps representing it would be ephemeral; and *fourth*, it would crowd the sheets and obscure valuable details. The impressions from the third plate are taken in black.

A system of lettering and conventional signs, of such type and character as to interfere as little as possible with the use of the maps for various purposes, has been adopted for the geographic bases.

In addition to the maps constituting sheets of the atlas of the entire country, it is necessary to prepare special geographic bases from time to time for 1) the representation of geologic detail too minute to find expression on the uniform sheets, 2) the delineation of the general structure of large areas, 3) the illustration of special preliminary reports, 4) the preliminary cartography of regions geologically investigated but over which the geographic surveys have not been extended, etc.; but so far as possible these special maps are made to conform in conventions with those constituting the atlas, and in dimensions with either the standard atlas-sheets or the plates of the letter-press publications of the Survey.

The Geologic Maps.

Upon the sheets of the prospective atlas and upon such special sheets as may be required, the geology of the country will be indicated by means of colors and symbols.

While only a small number of geologic maps have thus far been issued by the United States Geological Survey, the plan for their preparation has been so definitely formulated as to be susceptible of statement and to admit of criticism. The methods practiced

are expressed in published maps and in the handcolored maps and proofs laid before the Congress; but it seems desirable to state at some length the principles upon which these methods and those in contemplation are founded.

General Considerations.

Cartographic or other description of a series of phenomena requires a series of conventions corresponding to the phenomena described. Manifestly, a definite and comprehensive system of ideographic conventions can not be formulated without classification of the phenomena represented thereby. Now, when the various elements belonging to any natural category are known, it is possible to frame a taxonomy in which these elements appear in their natural relation; and such a taxonomy at the same time forms the exponent of the philosophy of the subject and affords (by the use of suitable conventions) a ready means of describing the objects comprised in the category and fixing in the mind the impressions to which they give rise. But in a nascent branch of knowledge like geology, the entire series of phenomena is not known, and indeed can not be known until the necessity for investigation has ceased to exist. Accordingly, all attempts to formulate final classifications in geology must be nugatory, and, in so far as they prescribe metes and bounds for undiscovered phenomena, antagonistic to scientific progress. For, unless the very foundations of modern science are to be overturned, preconceived ideas of natural relation, whether based on inadequate observation or derived from *a priori* considerations, can not be permitted to trammel investigation — the inductive method must be faithfully followed in geology as in cognate sciences. As well, indeed, reduce the organic life of the globe to the orders, genera, and species observed on a single continent as attempt to define the ever varying rock-formations of one continent by those of another.

Meantime, the requirements of the people and of science necessitate publication from time to time of the preliminary results of geologic investigation; and among such necessary publications are maps, charts, diagrams, and other works embodying graphic conventions. Thus the geologist is called upon from time to time to devise tentative taxonomies representing the current status of geology and to frame systems of conventions at once so definite and comprehensive as to fairly represent the entire range of phenomena contemplated in the taxonomy, and so elastic as to yield to every possible requirement of the discoverer of new phenomena. Moreover, the

classificatory elements and the corresponding conventions must be chosen with a view to convenient and economic employment in the construction and publication of the works.

In the United States, and to an extent in all countries in which geologic surveys are prosecuted under State auspices, there are other conditions to be fulfilled by taxonomic and cartographic schemes: The maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately available alike to the theoretic physicist or astronomer, the practical engineer or miner, and the skilled agriculturist or artisan.

So it appears that the first requisite in a cartographic system is such breadth and elasticity that it shall not in any way trammel the investigator in the expression or interpretation of phenomena; that the second requisite is such simplicity that it shall meet the wants of all classes of people; and that it is only subordinately requisite that it shall represent the philosophy of the science.

Accordingly, the classification involved in a cartographic system designed for general use should be objective rather than theoretic; it should be based upon rock-masses in their observed and readily observable relations rather than upon the time-intervals contemplated in historic geology or even upon the organic remains contemplated in biotic geology; it should be petrographic rather than chronologic or paleontologic.

The value of a cartographic scheme depends directly upon the accuracy with which it represents natural phenomena recognizable alike by the untrained observer for whose use they are recorded and the trained observer who records them. But while the minor geologic divisions must therefore have a natural basis, those of greater magnitude may be somewhat differently defined. It has been found with the extension of geologic investigation, that the structural planes separating the great rock-groups in one country do not necessarily coincide with those existing in other countries; that the unconformities in one section may correspond to series of conformable strata in other sections; that epochs of rock destruction in one geologic province were epochs of rock construction in others; and that no natural division of the rocks of the earth maintains its integrity throughout the continents. It has been found, too, that while the great rock-groups exhibit some moderately constant diagnostic features, they are no more trenchantly separable than the minor rock-

masses discriminated only by special students. Accordingly, while it may have a partly natural basis, any classification of the broader categories of geologic phenomena must be to some extent artificial and arbitrary. In the United States, for example, geologists are scarcely agreed as to the position of the common boundary of the Carboniferous and Devonian groups of rocks, and not at all agreed as to the position of the Silurian-Cambrian boundary; but while it is desirable to retain these divisions it is not so much because they are essential or logical as because they are generally recognized and convenient.

The cartographic system in use by the United States Geological Survey is determined by these and analogous principles; and while it is not professed that this system is final, or even unobjectionable, it represents the present state of knowledge and opinion in that institution.

It will be observed that in its fundamental principles this system is the antithesis of that in common use. With the evolution of geologic science there grew up a system of symbolic and sometimes denominative conventions for the representation of geologic phenomena, in which the conventions are designed to suggest the characters and relations of the phenomena. It implies a classification of the phenomena in which each element is properly correlated with each other element, and in which the sum of recognized elements forms a complete and symmetric whole; in view of the manner in which scientific classification is effected, it involves conference among geologists concerning obscure and doubtful points, in order that consensus of opinion may be secured; and it requires modification of the classification and consequent repetition of conference with each important geologic discovery. Though natural and simple in its inception, the fully developed system is highly artificial and cumbersome. In the system here advocated the conventions, both symbolic and denominative, are purely arbitrary. No classification save a semi-arbitrary allocation of the grander divisions of the geologic column is necessarily implied in the system, but any classification may be adopted without affecting its integrity; it affords the means of immediately representing new discoveries and of either tentatively or finally distinguishing phenomena of doubtful significance; and it permits modification of classification, the maintenance of diverse classifications, and the development of classificatory theories at all stages of investigation. Though resting on a partly artificial basis, it is simple and natural in its application.

The old system is ideographic, connotative, and analytic, while the new is alphabetic, denotative, and synthetic; the old system trammels the observer by prescribing rules and limits to which his observation must conform, while the new encourages originality by allowing the utmost latitude in expressing the results of observation; the old system tends to retard the development of geologic science and to restrict its practical application by implicitly postulating its completeness, while the new promotes geology and extends its useful applications by providing the means of expressing discoveries in new as well as in old lines of investigation.

Taxonomy and Nomenclature.

The system of classification of rock-masses proposed by the Survey contemplates the discrimination of three grand categories of rocks comprising respectively, *first*, the known clastics (sedimentary, eolic, glacic, and other detrital deposits); *second*, the classified and unclassified non-volcanic crystallines; and, *third*, the known volcanics.

The Clastics. — The rocks of the first grand category are arbitrarily classed in taxonomic divisions of three orders of magnitude, viz.; systems, groups, and formations. The limits and values of the first two of these divisions are determined by the Survey; while the minor divisions are formulated by the working geologist alone, and have such limits and values as he may find it expedient to assign to them.

The great divisions of the geologic section defined by paleontology and frequently denominated »systems« by the geologists of different countries, are useful in general description and nomenclature but do not ordinarily demand cartographic representation. Partly in deference to common usage, and partly because they express an elementary but convenient conception of geologic relation, these divisions are retained in the classificatory scheme of the Survey and denominated respectively »Cenozoic«, »Mesozoic«, and »Paleozoic«.

It is at the same time convenient and consistent with general usage, to recognize a series of divisions either defined mainly by paleontology and subordinately by petrography, or fixed, semi-arbitrarily, by consensus among geologists. Those recognized by the Survey have been discovered in various countries, are presumptively world-wide in distribution, comprehend all known elastic formations, and appear to approach equality in volume. It is not held that their limits are clearly marked, that they are precisely conterminous in distant portions of the country, nor that the evidence of different classes of fossils — vertebrate, invertebrate, and plant — is con-

sistent, either mutually or with petrography, as to their boundaries. To some extent they are made arbitrary divisions, which may at any time be increased or diminished by the addition or removal of border-land formations, just as the orders of biology are perpetually increased or diminished by the creation, transfer, or abandonment of genera and species, but nevertheless maintain their integrity. It is believed, however, that they represent fairly well defined periods in the history of the continent.

Groups require frequent cartographic representation. The color schemes employed in the maps of the Survey are determined by these divisions; and great care has accordingly been exercised in fixing their limits. The nomenclature made classic by the pioneers in geology, Murchison, Sedgwick, and Lyell, is retained as far as practicable. The groups at present recognized in this institution are exhibited, with explanatory remarks, in the accompanying table:

<i>System.</i>	<i>Group.</i>	<i>Remarks.</i>
Cenozoic.	{ Quaternary.	Includes recent deposits.
	{ Neocene.	Pliocene and Miocene.
	{ Eocene.	Includes Oligocene.
Mesozoic.	{ Cretaceous.	Includes Laramie.
	{ Jurasso-Triassic.	Jurassic and Triassic
Paleozoic.	{ Carboniferous.	Permian, Coal-Measures, and Sub-Carboniferous.
	{ Devonian.	
	{ Silurian.	Upper Silurian and Lower Silurian or Ordovician.
	{ Cambrian.	All rocks between summit of Potsdam and summit of known Archean.

The structural geologic unit is the »formation«. It is defined primarily by petrography and secondarily by paleontology; and, in thoroughly studied regions, is generally found to constitute a genetic unit. It would be desirable, indeed, to restrict the term to a deposit or series of deposits produced by definite agencies in a definite area within a definite epoch; but for the present such restriction is impracticable, and in the Survey the term is applied to any rock-mass which the geologist may find it convenient or necessary to discriminate in the field.

Since the formation is the fundamental element of geologic classification, it is essential that the utmost latitude in defining it be allowed the student engaged in investigating and classifying geologic phenomena; for the entire superstructure of geologic science must be based upon and limited by the characters of individual formations, just as the superstructure of biologic science is determined by individual organisms.

In practice it is found that the strata constituting a formation in one district are not duplicated in any other district — that in passing from one geologic province to another new lithologic, structural, and paleontologic features are discovered; and it is necessary that the geologist shall have the means of distinguishing them. Latitude in the identification, correlation, and graphic representation of these local phases of rock-masses is secured, first, by the application of local and purely denotative names to minor rock-masses, and, second, by the employment of a system of conventions affording a great variety of distinctions. It is the custom of the Survey to apply to formations geographic names taken from localities of typical development; and these names are applied in their recognized forms — i. e., without adjective terminations.

It is also found in practice that certain isolated rock-masses are destitute of diagnostic characters, and can not safely be referred to any recognized group; but the exigencies of publication require the geologist to formulate some expression of opinion concerning them. Latitude in this respect is secured by indicating taxonomic relation (whether of formation or group) in three degrees of certainty; i. e., *first*, known relation (expressed by unquestioned reference of rock-mass to taxonomic position); *second*, supposed relation (expressed by reference of rock-mass to taxonomic position, with a query); and, *third*, unknown relation (expressed by a query in connection with the name of the taxonomic division to which the uncertainty relates). In the third case, the query may indicate a) absolute ignorance of taxonomic relation, b) uncertainty as to which of two or more divisions the rock-mass represents, or c) the hypothesis that it represents a division not yet formulated. (It is immaterial which of the last two conditions of uncertainty obtains, since unformulated classificatory elements have no existence in exoteric science.)

Sometimes, too, it is found in practice that while the diagnostic characters of an isolated rock-mass are of such value as to justify its reference to a group, they are too indefinite to indicate its position in the group; and it is imperative that the student shall have the option of representing it without expressing opinion as to its relations to other formations in the same group. This is readily effected by appending the formula »Position?« to the formation name in the taxonomic scheme entering into the legend of the map. The force of this reservation will be intensified when it is understood that the Survey does not recognize any such thing as a typical section representing the succession of rocks over a considerable area, and

that the taxonomic scheme in any legend may apply to two or more natural geologic provinces whose formations can never, perhaps, be correlated.

It frequently occurs in practice, too, that while the rocks of a region may be confidently referable to a group, the areal limits of the constituent terranes may be indeterminate by reason of obscurity in diagnostic features of the formations or concealment of the rocks by superficial deposits. In such cases cartography representing accurately the certainty and uncertainty in the mind of the investigator is effected by extending the ground color over the entire area referable to the group and limiting the overprint to the areas over which the different formations have been actually traced.

Again, it is found in practice that associated rock-masses sometimes exhibit diagnostic diversities of such magnitude as to warrant their discrimination and at the same time such resemblances as to lead the untrammelled student to combine them in divisions of much less taxonomic value than the group. While the custom of recognizing such divisions may eventually become obsolete and is not encouraged by the Survey, provision is made for representing them in the taxonomic schemes as *series* (or subgroups), and the system of conventions is sufficiently elastic and comprehensive to permit their representation on the maps.

Finally, it is found in practice that the tendency of exhaustive investigation of restricted areas, whether economic or scientific, is to promote nice petrographic distinctions — to lead to the discrimination of the elements of the formation; and in certain cases it may be desirable to represent the subformations so discriminated cartographically. This is permitted in the Geological Survey by the great variety of distinctions contemplated in the system of conventions.

The Non-volcanic Crystallines. — It is impossible to co-ordinate the various Azoic rocks of the earth with the clastics without committing geologists to some opinion, either expressed or implied, as to the genesis of these rocks; but in the present state of geologic science the conservative student is not justified in finally committing himself to any of the current hypotheses of genesis, or even to the hypothesis of community of genesis of such rocks. Accordingly, these rocks are combined by the Geological Survey in a grand category, sharply distinguished from the clastics in the taxonomic schemes and upon the geologic maps, in which the classification may be based on any criteria — petrographic, genetic, chemic, etc., — and in which the taxonomic divisions may have any value, that may be proved to be suitable by future research.

At present, it is the method of the Survey to unite the non-volcanic crystallines, including the vast series of schists regarded by some geologists as undoubtedly pre-Paleozoic and by others as Paleozoic formations, in a single class to which the term Archean is applied. (Crystallines found to be metamorphic and chronologically identifiable with clastic strata, are, however correlated with synchronous deposits from time to time as the data for such correlation accumulate.)

Many American geologists separate the Archean rocks into two or more divisions, sometimes regarded as co-ordinate with the clastic groups. Perhaps some such separation will be made by this institution when the investigation of the crystalline terranes recently inaugurated in New England, the Lake Superior region, and the Piedmont division of the Appalachian region, shall approach completion; but at present no attempt is made to formulate divisions of the Archean rocks of a second order of magnitude nor to coordinate these rocks with the clastics.

Minor crystalline rock-masses have not yet been discriminated in the published maps of the Survey; and it has not yet been finally decided (when, in the progress of investigation, their recognition becomes necessary) whether 1) they shall be defined petrographically and designated by terms expressing petrographic character; 2) whether they shall be defined structurally, and described by denotative nomenclature similar to that of the clastic formations, or 3) whether both methods shall be employed. The systems of conventions in use and proposed for the future by the Survey are believed to be so comprehensive as to fully meet the requirements of the original investigator whatever course be adopted.

The Volcanics. — There are even weightier reasons for establishing a separate category for the volcanics than for the non-volcanic crystallines, since they are known to be distinct (at least from the clastics) in genesis; and such disposition is accordingly made of these rocks by the Survey.

Minor eruptive rock-masses are defined by petrography and in some cases by genesis. It is the present usage of the Survey to distinguish them by their petrographic designations — basalt, trachyte, rhyolithe, etc.

The Conventions.

When the Director had the honor to present a communication before this body of eminent geologists at Bologna four years ago, he mentioned the adoption of a scheme of colors controlled by the following principles:

- »1) The scheme should represent common usage as far as possible.
- 2) The scheme should commit the geologist to distinctions and correlations not warranted by the facts at his command.
- 3) The colors should be so distinct as to be easily determined on the charts.
- 4) The desired results should be secured with the greatest economy in color printing.
- 5) The needs of the various portions of the country for distinctions necessary to represent the formations recognized therein by geologists should be subserved; and the several portions of the color scale should be equitably divided.«

Guided by these principles, a scheme of colors and other conventions for geologic cartography was formulated. In this scheme the colors were arbitrarily classified as grey, yellow, green, blue, purple, red, and brown, some of which were used in two or three distinct tints; and these color distinctions were indefinitely multiplied by employing light tones as bases and dark tones of the same color as over-prints in various mechanic arrangements.

The color scheme thus devised has been employed with a fair measure of success in the various maps published by the Survey during the past three years.

Prolonged consideration has led to the conviction that the first of the principles enumerated above — viz., that the scheme should represent common usage — is bad. It is bad partly because such usage is vicious in that it is based upon the attempt to represent the rock-masses by their natural colors; for now that geologic investigation has extended into all lands, it has been found that color is the most fleeting and untrustworthy of all diagnostic characters, and that (with a few exceptions) no given color is more characteristic of a given formation than of any other. The usage is bad, too, in that it does not represent the natural color-scale equitably divided, as a perfect color scheme must. The scheme is defective, moreover, in that it does not afford sufficient number of distinctions for the representation in detail of the structure of a great area, and in that too few colors were assigned to the lower Paleozoics. At the same time, prolonged consideration has only served to strengthen the

essential conviction which led to the proposal of the scheme — viz., that while a limited number of terranes may be satisfactorily represented by means of distinct colors and tones, the eye is incapable of distinguishing a sufficient number of colors and tones for the representation of the vast number of terranes necessarily discriminated in a detailed geologic map of a continent.

Accordingly, it is proposed to submit an entirely new and arbitrary color-scheme to the test of experiment. In this scheme the colors of the spectrum are employed in their natural order, with the addition of grey at one end of the series and brown at the other; and the scheme contemplates the employment of such mechanic devices in combination with the colors as will permit the use of the entire series, first for the clastics, again for the non-volcanic crystallines, and once more for the volcanics.

The colors are used in such manner that the non-volcanic crystallines shall be distinguished by light tints, the clastics by medium tints, and the volcanics by strong tints. Moreover, two classes of distinctions in each of the grand categories of rocks are contemplated in the scheme. 1) It is essential that the geologist shall have the means of clearly distinguishing the juxtaposed terranes of a single sheet, whether it be a large scale map of a small area, or a small scale map of a large area. 2) Even when it is unnecessary that the distinction between related formations in widely separated localities shall be strongly marked, it is essential that the geologist shall have the means of representing them without implicitly suggesting their equivalence by the use of identical conventions for them. Both of these conditions are fulfilled by the scheme, in which there is a sufficient variety of distinctions for the representation of all the formations of the country, and from which a sufficient number of strongly marked distinctions for local or general use can be selected.

Among the clastics, colors of a single tint printed solid, are used for the groups; and, as in the old scheme, the same ground colors and over-prints in lines of these colors, in either the same or different tones but in stronger tints, are used for the formations. The magnitude of the taxonomic division is thus indicated by the character of the coloration. The over-prints may be of different tints and in single full lines, horizontal, vertical, right-oblique, and left-oblique in direction; similar lines crossed; single broken lines, horizontal, vertical, right-oblique, and left-oblique in direction; double full lines in the different directions and crossed; double broken lines in the four directions; triple full lines; triple broken lines; and va-

rious combinations of full and broken lines. Differences in shade essential to the discrimination of the formation without close inspection of the map are secured by varying the tint of the over-print, by varying width of lines and inter-spaces, and by related mechanic devices. Several hundred distinctions for the clastic rocks are thus available.

The non-volcanic crystallines are represented by angular figures on a white ground. When a single division comprehending either all or a part of the Archean is indicated, the color of these figures may be selected with a view to artistic effect; but when it becomes necessary to distinguish Archean divisions, all may be represented, whatever their magnitude, by angular figures in the colors of the general scheme, which should be used in the same order as in the clastic series. Greater variety is afforded by the employment of different figures, +, L, □, △, ∠, etc.; and distinctive shading may be effected by varying the weight, size, and closeness of the figures. Several hundred distinctions can thus be made in the Archean.

The volcanics are represented by round dots of strong color printed on a colored ground. As in the non-volcanic crystallines the dots may be of any color, and the ground may also be of any color, when only a single division is represented; but when additional divisions are indicated, different colors selected from the general color-scheme should be employed (and in uniform order) for the dots of each division; and the ground color may also be varied. Greater expressiveness may be secured by grouping the dots in any definite way; and the necessary diversity in general effect may be obtained by varying size, form, and closeness of dotting, and by varying the tone of the ground color. One or two hundred distinctions may easily be made.

By thus using the entire color series thrice over, a greater variety of distinctions is secured than would otherwise be possible; and there is a mnemonic advantage in indicating relative age in all of the great classes of rocks by using the colors of a generally recognized scale in the same order for each. It is partly for this reason, and partly because it is the natural and perfect color-scale, that the experimental color-scheme is based on the spectrum. Still, the Survey does not hold to this, or indeed any, color-scale with extreme tenacity, but is ready to adopt any generally approved series of colors susceptible of use in the manner described. The color-scale *per se* is of only subordinate, and the manner of employing the color-scale of primary importance in geologic cartography.

Since the pigments employed in the arts alter with time, it is desirable that the divisions represented on geologic maps should be indicated by letter-symbols printed in black as well as by colors; and in order that these symbols may not be confounded with the lettering of the base, it is necessary that they shall be of distinctive type.

Accordingly, it is proposed to employ skeleton letters of either Doric or Gothic type for the letter-symbols, representing the groups by capitals and the formations by lower case letters of the same type. The letter-symbols employed for the groups are, as far as possible, initials of the group-names. The series of group symbols has already been selected and will be used in uniform manner in the various maps prepared by the Survey. The formation letter-symbol may be either 1) the initial of the formation name, 2) this initial combined with one or more lower case letters of the same style and type, occurring in the formation name as may be required to distinguish it, or 3) either of these symbols in connection with the group initials. Thus, the Chemung formation may be represented either by c, ch, che, Dc, Dch, or Dche, as the character and scope of the map may suggest.

General Regulations.

When, during the past decades, the same individual combined the functions of explorer and geologist, and when rapid field work and elaborate reports were required of him, there was strong tendency to premature classification and hypothetic cartography; and discrepant maps appeared too frequently for the good repute of geography and geology. Now that well equipped surveys have been established in the United States, the necessity for hasty and immature publication of the results of incomplete surveys has vanished. Accordingly, the publication of hypothetic cartography is discouraged by the Survey; and, except in certain special and clearly specified cases the area mapped will correspond exactly with the area surveyed.

Partly out of consideration for the convenience of the lithographer, and partly, perhaps, from a desire to publish imposing maps and atlases, there has grown up in the United States a fashion of printing geologic maps on unnecessarily large scales; and the maps and atlases have thus become needlessly cumbersome and inconvenient for the user and expensive for the producer. This is opposed by the United States Geological Survey. Every effort is made to reduce the maps to a minimum scale; and all possible detail is indicated on each. In regions of complex structure photo-

graphic enlargements of the geographic bases are supplied to the field geologists; and the geology delineated thereon is carefully reduced by skilled artists to the scale adopted for publication.

Duplications of conventions on the same area is clumsy and unsatisfactory at the best, and often impossible. Accordingly, no attempt will be made by the Survey to delineate the superficial formations and the sub-surface structure of the country on the same sheets. Separate sheets will be devoted to these subjects, and analytic maps constructed to exhibit phenomena at different depths or during different periods will be issued whenever required to elucidate the structure.

In order that geologic maps may be of maximum value to all classes of users, it is desirable that each sheet be self-explanatory and complete in itself. Such maps are designed to exhibit in the two-dimensional horizontal plane the absolute and relative position of masses of three dimensions whose essential relations are in the vertical direction; and the skilled geologist — and he alone — instinctively interprets the map in tridimensional terms and conceives of the relations of the masses in the vertical as well as in horizontal directions. To enable the great majority of map-users to similarly conceive of the relations of the rock-masses and thus fully appreciate the significance of the map, it is necessary that a key to the stratigraphy of the region be provided. Moreover, the map-user should not be unnecessarily compelled to guess at the opinions or knowledge of the author as to the taxonomic relations of the formations represented, even though expediency demands that he refer to the text to discover shades of opinion interesting to special students. In the Survey these conditions are fulfilled by making the legend of the map at the same time a structural key in which the stratigraphic relations of the rock-masses are shown and a taxonomic scheme, as definite as the author is able to formulate, representing his convictions as to their systematic relations. Thus, the legend is not a simple »explanation of colors« but an essential and important part of the map.

In addition to the conventions employed in geologic cartography *per se*, various devices are in use by the Survey for the representation of certain features in geologic structure. Thus, in stereograms, graphic sections, bird's-eye views, landscape sketches characterized by geologic indications, etc., arbitrary conventions are necessarily employed; but care is constantly exercised to render these conventions, and the illustrations into which they enter, self-explanatory.
