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A TOPOLOGY OF MINERALIZATION AND ITS MEANING FOR PROSPECTING

By

George J. (ralph) Neuerburg, 1924-

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ABSTRACT

Epigenetic mineral deposits are universal members of an orderly spatial-temporal arrangement of igneous rocks, endomorphic rocks, and hydrothermally altered rocks. The association and sequence of these rocks is invariant whereas the metric relations and configurations of the properties of these rocks are unlimited in variety. This characterization satisfies the doctrines of topology. Metric relations are statistical, and their modes are among the better guides to optimal areas for exploration. Metric configurations are graphically irregular and unpredictable mathematical surfaces like mountain topography. Each mineral edifice must be mapped to locate its mineral deposits. All measurements and observations are only positive or neutral for the occurrence of a mineral deposit. Effective prospecting is based on an increasing density of positive data with proximity to the mineral deposit. This means sampling for maximal numbers of positive data, pragmatically the highest ore-element assays at each site, by selecting rock showing maximal development of lode attributes.

INTRODUCTION

Mineral deposits are an intrinsic part of a widely distributed and locally repeated petrographic-structural association, conceptually an edifice. Mineral deposits are associated with igneous rocks by proximity, especially superposition, and by a common focus on a major structural discontinuity in the Earth's crust. A single edifice consists of a prism of the crust, alternately and repeatedly opened and sealed (Marler and White, 1975; Sibson and others, 1975). The openings are filled by an evolutionary progression of widely varied igneous rocks, recrystallized igneous rocks, secondary rock minerals, and lode (ore and gangue) minerals. Mineralized segments of the crust normally are composed of clusters of mineral edifices, in part interpenetrating, but not necessarily closely related in time. The constructive progression of crystalline components culminates in or converges with the disaggregations and dispersions by weathering and erosion onto the crust.

Heuristically, a mineral edifice is composed of four classes of rocks, each of multi-hued character, located on notably broken segments of the Earth's crust. An analogy with crystallography and its constancy of interfacial angles but wide diversity of crystal habit is pertinent. Relations in both ore petrology (Stanton, 1972) and crystallography are contained in topology, the branch of mathematics dealing with the properties of position that are unaffected by changes in size or shape. Topology affords a rigorous and objective ordering of the observations and measurements that serve to characterize the phenomenon of mineralization. Neither deterministic nor genetic attributes are in any way predicated by a topology. A mineral edifice is the set (igneous rocks, recrystallized igneous rocks, hydrothermally altered rocks, mineralized rocks), and the operation addition, as modulated by repeated opening of rock; the topology is four-dimensional. Erosion, corresponding to the tearing operation of topology, and deposition of the pieces restructure the components of the mineral edifice into different arrangements to form the set (sedimentary rocks).

The subject of this discourse is (1) a description of the phenomena of mineralization in the framework of topology and (2) an analysis of the significance of this kind of description to methods of prospecting for ore deposits. The topology described herein is the culmination of a search for rationale and system in dealing with the undeniable uniqueness (Bunge, 1962; Tischendorf, 1969) of each mineral edifice and the heterogeneity manifest in all spatial properties of mineralized rocks. The problems are those of scientific method and philosophy, and are difficult of expression as well as of agreement (Moss, 1972; Stegmüller, 1979).

TOPOLOGY OF MINERALIZATION

Two principles of topology govern the present description: (1) "structural stability" (Woodcock and Davis, 1978)--the invariance of the qualitative spatial and temporal arrangement of the four intrinsic structural components (the building blocks, or modules) that make up the edifice and which are ultimately subsumed into the sedimentary set; and (2) distortion--the functionally independent and theoretically infinite number of shapes, sizes, and compositions that describe individuals of each module class. Structural stability is the essence of taxonomy; patterns of distortion are the subdivisions of a classification.

Each of the four modules, here called igneous, endomorphic, alteration, and lode, appear repeatedly in the edifice, apparently in unvarying cycles of pyrogenic crystallizations, igneous recrystallizations, metasomatic recrystallizations, and solute precipitations. Each cycle and subcycle is separated by episodes of rock opening. Compositional properties of the modules change discontinuously between cycles. The changes are broadly unidirectional, that is evolutionary with time, but reversals are numerous along the time axis.

Mappings of modules are metric configurations, statistical or geometrical (March and Steadman, 1971) as appropriate, of the physical and chemical properties of each module and of the relations among modules within and between edifices. Examples of such mappings are (1) the mathematical (trend) surfaces that describe metal halos around veins, (2) the sizes and shapes of igneous bodies, (3) the frequency distribution of igneous rock types in a cluster of edifices, and (4) metal specialties (Tischendorf, 1970) of the mineral deposits of an edifice. The mappings are unpredictable, mathematically unworkable functions (Burger and Skala, 1978) and scale-constrained, which means that the unit of measurement, such as sample size, is arbitrary but must be held constant for any one mapping. Each geometrical configuration is unique, and can be determined only by mapping. An analogy with topographic maps is appropriate and complete.

Empirically, the variety of statistical mappings of module relations--for example, the frequency distribution of tin lode modules among igneous rock types over all edifices--is a limited set and the members of the set are statistically distributed (Taylor, 1979). The modality or peakedness of a statistical mapping is greatest within a cluster of edifices--the parochial arena, somewhat less in a mineralized segment of the crust--the province arena, and least pronounced in the full Earth set.

Igneous modules.--An igneous module is geometrically characterized by continuity of crystallized material within the space it fills, which material has the further characteristics of having congealed from an equally continuous melt. The chemistry and texture of an igneous module are remarkably homogeneous. Observed chemical structuring is of low amplitude and is either without detected system or functionally related to module shape or to the Earth's gravitational field.

The igneous component of mineral edifices is identical with the universal Earth set of igneous rocks. However, some modal associations are evident; thus brecciaform (Gilmour, 1977) and porphyritic hypabyssal intrusives are prominent modules of mineral edifices, and felsic igneous rocks are markedly dominant over other igneous rock types in close spatial association with metallic ores. Three major compositional subsets are manifest, each modally associated with a singular part of the crust: (1) mafic rocks in oceanic crust, (2) alkalic rocks in cratonic crust, and (3) calcalkalic rocks in orogenic crust.

Compositions of igneous modules range widely in most mineral edifices, but the aggregated modules are distributed among empirically few compositions. Each composition occurs in several modules, such as dikes and sills, that are repeated and alternated along the time axis. A general progression of compositional changes, paced by an increase in SiO_2 content, is evident. This progression is described by a fractal curve (Mandelbrot, 1977), like the path of a pebble cascading down a talus slope.

Endomorphic modules.--An endomorphic module is made up of numerous small bodies of partly space-filling, mainly replacive, and dominantly coarse-crystalline rock. This module includes such diverse rocks as (1) pegmatite intrusives, patches and "veins", (2) miaroles and their linings, (3) internally recrystallized parts of igneous bodies, with or without compositional change (Hollister and Baumann, 1978; Lutton, 1959), and (4) symplectitic intergrowths of rock minerals and of lode minerals such as tourmaline and topaz. The unifying characteristics are (1) the morphology of clusters of discrete to irregularly merging objects, and (2) the generally radial-structured compositions and (or) textures. These modules are mainly made up of the more felsic minerals of the enclosing rocks.

The endomorphic module is virtually restricted to igneous rocks and to the adjacent metamorphic wallrocks. Modal occurrence is in the late felsic intrusive modules of an edifice. The endomorphic module is morphologically and phenomenologically similar to the lode module; the two are not everywhere separable.

Alteration modules.--In the present context, alteration is the exchange reaction between rock minerals and aqueous fluids resulting in different mineral compounds and in different rock compositions, with the specific constraint that the secondary minerals retain the spatial co-ordinates of their progenitors. Alteration petrography varies in concert with the original petrography; thus, tactite with limestone, propylite with andesite, and greisen with granite. Rock-mineral species are separately and successively altered to produce a progression of mineralogically distinctive assemblages, which are called alteration zones. The number of species altered is a measure of alteration intensity. Extent of alteration is equated with the proportion of a mineral species that has been altered, and is distance-dependent within a zone.

The alteration module is a diffuse body of dispersed secondary minerals--a body with irregular and gradational outline, described by a fractal surface. Its morphology maps a permeating tenuous fluid, in contrast to the displacive viscous fluid of an igneous module. The extent and intensity of alteration decay outward from surfaces of origin (contacts, fractures, faults). The sequence in which rock mineral species reacted, and thus the identity of a zone, differs from cluster to cluster of mineral edifices, and is a parochial property. Zonal mappings in all mineral edifices are the same for all sizes of alteration module, from the thin selvedge on a joint to the huge masses of pervasively altered rocks of a porphyry copper deposit--a property of topology called self-similarity (Mandelbrot, 1977). Self-similarity is the generalization of Euclidean similitude; the general trace of a fractal curve, such as the outline of the British Isles, persists through changing scales of mapping.

The alteration module is prominently localized by extensively fractured crust along with numerous and varied igneous modules such as make up volcanic centers, calderas, and batholith-cupolas. Alteration modules are commonly centered on intrusive contacts and are zone-structured outward along a plexus of fractures and intergranular separations in the adjacent rocks.

Lode modules.--In topologic context, lode minerals comprise a set of chemical compounds that are distinguished by having been precipitated in once open textures and structures. Most lode minerals differ compositionally from the rock minerals of their matrix; all differ in crystal habit and (or) fabric. Chalcophilic elements, like the heavy metals and minor lithophilic elements such as B, Be, and F, occur most commonly in lode minerals--and these are the majority of the chemical elements of commerce. A lode module is a variously interspersed to dendriform configuration of lode-mineral fillings. The topologic invariants are the physical-chemical integrity and transgressive relationship of lode minerals with respect to a matrix of rock minerals. Mineral deposits of pyrogenic minerals, such as chromite disseminations and some pegmatites, are not lode modules but compositional varieties of igneous modules. These varieties may aptly be called lode differentiates. The lode module contains the classical epigenetic mineral deposit(s), but is much larger and is a topologically discrete object of the same taxonomic rank as an igneous dike.

Metric compositions of lode samples are parameters of nearness to ore, both in space and in quality. The lode sample is compounded from four unrelated variables: (1) permeability, or accessible open space, (2) geometry of the lode filling, as fracture-filling versus disseminated, (3) extent of space-filling, which may even exceed permeability by way of metasomatism, and (4) chemical composition of the filling matter. Weathering changes of uneven degree are unavoidably a fifth independent--and wild--variable. Spatially dependent but unpredictable differences in each of these variables are characteristic at all scales of sample size, although their magnitude diminishes with increasing sample size. This topologic property is the "nugget effect" of geostatistics (David, 1977). Compositional mappings of lode modules are arbitrarily shape- and scale-constrained for internal consistency. The mappings comprise distance-dependent mathematical surfaces that are self-similar fractal sets, like topographic maps of volcanic islands. Compositional magnitudes decay exponentially from distributary structures ("mineralization centers"), which structures map as mathematical singularities--graphically, peaks on the trend surfaces (Botbol and others, 1978; Neuerburg and others, 1974).

Metal specialties, quantity gradients ("halos"), and metal zonings of lode modules are varied, numerous, and complex. Their modalities are dominantly geography-related; that is, provincial-distinctive or parochial-distinctive. A few modal metal-rock associations are apparent, such as molybdenum with granitic rocks, rare earths with alkalic igneous rocks, and diamond with kimberlite.

Lode modules infuse limited segments of endomorphic and alteration modules. As distinct from lode differentiates and the analogous lode facies of sedimentary rocks, lode modules are universally enclosed in altered rock. Structural styles of lode fillings relate to the geometry of openings characteristic of the host module: (1) intergranular moldings in massive igneous modules and interspersions among particles of clastiform igneous modules, (2) central cavity fillings and linings in endomorphic modules, and (3) fillings and linings along the complex of fractures on which alteration modules are focused. The crustal distribution of lode modules is more restricted than that of the other modules; volumetrically, it is the least part of the edifice.

Sedimentary-set.--The mineral edifice decomposes on exposure at the Earth's surface into chemical (dissolved) and physical (clastic) fragments. The fragments are dispersed in myriad sortings onto the crust. The four intrinsic structural components of the mineral edifice are combined to form one infinitely varied structural component of the set (sedimentary rocks). Geopetal accumulations of rock fragments and chemical precipitates--and their metamorphic transforms--comprise this sole module of the sedimentary-set. Mineral deposits are in the set but are not topologically discrete. They grade without discontinuity into other sedimentary rock types; they are lode facies, not lode modules.

The outcrop arena of a mineral edifice is an area of ongoing physical and chemical destruction of the exposed modules and of mechanical dispersion of the pieces. Mappings of the debris ("landscape geochemistry"--Bradshaw, 1975) within the outcrop arena are recognizable deformations (Maranzana, 1972; Neuerburg and others, 1978; Siems and others, 1979) of the corresponding mappings of the mineral edifice. Overall, modules of the mineral edifice lose their integrity with distance from the outcrop. The fragmented modules are blended and the pieces are variously sorted. The fragments become smaller and their physical-chemical properties are modified so that at some distance from its source a fragment is no longer recognized as being derived from a mineral edifice.

The decay of identity of fragments with distance and (or) time from the materials source (provenance) is the pertinent topologic invariant of the sedimentary-set. As used here, "identity" is pragmatically ranked by the certainty of recognizing debris from a mineral edifice despite (1) chemical modifications, as in oxidation of sulfides, (2) extreme reduction of grain size, as with brittle minerals (Mannard, 1968), (3) infinite dilutions, as expressed by the particle sparsity effect (Clifton and others, 1967), or (4) chance intersections with exclusive sortings, such as heavy mineral concentrations. The curve of identity decay is inevitably fractal and unpredictable.

TOPOLOGY AND PROSPECTING

The application of topology to prospecting is treated purely from the perspective of how best to find an object of specified characteristics: a mineral deposit, a mapping singularity, a chemical extremum. The object exists and is manifest in the landscape by inherent properties that can be observed and measured and (or) by known patterns of association (Callahan, 1977). Economic aspects of prospecting (Parker, 1974; Vannier and Woodtli, 1979) are excluded from this analysis because they are ephemeral value judgements.

Prospecting is divisible into three phases, each guided by appropriate rules for its methodology. The phases are: (1) determining an optimal search arena on or in the crust, (2) locating lode modules within that search arena, and (3) mapping the lode module to locate and identify its singularities (metal concentrations; mineral deposits). Testing the singularities for qualifications as ore is a separate discipline and is not treated here.

The intrinsic and orderly position of the lode module and lode differentiates in the intra-crustal mineral edifice together with the inclusion of lode deposits as non-singular facies in the supra-crustal sedimentary-set means that mineral deposits are a normal although unpredictably disposed component of all parts of the crust. With this observation comes a recurring dictum: no spatial or temporal relations, quantitative or qualitative, exclude the possibility of a nearby mineral deposit. Metric data are only positive or neutral (Botbol and others, 1978). Likewise, empirical modes derived from published mappings of mineral edifices serve to outline optimal search areas (Tischendorf, 1969), never to exclude areas. Obviously, the positive data and optimal modes are the particular attributes of significance to prospecting.

Apart from known exposures and geologic inferences, lode modules, lode differentiates, and lode facies of a search arena are located by following recognized lode debris upstream to its source, the ancient practice of "shoading" (Thrush, 1968). This phase of prospecting is governed by the parameters of identity decay in the sense that the lode identity of fragments is more easily seen and more certainly recognized with proximity to the lode module or lode rock, whether by better preservation, larger number of fragments, or both.

The lode module is all the materials emplaced by mineralization; quantities of these materials vary irregularly in space. The quantity distribution of each lode element is spatially focused on one or more geologic structures, which appear as singularities on a composition mapping. Thus, mapping is the topological method of choice for locating element singularities that may pinpoint an ore deposit.

The quantity of an element at each point in the lode module is measured from a sample and is unique to the particular piece of rock as a function of the size and shape of the rock sample. The scale of sample size must be constant for any mapping in order to preclude artificial singularities or gradients, but may differ between mappings. Ideally, sample size is the bulk volume from which the subsample for analysis is taken. Sample size is a spatial attribute and must be in units of volume (Whitten, 1975). Sample shape must be uniform and preferrably isotropic over all styles of lode geometry in order to assure objectivity. Except for homogeneous rocks of massive structure, an isotropic sample shape is ideally spherical (impractical!).

Site-heterogeneity and the fractal configurations of lode mappings bring to mind the identity parameter for useful and pragmatic methods of mapping singularities of a lode module. Recognition of a singularity is based on a gradient of increasingly higher assays and on an increasing density of visible signs of lode filling toward the singularity. Thus, samples with maximal attributes of lode fillings are chosen, such as multi-fractured sulfidic rocks as little weathered as possible. Several samples are taken from each collecting site as an additional gambling strategy for finding and measuring maximal assays. To further aid recognition of lode fillings, lode-selective methods of analysis (Neuerburg, 1975; Olade and Fletcher, 1974) are used. The highest assays from the several samples of an outcrop, or of a specified area, are used for the mapping points of an identity-trend surface of lode modules (Neuerburg and others, 1974, 1978).

TOPOLOGY, ORIGIN AND PROSPECTING

Theories of origin of mineral deposits address questions of sources and timing in relation to the host rocks, of processes of formation, and of the intensive properties of the lode-depositing environment. Each of these questions relates to some aspect of the topology of mineralization. Questions of source and timing relate to invariants of morphology and of position. Theories of processes of formation are explanations of associations, sequences and the parochial distortions. Intensive parameters (such as temperatures of deposition) are equivalent to a conversion and generalization of empirical properties into dynamic properties.

Questions of source and timing are fundamental dichotomies of geology (Amstutz, 1960); the dichotomies are inherent in topology. The morphology produced by exogenesis (permeation from a center) and that produced by endogenesis (secretion into a center) are identical; the configuration is a mathematical property of particle distributions about a center (Mandelbrot, 1977). Lode facies of the sedimentary module may be judged as epigenetic or syngenetic (Lovering, 1963) depending upon whether the lode minerals are clastic particles or interstitial chemical precipitates (cement) in the rock, but this judgement is only a secondary mapping. Parenthetically, a lode facies is part of an identity decay pattern, as illustrated by ancient epigenetic uranium deposits in Wyoming (Stuckless and others, 1977) and by modern syngenetic gold placer deposits in general.

Process models, descriptive of the mechanics of construction of the mineral edifice (such as plate tectonics and igneous differentiation schemes) summarize empirical relations in Ernst Mach's imagery of scientific economy, but add no new road signs to mineral deposits. Likewise, substitution of intensive parameters for the objective measurements of a mapping is conceptually no more than a change of scale--a secondary mapping. Both processes and intensive parameters depend upon empirical mappings so have no direct practical application to prospecting, although they often suggest some useful relation or parameter that has been overlooked. Finally, "answers" of origin are largely irrelevant for prospecting; the mineral deposit exists however it may have formed (Bridgman, 1956; Hosking, 1967).

CONCLUSIONS

The ordering of the known, objective spatial and metric properties of mineralized rocks onto topology makes clear the universality of mineralization as a phenomenon in crustal evolution, and is a rationale for the unpredictability of the dimensional attributes of mineralization as well as of its geographic co-ordinates. The strictures of this topology are that each metric configuration must be mapped and that scale integrity is mandatory for each mapping. Position is the paramount parameter of mineralization for prospecting. Position is quantified as the degree with which recognized properties of the materials at a sampling site match the properties, the identity of the object being sought. Finally, although topology excludes precise prediction of ore, no measured property or observed relationship excludes the possibility of a mineral deposit.

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