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A preliminary scheme for multihierarchical rock classification for use with thematic computer-based query systems

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Abstract: A multiple hierarchical system of rock classification is introduced to permit widely applicable thematic querying of bedrock geological databases. The classification is based on three main rock characteristics: composition, texture, and fabric. These characteristics permit queries that would yield results useful across scientific disciplines that rely on rock properties (e.g. agriculture, forestry, fishery). In addition, rock names in the classification are linked to the common geological genetic criteria: igneous, sedimentary, and metamorphic. These genetic assignments would yield results useful for traditional geological thinking. The linkage between a rock classification built on rock properties and fundamental rock genesis appears to provide the most versatility for computer-based rock database systems. The scheme is extensible and can easily adapt to the evolution of genetic concepts.

Résumé : Un système de classification des roches à hiérarchie multiple est présenté. Celui-ci devrait permettre de réaliser des recherches thématiques aux applications étendues dans des bases de données géologiques sur le substratum rocheux. La classification repose sur trois caractéristiques principales des roches : la composition, la texture et la fabrique. Ces caractéristiques permettent d'effectuer des recherches qui devraient procurer des résultats utiles à tout un éventail de disciplines scientifiques ayant recours aux propriétés des roches (p. ex., l'agriculture, la foresterie et la pêche). En outre, les noms de roche utilisés dans la classification sont liés aux critères génétiques usuels en géologie : magmatique, sédimentaire et métamorphique. Ces attributs génétiques devraient fournir des résultats utiles pour les études fondées sur les approches géologiques classiques. La création d'un lien entre un système de classification des roches qui repose sur les propriétés physiques et un autre qui s'appuie sur les aspects génétiques fondamentaux semble offrir le plus de polyvalence quant aux systèmes de bases de données informatisées sur les roches. Le modèle est extensible et peut facilement être adapté à l'évolution des concepts génétiques.

INTRODUCTION

This paper describes a model for rock classification designed for use with geological map databases, particularly the North American Data Model (NADM). This classification model was created for use with the prototype Canadian digital bedrock geology map dataset being prepared for the Canadian Geoscience Knowledge Network (CGKN) (P.H. Davenport, J.M. Journeay, E. Boisvert, and S.P. Colman-Sadd, GSC project proposal, 2000; J. Broome, E. Grunsky, and J. Rupert, Geoconnections Project Proposal, May 2001). For the Canadian Geoscience Knowledge Network digital bedrock geology map of Canada, the rock classification scheme must accommodate the diversity of rock names present in existing and future map legends. It is distinct from the classification system for rock names being developed within the North American Data Model science language committee (Digital Geologic map data model; Science Language Technical Team Charter; http://geology.usgs.gov/dm/steering/teams/language/charter.shtml, 1999) and the rock naming system developed by the British Geological Survey (Gillespie and Styles, 1999a, b; Hallsworth and Knox, 1999; Johnson et al., 1998a, b). The multihierarchical model of classification is meant to take the full gamut of existing rock names and instill them with information designed to maximize the query capability of a geological GIS. As such this model would work with different existing rock-naming systems. Some characteristics of the classification system used here would permit more diverse naming systems than presently exist. The multihierarchical classification system is yet to be implemented and changes and additions are anticipated prior to and during implementation.

Rock classifications for thematically based computer queries of geological databases are most useful in a hierarchical structure (Gillespie and Styles, 1999a, b; Hallsworth and Knox, 1999; Johnson et al., 1998a, b). Existing rock classification schemes are based on a single hierarchical system. Rock names, however, imply a combination of several attributes, commonly including: composition, texture, fabric, and genesis, and because of this mixed parentage they are not easily assigned to a single hierarchical classification. The system proposed here consists of a set of hierarchical classifications. Each hierarchy is independent and based on a single attribute. Each rock type is assigned to its most specific characteristics within the set of attribute hierarchies. Queries done on one or more generic characteristics would then capture occurrences of all the specific rock names that are linked to those characteristics. This would allow diverse queries, using standard attribute classes, of the varied lithological nomenclature used by geologists.

Traditional rock classification has been based on a mixture of criteria reflecting the diversity of distinct rock features and our penchant for association of the rock with how it might have formed (Grabau, 1920; Tyrrell, 1948; Williams et al., 1954; Deeson, 1983). When setting up rock classification systems geologists generally vacillate between this penchant and wanting to set up a classification scheme devoid of genetic implications (an exception was Grabau (1920)). This dichotomy is reflected in the use of the genetic terms igneous, sedimentary, and metamorphic for the highest level of rock classification, and the change to the use of rock properties at the more detailed levels of classification (Tyrrell, 1948).

The thesis of the classification system presented here is that both property and genetic classifications can be used together to reflect the diversity of our intended uses. The internal hierarchies of the classification schemes are each based solely on individual rock properties or genesis. Such a system provides purity of classification, diversity of use, extensibility of classification, and ease of modification to the genetic interpretations.

The primary rock classification hierarchy of this system is based on rock properties. Individual rock types are then assigned a genetic heritage. By doing it this way we satisfy the expressed desire to define rocks solely on their properties (Gillespie and Styles, 1999a, b; Hallsworth and Knox, 1999; Williams et al., 1954; Tyrrell, 1948). This paper primarily uses the rock names and the rock naming scheme of the British Geological Survey (BGS) to illustrate the multihierarchical classification system. The paper shows an example of how that scheme can be broadened into a model using the diversity of the multihierarchical classification.

ROCK CLASSIFICATION SYSTEM

The proposed rock classification system consists of two main parts; hierarchical indexes based on material properties and a hierarchy of rock genesis to which each rock is assigned. The material property hierarchies are based on three criteria: composition, texture, and fabric. The genetic hierarchy is based on the three categories: igneous, sedimentary, and metamorphic. The underlying principles of the classification system are: to maintain as broad a diversity in rock properties as possible to maximize the thematic query potential of the database; to maintain distinct material property versus genetic hierarchical classification; and to provide an extensible property classification system to expand future thematic query possibilities.

Rocks have more than one material property and by definition have a unique genetic history. Because they can have multiple properties, they can be classified by more than one property. Using hierarchical indexes, a rock name (and any qualifiers) can be classified as generally or precisely as the source information allows. In developing this scheme, the source information considered is mainly the unit descriptions from geological maps, since it is being developed as part of a national bedrock geology database project (P.H. Davenport, J.M. Journeay, E. Boisvert, and S.P. Colman-Sadd, GSC project proposal, 2000), but with a view to making it extensible for other sets of rock names. This contrasts with other classification systems which attempt to assign a unique position to a rock type in a single hierarchical scheme. A single scheme constrains the classification by making genesis or one type of property more important than others, and introduces bias from the outset. Our system is designed to work with the North American Data Model for geology (Johnson et al., 1998a, b), and in particular its later variant (version 5.2).

Composition, texture, and fabric were chosen to create the material property hierarchies for rocks because they are the key properties used to describe and identify a rock. It could be argued that fabric is a subcategory of texture. It is separated here because fabric is the predominant differentiating characteristic of deformed rocks. Crystalline and some other rocks have been most commonly differentiated using their composition. Textural variation is the most ubiquitous criteria for all rocks, and fabric has been the most prominent naming criterion for deformed rocks.

Composition

Within the proposed classification system, silicate versus nonsilicate rocks head the compositional hierarchy (Fig. 1a, 1b, 1c), as silicate rocks are the predominant class of rock types in the Earth's crust. Silicate rocks in turn are divided into felsic, intermediate, mafic, and ultramafic compositions to reflect the chemical spectrum of rock classification traditionally applied to silicate rocks (Williams et al., 1954; Fig. 1a, 1b, 1c). Nonsilicate rocks have been divided into various types dependent on their principal anion (e.g. carbonate versus halide). A few fourth-level subclasses are included in the compositional hierarchy (Fig. 1), but more could be added to accommodate more specific compositional information.

Texture

Texture within this classification scheme describes the size, shape and arrangement of a rock's distinguishable components and the variation of those features within a rock. Texture is divided into crystalline versus granular rocks (Fig. 2). This differentiation separates rocks with completely intergrown components from those that potentially have pore space between their components (i.e. interlocking versus noninterlocking).

Crystalline and granular rocks are further subdivided by three categories of grain-size characteristics: cryptocrystalline or cryptogranular, equicrystalline or equigranular, and inequicrystalline or inequigranular. Cryptocrystalline or cryptogranular describe rocks whose grain size cannot be visually discerned. Equicrystalline rocks may be further divided (if the information is available) into fine, medium or coarse grained. Inequicrystalline rocks are subdivided by the nature of their coarser crystals (porphyritic, augen, blastogranular). A further set of classes based on the size of the coarser crystals could be added as an additional level.

Equigranular rocks are divided into two classes based on grain size: sand size and silt size. Coarse-grained granular rocks are almost invariably visibly inequigranular. Inequigranular rocks are subdivided by clast shape (angular (breccia)) or (rounded (conglomerate)), then by clast size: coarse and very coarse. The terms coarse and very coarse are introduced to accommodate the difference between the clast-size scales of sedimentary and fragmental volcanic rocks. Coarse in this context is equivalent to granule and pebble sizes in the sedimentary scheme and lapilli in the volcanic scheme (Hallsworth and Knox, 1999). Very coarse is equivalent to cobble and boulder sizes in the sedimentary scheme, and bombs and blocks in the volcanic scheme.

Fabric

Rock fabric is used here to separate rocks that are uniquely massive, from those which, as part of their definition, have some degree of sheeting. Fabric is subdivided into massive, foliated, gneissic, platy, and flaser (Fig. 3). Foliated rocks look like amalgamated leaves (folia) aligned in sheets that usually flow around small globular grains or crystals. Gneissic rocks are characterized by dominantly coarse globular to aligned elliptic grains or crystals in a matrix of similarly aligned amalgamated leaves. Platy rocks have a strong planarity like that of slate. Flaser rocks have an alignment of compositional or coloured banding of fine grains or crystals that may surround or appear to flow about globular grains or crystals (e.g. ultramylonite). Fabric is the dominant feature that defines such rocks as schist, mylonite, and gneiss.

Genesis

The genetic hierarchy for rocks is used in this classification to assign a genetic attribute to all rocks (Fig. 4). This is done to satisfy the working requirements of geologists who primarily think about rocks in the context of how they formed. For example, a geologist would want to be able to plot the location of all volcanic rocks in a map area, regardless of their compositional or textural characteristics. The existing emphasis to divide all rocks by whether they are igneous, sedimentary, or metamorphic may owe itself to this persistence of geologists to think genetically. The genetic terms in this particular hierarchy are for lithologies as opposed to rock units. This distinction is emphasized, as genetic scenarios as complex as paleotectonic settings can be determined for suites of rock within a geological unit or grouping of units, whereas in most cases a simple physical process of formation or possibly a physical environment is all that can be determined from a rock name.

Subdivision of igneous rocks into intrusive and extrusive permits the query and reporting of these classic divisions of primary genesis. Further subdivision of extrusive rocks into explosive and flow appear to be as far as genetic information can be inferred from unqualified rock names. For example andesite can be an intrusive or extrusive rock, whereas andesite tuff is an explosive extrusive rock. To establish a genesis of, for example, a Plinian explosive extrusive requires a degree of qualification to the term andesite tuff that rarely exists in geological map legends.

Subdivision of sedimentary rocks by deposition into mechanical (clastic) and chemical (precipitates) follows the scheme of Williams et al. (1954). A third subclass, biogenic, is added to adequately classify rock such as coal. In some cases, rock names themselves provide information that allows a further level genetic classification (subaerial, glacial, or subaqueous for mechanical deposition, and evaporitic or nonevaporitic for chemical precipitates). As with igneous rocks, unqualified rock names yield little genetic information beyond these categories, and many can only be classified at the igneous-sedimentary-metamorphic level.

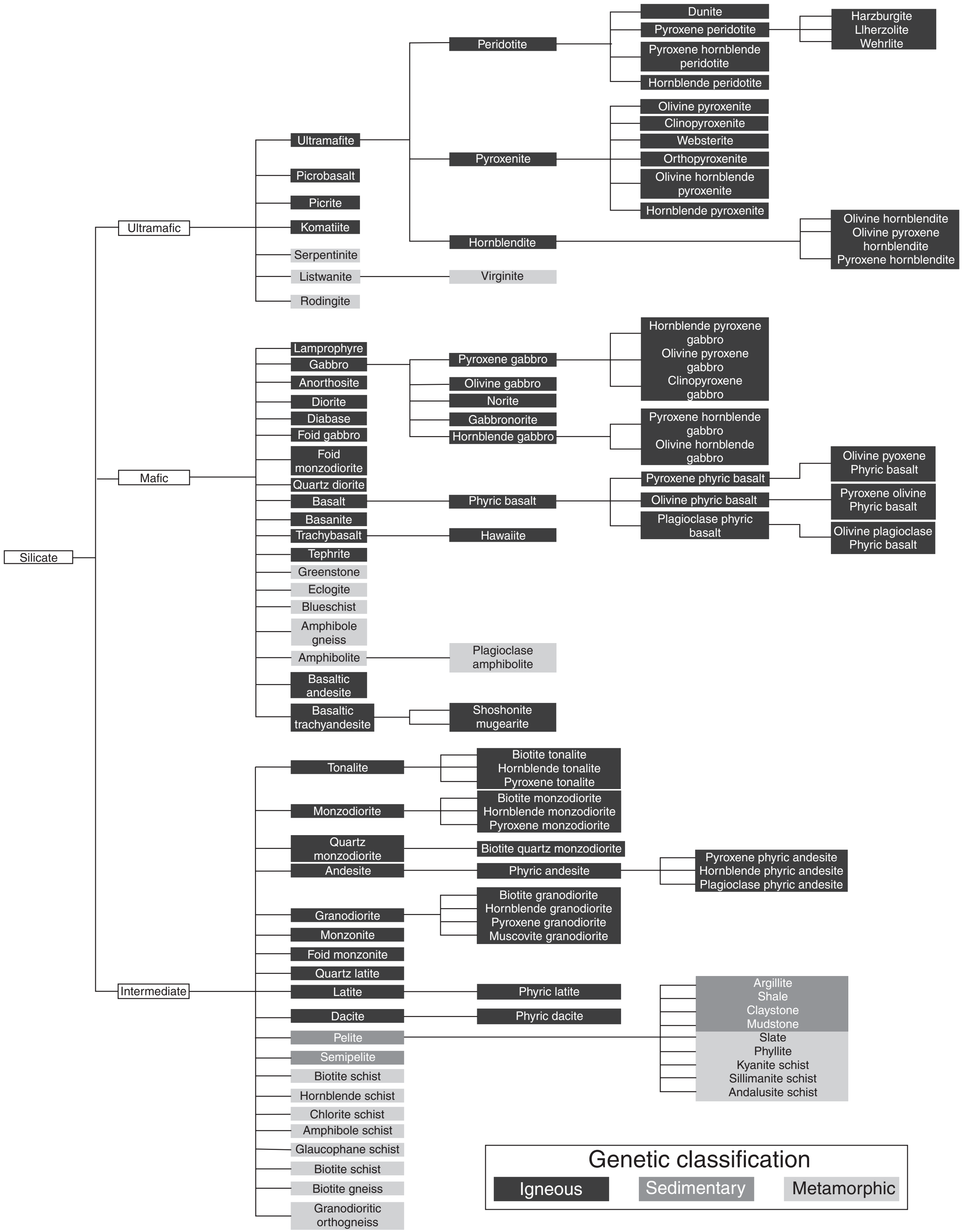

Figure 1. a) *Hierarchical classification of rock types based on composition: silicate rocks. Examples of rock names that fall into each of the most detailed classes are included and coded by their top-level genesis.*

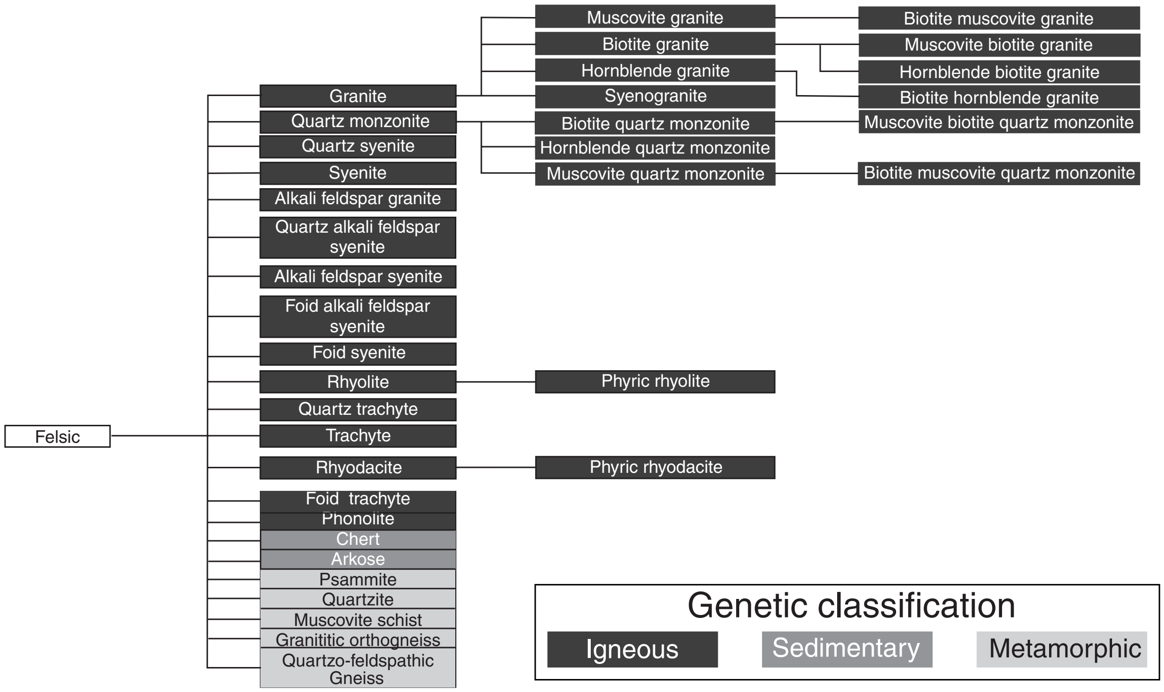

***Figure. 1b**) Hierarchical classification of rock types based on composition: silicate and/or felsic rocks. Examples of rock names that fall into each of the most detailed classes are included and coded by their top-level genesis.*

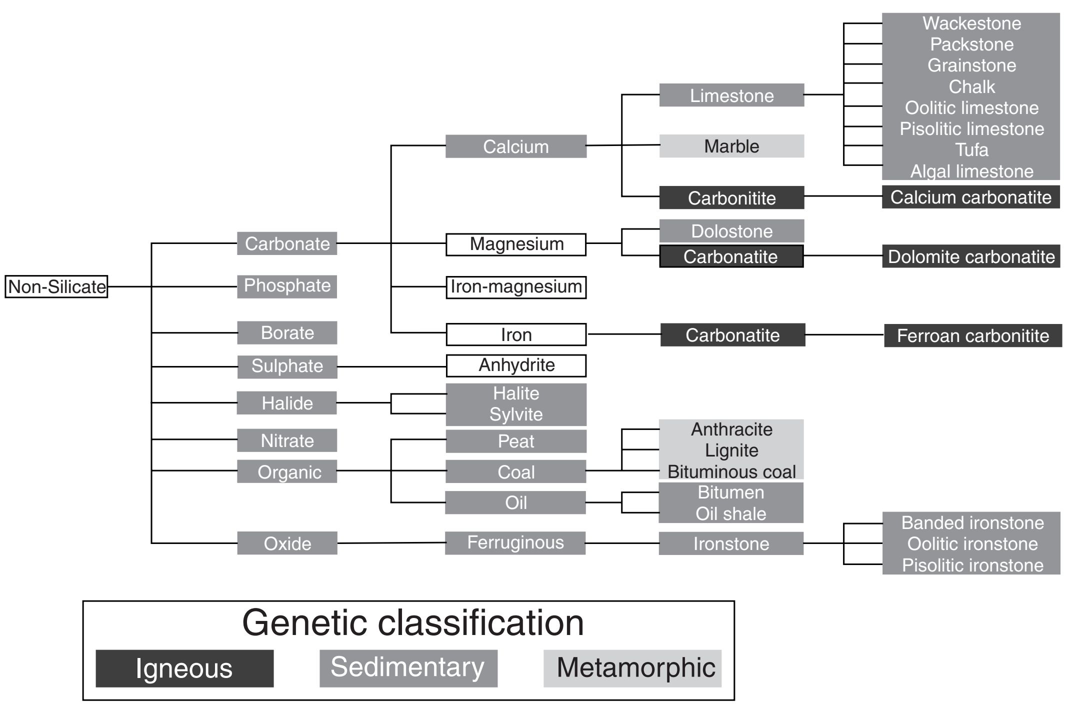

***Figure. 1c**) Hierarchical classification of rock types based on composition: nonsilicate rocks. Examples of rock names that fall into each of the most detailed classes are included and coded by their top-level genesis.*

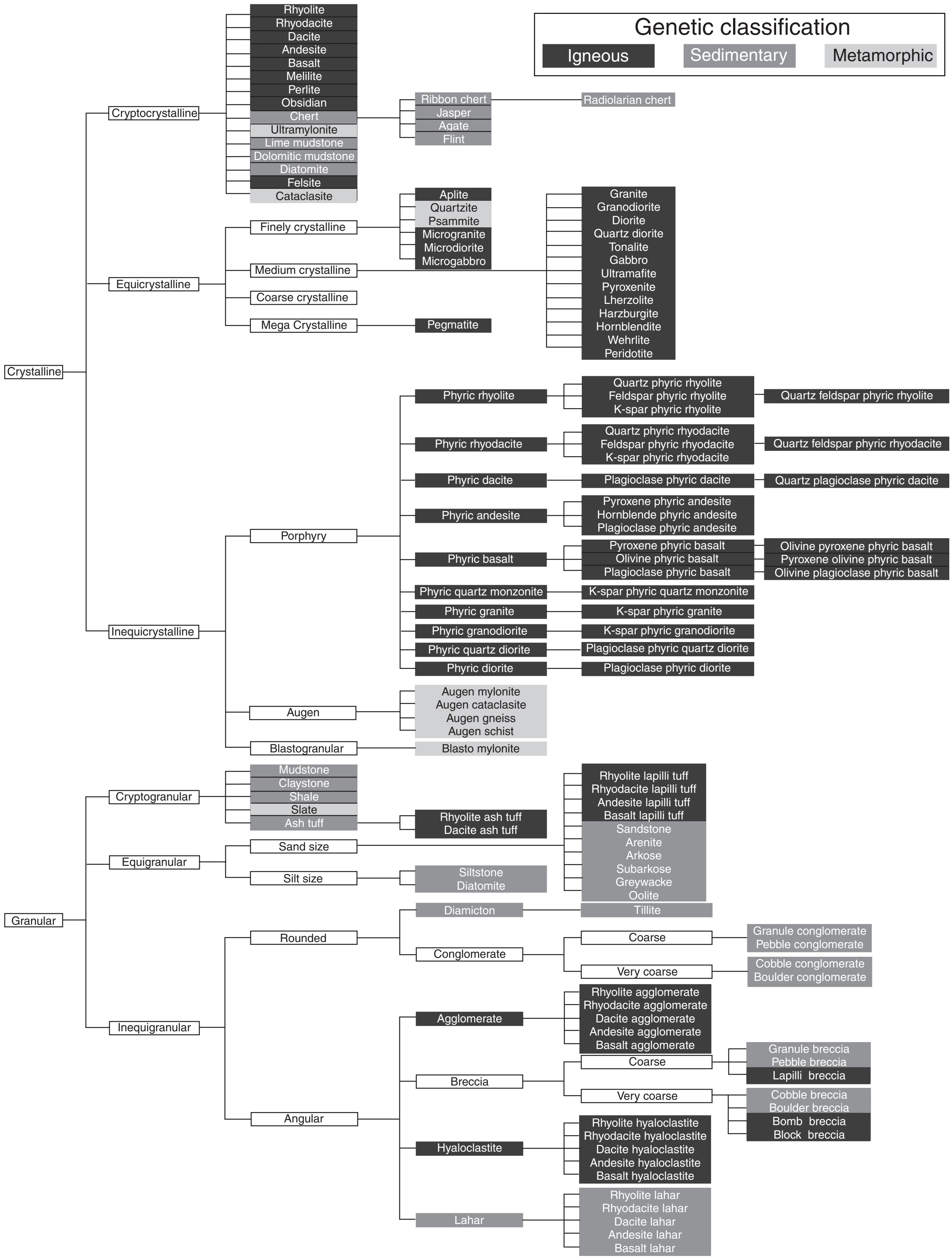

Figure 2. *Hierarchical classification based on texture. Examples of rock names that fall into each of the most detailed classes are included and coded by their top-level genesis.*

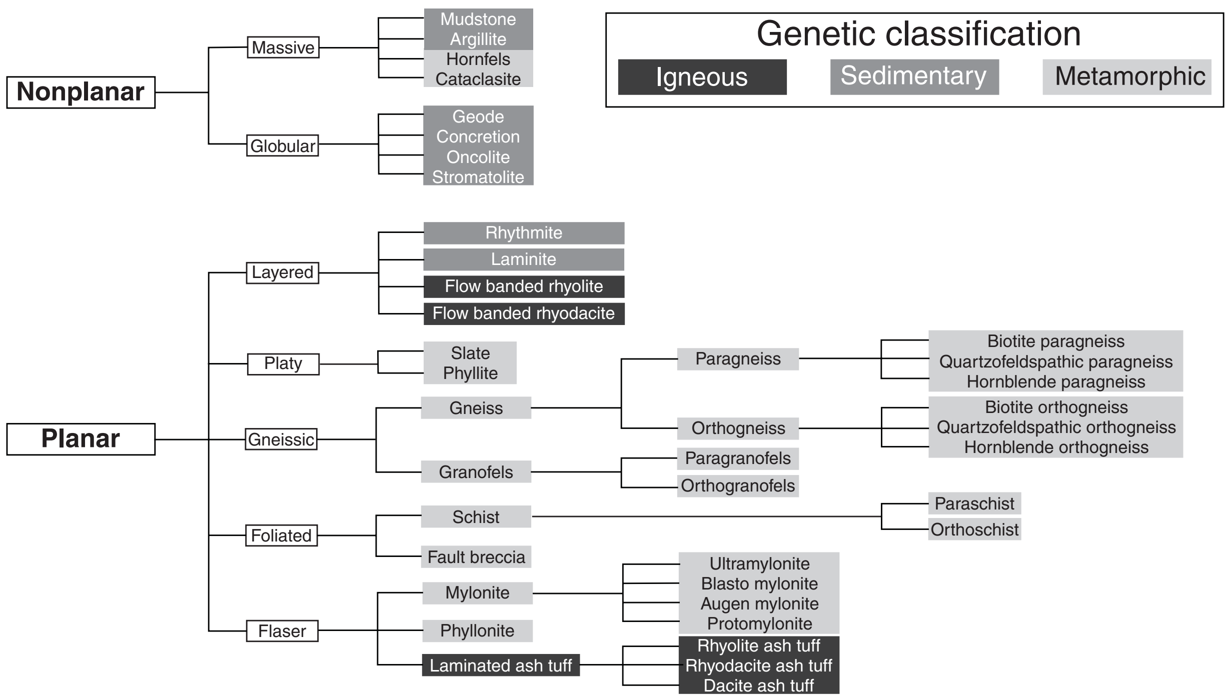

Figure 3. *Hierarchical classification based on fabric. Examples of rock names that fall into each of the most detailed classes are included and coded by their top-level genesis.*

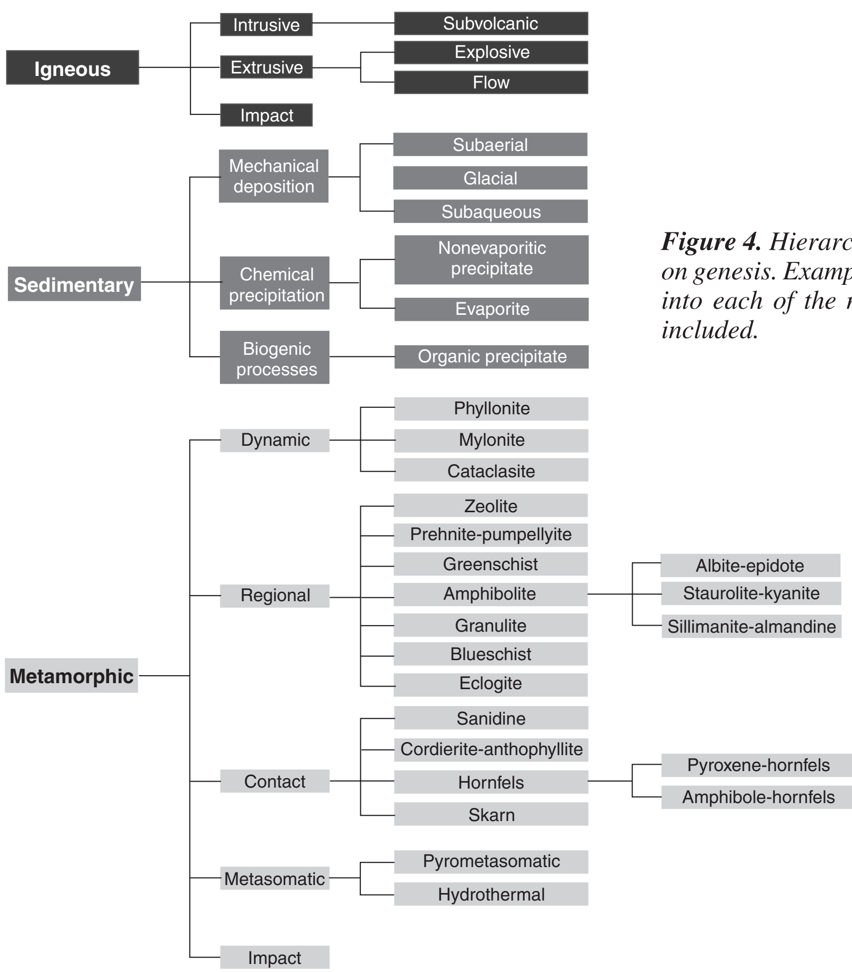

Figure 4. *Hierarchical classification based on genesis. Examples of rock names that fall into each of the most detailed classes are included.*

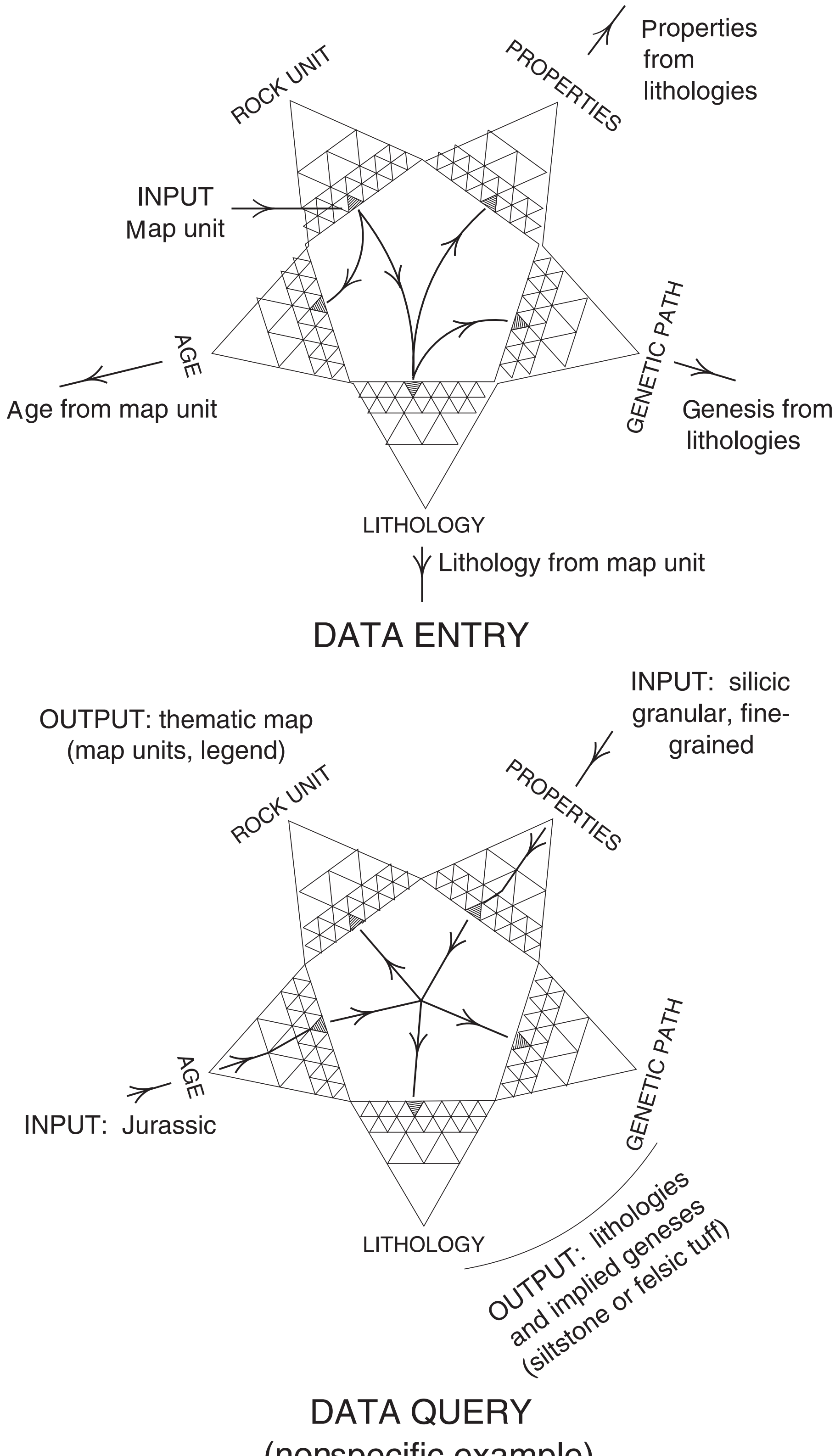

Figure 5. *Information flow during data entry and data query stages in the National Bedrock Geology Database project. A general level (nonspecific) example of a query is shown. Input requests could be through any of the five hierarchies.*

Metamorphic rocks are divided into four subclasses: dynamic (unannealed high strain), regional, contact, and impact. Regional metamorphism has been subdivided into seven subclasses, and others could be added. Both the dynamic and contact classes could also be extended to a more detailed level if necessary. Two subclasses of metasomatism are probably adequate to capture the genetic information contained in most rock names, although, as in all of these classifications, subdivisions can be added to the branches to increase the level of detail.

DISCUSSION AND CONCLUSIONS

The hierarchical rock classification scheme proposed here is an attempt to create a thematically consistent means to allow queries of lithological information in a bedrock geology database, where the rock names imply a variety of combinations of genesis and rock properties (composition, texture, and fabric). It is intended to add further options to the diverse query needs of geologists and nongeologists.

In practice, the rock names used to describe map units by their authors will be identified and indexed by as many of the four classification schemes as is implicit in each name itself. In each of Figures 1 to 4, a selection of hierarchically related rock names are linked to each of the most detailed classes to illustrate how we envisage the hierarchical indexes being applied. The use of hierarchical classification schemes means that each rock name can be categorized as generally or as specifically as the author's description allows. Because the most detailed levels are related in the database to all the higher levels in the branch, a query such as "select all rocks whose genesis = metamorphic" will not only select those indexed at this level (Fig. 4), but also all those classified in more detail on this branch (dynamic, regional, contact, and impact, and any further subclasses of these categories). Furthermore, queries based on combinations of two or more criteria from the four schemes can be constructed, and return the rock names that satisfy these criteria. As the rock names come from an analysis of the map unit descriptions, ultimately these queries can be made to return map units, and thus produce a map of the query results — a customized geological map. This information flow, data input, and query result output is illustrated in Figure 5.

The scheme is extensible, as it permits the addition of new classification subtrees to accommodate more map information, or to allow additional ways to query the information. In addition, it provides the flexibility to change genetic interpretations of rocks, without redefining its relationships within the material property-based hierarchy. The hierarchy does rely in part on how rocks are named as addressed by the classification proposed by the BGS (Gillespie and Styles, 1999a, b; Hallsworth and Knox, 1999). Continued refinement will be necessary as we gain experience in building and using the map database.

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Boyan Brodaric and Murray Journeay provided connections to current thinking on classifications systems and particularly to the science language committee of the North American Data Model working group who were developing ways to incorporate composition, texture, and fabric into their classification schemes. Thanks to the Canadian Geoscience Knowledge Network and Bedrock Geology Database for Canada working teams for their support. The authors wish to thank J.M. Journeay for critical review of the manuscript.

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