APPENDIX B

CLASSIFICATION OF METAMORPHIC AND OTHER COMPOSITE-GENESIS ROCKS, INCLUDING HYDROTHERMALLY ALTERED, IMPACT-METAMORPHIC, MYLONITIC, AND CATACLASTIC ROCKS

Version 1.0

North American Geologic-map Data Model Steering Committee

Science Language Technical Team (SLTT)

Composite-Genesis Subgroup

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

A provisional draft classification system for metamorphic rocks and other composite-genesis rocks is proposed as part of a comprehensive scheme for use in digital geologic maps and computer-based geoscience information systems in North America. The purpose of the rock classification is to identify lithologic constituents of map units or to search digital geologic-map databases for specific rock types.

The domain of this classification system includes not only metamorphic rocks as commonly understood, but also a variety of hydrothermally altered, mylonite-series, cataclastic, and impact-metamorphic rocks. We classify these composite-genesis rocks according to descriptive properties that reflect the multiple processes that make the rock composite. This classification is fundamentally descriptive, based mainly on rock composition and fabric; therefore, different observers should be able to classify a rock in the same way. Assignment to a lithologic class implies that certain descriptive criteria are met, and these criteria must be defined in the database. This classification also attempts to follow common usage of terms in the geoscience community, reconciling that usage and database requirements wherever necessary.

This report summarizes the logic and rationale for the classification system, which is presented in a series of four diagrammatic decision trees, two class hierarchy diagrams, and a glossary in the form of a Microsoft Access database that has definitions and parent-child relationships for terms in the classification system. Comments from the geoscience community on this proposed classification are encouraged.

2 INTRODUCTION

This document (hereafter referred to as SLTTM_1.0) proposes a provisional classification system for metamorphic rocks and other composite-genesis rocks as part of a comprehensive scheme for use in digital geologic maps and computer-based geoscience information systems in North America (http://geology.usgs.gov/dm/). The purpose of an Earth material terminology system (or controlled vocabulary, see introduction to NADM science language) is to provide a basis for identifying and describing materials that are the substances of the Earth by classifying them using standard terms and definitions. Classification links the normative description (definition) for a term to the material being described. Rock-lithology classification has two important functions in geoscience information systems. First, in the case of rock descriptions, a lithologic constituent of a geologic-map unit may be identified using a standard rock classification in cases for which a detailed description of the rock is unavailable or unnecessary. Second, in cases for which lithologic constituents are described in detail, assignment of the constituent to a standard rock classification allows users to search for standard kinds of rock without having to design queries that analyze the complete description structure. A lithology field in a geoscience database is a place for classification of the constituents used to describe bodies of rock.

This report describes the rationale for the accompanying classification system, which is presented in a series of four linked decision trees (flow charts), two class hierarchy diagrams, and an accompanying glossary in the form of a Microsoft Access database that has definitions and parent-child relationships for terms in the classification system for composite-genesis rocks.

The domain of this classification system includes composite-genesis rocks, defined as rocks that are the product of more than one rock-forming process. They are not purely igneous or sedimentary. This domain includes metamorphic rocks as commonly understood, as well as impact metamorphic rocks, hydrothermally altered rocks, mylonite-series rocks, and cataclastic rocks. These composite-genesis rocks are classified strictly according to descriptive properties related to the changes that made them ‘composite.’

2.1 Composite-genesis rocks

2.1.1 Definition

Composite-genesis rock—Any rock having observable features that document mineralogical, chemical, or structural change of a preexisting earth material essentially in the solid state. It includes metamorphic (*sensu strictu*), hydrothermally altered, cataclastic, and impact-metamorphic rock, but not weathering products or soils.

A metamorphic rock has observable features that document change after the original formation of the rock, under physical or chemical conditions that differ from those normally occurring at the surface of the Earth and in zones of cementation and diagenesis below the surface (Smulikowski and others, 1997). Hydrothermally altered rock has fabric and composition indicating solid-state mineralogical and chemical changes in response to hot, mineral-rich waters, and is included as ‘metamorphic rock’ in this classification. Cataclastic rock, impact-metamorphic rock, and composite-genesis melt rocks are treated as special classes. Where possible, metamorphic classification schemes proposed by the British Geological Survey (Robertson, 1999) and preliminary recommendations of the IUGS Subcommission on the Systematics of Metamorphic Rocks (SCMR) (Schmid and others, 2002) were adapted to meet SLTT database requirements.

The composite-genesis rocks are classified along two orthogonal dimensions, fabric and composition (Figs. 1 and 2). Class hierarchy is a directed acyclic graph rather than a tree. Classes that have composition and fabric criteria are ‘children’ of both a ‘composition and fabric’ lithology parent, and of a generic composition and a generic fabric parent. Class names have a fabric component (such as granofels) and a compositional component (modifier such as marble or quartzofeldspathic).

2.2 Background and purpose

A standard North American database model for the input, storage, manipulation, retrieval, and analysis of digital geologic-map information is being developed as a cooperative effort by a consortium of interests including the Association of American State Geologists (AASG), the U.S. Geological Survey (USGS), the Geological Survey of Canada (GSC), and the Canadian Provincial Surveys. The standards for this data model are being developed under the auspices of the multi-constituency North American Data Model Steering Committee (NADMSC, http://nadm-geo.org). The NADMSC has commissioned technical teams, including the Science Language Technical Team (http://nadm-geo.org/sltt), to develop aspects of the data model. Thus, the purpose of the Science Language Technical Team (SLTT) is to develop standard terminology for classifying and describing geologic materials for digital geologic-map databases produced throughout North America. The Science Language Technical Team includes four subgroups: the Subgroup on Plutonic Rocks, the Subgroup on Volcanic Rocks, the Subgroup on Sedimentary Materials, and the Subgroup on Metamorphic Rocks. This draft report was produced by the Subgroup on Metamorphic Rocks.

2.3 Definitions: classification, naming, and description

Classification is the assignment of an instance (individual object from some point of view) to a group (class) that is defined based on a shared set of properties. It answers the question "what kind of X is Y?" where X represents the domain of the classification. A class of things is defined by the set of the properties shared by members of the class. Boundaries of the class are defined by threshold property values.

Naming is assignment of an identifier to an instance (object within a class). Ideally, every instance would have a unique name, but of course in the realm of earth and planetary materials, this is not the case. Formalized stratigraphic nomenclature is an example of naming mappable units. Lithologic naming provides an identifier for a particular rock or Earth (and planetary) material that allows geologists to communicate when formal nomenclature is not defined, or when they need to subdivide in more detail than the formal nomenclature allows. Names are also assigned to identify individual classes in a classification system (each class is an instance of a class!).

Description is a set of statements that characterize the nature of a thing (a class or instance) such that the thing may be identified. The set of shared properties that define a class constitute a description.

2.4 Conceptual framework

Lithologic classification is the assignment of a rock or unconsolidated material to a named class defined based on its physical properties. The scope of the classification, 'rock or unconsolidated material', corresponds to the concept 'CompoundMaterial' as defined by the North American Geologic Map Data Model Steering Committee Data Model Design Team (NADMSC, 2003). In this report, the term 'material' is used in place of the more precise, but less familiar, term 'CompoundMaterial' to mean 'rock or unconsolidated material'. Note also that this concept may be extended to include not only materials found on Earth (as defined by NADMSC, 2003), but also any planetary material. Lithologic classification is used in a number of contexts. The field geologist classifies rocks as part of the process of defining mappable bodies of rock within a geographic area. A map compiler uses the classification of rocks that compose geologic map units to determine similarity between units on different maps, or as criteria to define composite map units that combine features of more detailed maps. A non-geologist uses the classification system to identify rocks of interest without having to study their descriptions in detail. Earth scientists use standard classification systems to characterize rocks as part of the process of describing them. These applications highlight two sorts of classification process—one aimed at identifying particular bodies of rock in a particular region, and one aimed at grouping similar kinds of rock that may be present in many places.

Lithologic classification is scale dependent. Hand-sample-dimension lithologic classification systems are designed to group kinds of material into named classes based on a 1-cm to 30-cm diameter representative volume. A particular rock name, based on a naming scheme such as that proposed by the British Geological Survey (e.g. Robertson, 1999) or by Travis (1955), corresponds to a lithologic class meant to identify a particular kind of rock described on the basis of hand-sample observations. The dimension of the representative volume used for lithologic classification may vary from hand-sample to kilometer scale.

An ideal lithologic classification system would assign every material in its scope (domain) to a unique class. However, there are many examples of materials that can be recognized as belonging to more than one class, depending on the criteria used for classification. Examples include low-grade metasedimentary rocks that may be described as metamorphic rocks and as sedimentary rocks, saprolites that may be described as an unconsolidated material and as their bedrock parent, and calc-lithic sandstone that may be classified as both a sandstone and a limestone. Any classification system that attempts to define disjoint (non-overlapping) classes over the entire domain of rocks and unconsolidated materials either must define ad hoc rules that allow ambiguous instances to be assigned to unique classes, or must add numerous new classes that include composite kinds of materials. A better solution is to allow separate classification schemes. Earth scientists who have different geologic interests may use different classification schemes. Individual materials may be classified differently using different schemes. Different lithologic classification schemes have different classification criteria, and may have different domains of classification. The domains of classification for different schemes may overlap, but classes in any particular scheme are disjoint. Lithologic classification over the whole domain of rock and unconsolidated materials is thus overlapping (i.e. not disjoint).

To produce a lithologic classification system that allows different observers to classify a given material in the same way, the system must be based on physical properties recognizable by all observers. Strict adherence to this rule would not allow use of genetic interpretations in the classification of a material unless they could be couched in purely descriptive terms (see discussion in Travis, 1955, p. 1). The properties used for field lithologic classification include:

- modal mineralogy
- grain size
- grain shape
- rock fabric (the arrangement of grains in an aggregate to form the rock)
- structures in the rock (bedding, layering, etc.)

Distinct bodies of rock may be defined based on other physical properties, such as magnetic susceptibility or density, but these are not generally used as field criteria.

The approach to a lithologic classification proposed here is fundamentally descriptive [unavoidable genetic classes such as impact-metamorphic rock are subdivided based on descriptive attributes]. Classification of a particular material is based on observable features, and assignment of a material to a lithologic class implies that certain descriptive criteria are met. These criteria must be archived in the database in order to document the classification system. The descriptions that define the lithologic classes also serve to provide default values for properties when a material is assigned to the class but not described in greater detail. The definition of a lithologic class must be part of a classification scheme (or terminology system, or controlled vocabulary) that defines the domain of classification and classification criteria. The definition must state the dimension of the representative volume for the class, the criteria that are sufficient to assign membership in the class, and to the extent possible, a default description of other aspects of materials that are assigned to the class.

In order to gain acceptance in the geoscience community, any lithologic classification system needs to be consistent with common usage. This may require some relaxation of the strict adherence to observable physical properties as criteria for classification, because traditional rock classification has always involved some genetic interpretation (e.g., igneous, sedimentary, metamorphic are fundamentally genetic). The operational rule for consistency is that existing terms may be redefined to narrow their meaning, but may not be redefined to include rocks that are not included as part of that class in common usage.

2.5 Guides and precedents

Pioneering efforts by the British Geological Survey to develop a comprehensive, systematic classification of metamorphic rocks (Robertson, 1999) have proven to be extremely useful as a precedent. In addition, the International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Metamorphic Rocks (SCMR) is following a precedent for igneous rocks (LeMaitre and others, 1989, 2002) in developing standards for the classification and nomenclature of metamorphic rocks (Schmid and others, 2002). Recent SCMR proposals (Appendix 1) include a systematic nomenclature that combines rock composition (mineral components) and structural root terms (gneiss, schist, granofels), as well as standards for non-systematic metamorphic-rock names in common use. Where possible, we have attempted to follow or adapt the SCMR proposals available at this time to meet the SLTT need for a rigorous hierarchical classification compatible with digital databases.

Useful glossaries of terms related to metamorphic rocks are available in Miyashiro (1994, Appendix II), Passchier and Trouw (1996), Jackson (1997), Barker (1998), and the IUGS proposals listed in Appendix 1. The IUGS SCMR is currently preparing an authoritative glossary of about 1500 terms for metamorphic rocks. That glossary will be similar to Le Maitre's (1989, 2002) glossary for igneous rocks. When completed, it will be released online at http://www.bgs.ac.uk/SCMR The final IUGS glossary will eventually provide authoritative definitions of common metamorphic terms for international use, recommendations for use of uncommon terms, and terms that should be abandoned and replaced by common rock names.

2.6 Philosophy of classification (SLTTM_1.0)

The classification system proposed here is designed for database applications. This makes it distinct from a system for naming rocks, which provides guidelines for giving a descriptive name to a particular rock or kind of rock for use in discourse. Two naming schemes have recently been proposed (Robertson, 1999; Schmid and others, 2002), and the reader is referred to those documents for more information.

The lithologic classification needed for a database is designed to answer the question 'what kind of rock is this?' The flexibility of the database allows a more complete answer to this question that can be encapsulated in a single rock name, and several equally valid answers that depend on the context of the 'kind' question can be provided. Ideally, the database system would also provide a 'free-form rock name' field that allows the geoscientist to give a rock being described whatever name they feel best characterizes the rock.

The philosophy of this classification is based (to the degree possible) on features that reflect the transformation of a rock from one state (the protolith) to another (the composite-genesis rock). Features from the original state are not the basis for classification as a metamorphic rock. If such features are still apparent, they are the basis for classification of the lithology of the metamorphic rock protolith, which will also be part of the database description of the rock.

Classification Rules:

- The domain of classification is hand sample (1 cm to 30 cm) scale metamorphic rocks.
- The scheme should be as descriptive as possible. Genetic considerations are used only to the extent that they can be defined based on features observable in the rock at hand-sample scale.
- Classification must be complete—if a rock is determined to be a composite-genesis rock, it must have a place in the classification scheme.
- A rock may be classified in more than one way based on different criteria (fabric, composition), but given a particular set of criteria, classification must be unique.
- The scheme is for *classifying rocks as metamorphic rocks*, thus interpretation of the protolith of a rock is not used to determine the classification of the rock. [However, where protoliths are known, the combined use of a metamorphic rock classification (as proposed here) and an independent protolith (sedimentary or igneous) rock classification should be permissible.]
- Modal mineralogy (mineral volume percentage) is described in database fields other than the field containing material names.
- Geologists can give a rock any name they feel is most appropriate using an informal ‘rock name’ field in the database that is separate from this lithologic classification.
- Classification must be hierarchical. Superclasses must be included that group the lithologic classes based on fabric or composition criteria. These should include a small number of sub-classes. Each sub-class may be further broken down into smaller subordinate classes, etc.
- Classification must be useful. The scheme should be sufficiently simple and flexible to facilitate use by workers of varying experience and expertise (Robertson, 1999), both in producing and using digital geologic maps and map databases.

The basic elements of the classification are rock fabric and composition (modal mineralogy). If both are known, both the fabric and composition parts of the classification decision tree must be navigated to determine the classification. If only one is known, only one of the two parts will need to be navigated. Fabric may be unknown, in which case the fabric term will just have to be 'rock'. The sorts of fabric that can be defined for aphanitic or very fine-grained rocks include massive, laminated, and glassy. A wider variety of fabrics is defined for phaneritic rocks, including schistose, gneissic, and granoblastic. Composition may be unknown, either because it is unspecified, in which case the fabric classification tree is used, or because the grain size is too small to determine mineralogy beyond silicic, calcsilicate, argillic, or calcareous.

In the class hierarchy, classes that have a composition and a fabric criteria are considered ‘children’ of both a ‘composition and fabric’ lithology parent, and of a generic composition and a generic fabric parent. The class hierarchy is thus a directed acyclic graph, not a tree. Ramifications of this knowledge representation in database implementations should be carefully considered.

2.7 Who developed this document, and how?

This document was developed by geoscientists from a variety of American and Canadian geoscience agencies (Table 2.7.1). The group was assembled in early 2000 as the Metamorphic Science Language Technical Team (SLTTM) of the North American Geologic-map Data Model

Steering Committee, although the panel soon came to be called the Composite-genesis Technical Team in recognition of the fact that earth materials they were classifying included more than just metamorphic rocks as traditionally envisioned. Panel members were appointed in the following ways:

(1) Most participants from the U.S. Geological Survey (USGS) were identified by Regional Geologic Executives from the USGS Western, Central, and Eastern Regions. Some USGS scientists were appointed by Coordinators of USGS line-item science programs;

(2) Scientists from the Geological Survey of Canada (GSC) were identified by Canadian members of the North American Geologic-map Data Model Steering Committee;

(3) Scientists from Canadian Provincial geological surveys were identified by Canadian members of the North American Geologic-map Data Model Steering Committee;

(4) Scientists from academic institutions were selected by the committee co-chairs.

The document was written by co-chairs Horton and Richard in consultation with members of the panel.

Committee Members Composite-genesis Science Language Technical Team (SLTTM) J. Wright Horton, Jr., and Stephen M. Richard, co-chairs	
William F. Cannon	U.S. Geological Survey, Reston, Virginia
Stephen P. Colman-Sadd	Geological Survey of Newfoundland and Labrador, St. John's, Newfoundland
Thomas D. Hoisch	Northern Arizona University, Flagstaff, Arizona
J. Wright Horton, Jr. (co-chair)	U.S. Geological Survey, Reston, Virginia
Bruce R. Johnson	U.S. Geological Survey, Reston, Virginia
Alison Klingbyle	Geological Survey of Canada, Ottawa, Ontario
Diane E. Lane	U.S. Geological Survey, Denver, Colorado
Jonathan C. Matti (ex officio)	U.S. Geological Survey, Tucson, Arizona
Stephen M. Richard (co-chair)	Arizona Geological Survey, Tucson, Arizona
Lambertus C. Struik,	Geological Survey of Canada, Vancouver, British Columbia
Robert J. Tracy	Virginia Polytechnic Institute and State University, Blacksburg, Virginia
Michael L. Williams	University of Massachusetts, Amherst, Massachusetts
Robert P. Wintsch	University of Indiana, Bloomington, Indiana
Michael L. Zientek	U.S. Geological Survey, Spokane, Washington

Table 2.7.1

3 COMPOSITE-GENESIS ROCKS

The domain of composite-genesis rocks includes rocks that record the effects of more than one sequential rock-forming process. The primary rock-forming processes are considered to be those related to the formation of sedimentary and igneous rocks. Sedimentary rocks are formed by the accumulation of sediment subsequent lithification by diagenetic processes to form rock. Igneous rocks are formed by the cooling of melted rock (magma) within or derived from the Earth's (or another planetary body's) interior. Composite-genesis rocks are those that record the effects of one or more geologic events subsequent to the primary rock-forming process. These may include burial, heating, ductile or brittle deformation, and open-system chemical changes. A purely descriptive definition of composite-genesis rock is problematic because the definition requires interpreting genetic process, which depends to some extent on the knowledge and skill of the observer.

The major classes of composite-genesis rock, based on genetic as well as descriptive criteria, are metamorphic (including hydrothermally altered) rock, cataclastic rock, composite-genesis melt rock, and impact-metamorphic rock. These classes are subdivided and organized based on descriptive criteria into separate hierarchies for rock fabric and composition. The application of this classification to particular rock units requires the dual use of both hierarchies as outlined later in this report.

3.1 Metamorphic rock definition and limits (including hydrothermally altered rock)

3.1.1 Definition

Metamorphic rock—any rock derived from pre-existing rock by mineralogical, chemical, or structural changes, essentially in the solid state (based on the *Glossary of Geology*, Jackson, 1997).

In order to be considered a metamorphic rock, there must be observable features in the rock that document change subsequent to the original formation of the rock, under physical or chemical conditions that differ from those normally occurring at the surface of the Earth (or other planetary bodies) or in zones of cementation and diagenesis below the surface (Smulikowski and others, 1997). Robertson (1999) stipulates that the process of metamorphism encompasses all of the solid-state changes that occur between the upper and lower limits of metamorphism. 'Metamorphic rock' thus includes hydrothermally altered rock and mylonitic rock, but not melt rock. Although 'cataclastic rock' and 'impact metamorphic rock' could be considered 'metamorphic' in the most general sense, they are here distinguished from conventional 'metamorphic rock' because their formative processes can be outside the lower and upper limits of metamorphism discussed below. Metamorphism does not include rock weathering or soil formation.

3.1.2 Lower limit of metamorphism

Because identification of a rock as a metamorphic rock is predicated on observation of features not resulting from the original rock-forming process, identification as a metamorphic rock depends on the skill and interests of the observer, and the kinds of features observed. Distinction of the 'original rock-forming process' as distinct from subsequent 'metamorphic processes' is not always clear. Sediment undergoes a continuous progression of changes from deposition through lithification to form sedimentary rock; this process is known as diagenesis. Changes in a deeply buried sedimentary rock may be continuous from diagenesis into recrystallization to form a metamorphic rock.

Robertson (1999) defines the boundary between diagenesis and metamorphism in sedimentary rocks as follows:

> "…the boundary between diagenesis and metamorphism is somewhat arbitrary and strongly dependent on the lithologies involved. For example changes take place in organic materials at lower temperatures than in rocks dominated by silicate minerals. In mudrocks, a white mica (illite) crystallinity value of < 0.42D.2U obtained by X-ray diffraction analysis, is used to define the onset of metamorphism (Kisch, 1991). In this scheme, the first appearance of glaucophane, lawsonite, paragonite, prehnite, pumpellyite or stilpnomelane is taken to indicate the lower limit of metamorphism (Frey and Kisch, 1987; Bucher and Frey, 1994; Frey and Robinson, 1998). Most workers agree that such mineral growth starts at 150 ± 50° C in silicate rocks. Many lithologies may show no change in mineralogy under these conditions and hence the recognition of the onset of metamorphism will vary with bulk composition."

3.1.3 Upper limit of metamorphism

At the highest grades of metamorphism, rocks begin to melt. The temperatures and pressures of the onset of melting range from approximately 650° C to more than 1100° C depending on bulk composition and the proportion of water in the fluid phase. Migmatitic rocks grade into igneous rocks as the proportion of granitic melt increases. The upper limit of metamorphism is defined somewhat arbitrarily. Here, a rock mass that consists >=50% (by volume) of rock having igneous composition and texture (crystallized from a melt) is classified as an igneous rock.

3.1.4 Hydrothermally altered rock

Hydrothermally altered rock has fabric and composition indicating solid-state mineralogical and chemical changes in response to hot, mineral-rich waters. Igneous rocks may continue to undergo mineralogical and chemical changes during cooling even after most or all of the magma has crystallized to produce a 'solid' rock. Hydrothermal activity due to residual heat and mineral-rich water from a pluton may change igneous rocks significantly following their crystallization. ***Hydrothermally altered (including metasomatic) rock is treated as 'metamorphic rock' in this classification.*** We propose the following criteria to distinguish hydrothermally altered or metasomatic rock from igneous rock. The rock is classified as metamorphic if (1) the texture has been modified such that it can no longer be considered igneous, (2) the bulk composition of the rock is inconsistent with compositions that can be derived purely from a magma and associated processes such as assimilation and differentiation, or (3) minerals inconsistent with magmatic crystallization are present.

3.2 Cataclastic rock, composite-genesis melt rock, impact-metamorphic rock

The classes of composite-genesis rock, in addition to metamorphic rock, include cataclastic rock, impact-metamorphic rock, and composite-genesis melt rock.

Cataclastic rock—A rock having more than 10% of its volume consisting of fragments bounded by fractures related to brittle deformation that occurred after the formation of the protolith. Cataclastic rocks are commonly associated with faults, although that genesis is not required by the descriptive definition, and they can form below the limits of metamorphism discussed above.

Composite-genesis melt rock—A rock that solidified from melt (liquid) of a preexisting rock under conditions (such as contact metamorphism, friction along faults, or meteorite impact) outside the domain of typical igneous rocks.

Impact-metamorphic rock—A rock formed by the impact of a planetary body (projectile) on a planetary surface (target). While this criterion is unavoidably genetic by definition, it is based on the interpretation of observable features such as shock-induced planar deformation features, high-pressure minerals, shatter cones, and crater structure, and subdivisions are based on descriptive features as discussed in a later section.

4 CLASSIFICATION COMPONENTS

It is important to remember that the proposed classification of metamorphic rocks is for use in a computer database. This classification system is presented in five diagrams, which include a class hierarchy diagram in two parts (fabric and composition) and four decision trees (metamorphic rock fabric, metamorphic rock composition, mylonitic rock, cataclastic rock). The classification system includes a glossary of definitions, parent-child relationships, and references for terms in the form of a Microsoft Access database. This glossary should be expanded in the future to encompass terms presently missing from the classification, including those to be discouraged on new maps, and recommended usage and suggestions for integrating them into the classification. Future expansion of the glossary for this classification should strive for agreement with the glossary of metamorphic terms under development by the IUGS SCMR [http://www.bgs.ac.uk/SCMR] except where precluded by database requirements or common North American usage.

The system proposed here classifies a given composite-genesis rock along two orthogonal dimensions, fabric (including texture) and composition. Class names thus have a fabric component (e.g., granofels, schist, gneiss) and a compositional component (e.g., marble, calcsilicate, quartzite, quartzofeldspathic, pelitic, amphibolite, serpentinite). The alternative classification rationale of Robertson (1999, Fig. 3) requires that a rock name is first assigned based on mineralogy, and in the absence of mineralogical information, the classification uses a textural term. In our view, this results in loss of information.

5 CLASSIFICATION BY ROCK FABRIC

Rock fabric (including texture), as defined in Appendix 2, is the complete spatial and geometrical configuration of all those components that are contained in a rock and that are penetratively and repeatedly developed throughout the volume of rock under consideration. It includes the shapes and characters of individual parts of a rock mass and the manner in which these parts are distributed and oriented in space.

5.1 Terminology—phaneritic and aphanitic

The IUGS Subcommission on the Systematics of Metamorphic Rocks (SCMR) extended the use of igneous grain-size terms ‘phaneritic’ (large enough to be distinguished by the unaided eye) and ‘aphanitic’ (too fine grained to be distinguished by the unaided eye) to metamorphic rocks, noting that these qualitative definitions correspond approximately to “aphanitic” (ca. <0.1 mm) and “phaneritic” (ca. >0.1 mm) (Schmid and others, 2002, Table 5). The British Geological Survey rock classification (Gillespie and Styles, 1999, section 3.2, p. 6) applies “phaneritic” and “aphanitic” to metamorphic rocks but interprets the actual grain sizes differently:

> “Placing the boundary between ‘medium grained’ and ‘fine grained’ crystals in crystalline igneous and metamorphic rocks at 0.25 mm essentially divides aphanitic rocks (in which individual crystals are too fine grained to be distinguished by the naked eye) from phaneritic rocks (in which individual crystals can be distinguished by the naked eye)…This is also the boundary between medium and fine sand for sedimentary clasts.”

Others interpret the phaneritic-aphanitic (visible-invisible) distinction as approximately equivalent to the sand-silt grain size distinction for sediments, which is variously considered to be in the range of 0.032 mm (Robertson, 1999, BGS grain size scheme) to 0.062 mm (Jackson, 1997) to 0.074 mm (Engineering grain-size scale, ASTM standard D422-63; D643-78). This is smaller than the phaneritic-aphanitic boundary of 0.1 mm proposed by Schmid and others (2002). However, in practical terms, such detailed grain size distinctions are impossible in the field, and very difficult under any conditions. The IUGS usage is endorsed and applied in this classification.

5.2 Fabric prototypes

Several basic types of rock fabric are recognized in virtually all approaches to composite-origin rocks. For classification purposes, the problem is defining the boundaries between the types based on descriptive criteria. There are terms in common usage (e.g., schist, gneiss, granofels, mylonite, cataclasite) that provide basic prototypes, but there is a great deal of variation in the definition of boundaries between the classes.

The basic level of classification is the definition of seven fabric prototypes. These are presented at this stage without assigning names (although the names may be obvious) to emphasize that they represent fundamental *kinds* of rock.

The following list of basic fabric classes is meant to partition the domain of composite-origin rocks based on descriptive criteria in a manner that different observers can agree upon. All quantitative boundaries (percentages, ratios, and dimensions) should be considered open to discussion—the qualitative distinctions are more important here. In general, ‘phaneritic’ (having visible grains) is implied except where ‘aphanitic’ is specified.

(1) Rocks that consist of angular fragments bounded by fractures. [A threshold for assignment of rocks to this category is proposed where ≥ 10% of the rock consists of fragments bounded by fractures.]

(2) Aphanitic metamorphic rocks that are too fine-grained to determine mineralogy. [This criterion is meant to separate rocks that can be classified based on modal mineralogy from rocks too fine grained to distinguish mineralogy.]

(3) Phaneritic metamorphic rocks that have granoblastic fabric and very little or no foliation. [Very little foliation means some foliation may be present, but does not meet the criteria for foliated. Foliated means that ≥ 10% of the mineral grains in the rock are fabric elements in the foliation. To be a foliation-defining fabric element, a mineral grain must have an inequant crystal habit, or an inequant shape due to deformation and an aspect ratios ≥ 1.5:1 between the long and short axis of the deformed grain.]

(4) Well-foliated rocks characterized by tectonic reduction in grain size and having a foliation defined by the shapes of oriented mineral grains or grain aggregates. [Criteria proposed here for implementation are a foliation defined by the shape of deformed mineral grains or grain aggregates having an aspect ratio > 1.5:1, and >10% 'matrix' showing evidence of tectonic reduction in grain size without loss of material continuity. The matrix consists of new or recrystallized mineral grains that are interpreted to be smaller than the mineral grains in the original, undeformed protolith. The definition is meant to identify a fabric in the rock due to crystal plastic and/or other types of non-cataclastic deformation.]

(5) Phaneritic rocks that have a well-developed schistosity. [The sticking point is the definition of "well developed" schistosity. We propose that >50% of rock consists of mineral grains having a tabular, lamellar, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric (following Jackson, 1997). Continuous is defined on a hand sample-scale, to mean that domains lacking the fabric are <1 cm thick if they are layers, and <5 cm in diameter if they are irregular patches, and constitute < 25% of the rock. The IUGS SCMR (Brodie and others, 2002) suggests using criteria that rock splits on scale <1 cm, but this criteria depends on the tool used to do the splitting, the skill of the operator doing the splitting, and the degree of weathering or alteration of the rock being split, and is thus not objective and universally applicable. The IUGS criteria could not be used to classify a rock in thin section. The IUGS (Brodie and others, 2002) also proposes to define schistosity as due to inequant mineral grains or grain aggregates, without specifying that their shape is due to crystallographic habit.]

(6) Foliated, layered phaneritic rocks that lack well developed schistosity and have laterally continuous compositional layering. [We here propose a definition of "laterally continuous compositional layering" as having layers > 5 mm thick that can be traced laterally > 10 cm (length of lateral continuity).]

(7) Foliated non-layered phaneritic rocks that do not have well developed, continuous schistosity or continuous compositional layering.

Table 1. Fabric classification terms

Name	Definition	Source
breccia	Generic classification for rock in which penetrative, through going fractures separate visible fragments (>0.1 mm diameter) that form > 30% of rock, and fragments are rotated relative to each other.	Sibson (1977), Snoke and Tullis (1998)
broken rock	Rock consisting of <30% fragments, or rock that consists of >30% fragments, but fragments are not rotated with respect to each other. Because protolith is assumed to be recognizable, do not apply a composition modifier. Composition is indicated by protolith link.	Robertson (1999)
cataclasite	cataclastic rock that maintained primary cohesion during deformation, and consists of 50-90% matrix. Matrix is broken mineral grains or rock fragments that are too small to be discernible (0.1 mm following definition of aphanitic). Equivalent to “mesocataclasite” of Brodie and others (2002)	Sibson (1977), Scholz (1990), Snoke and Tullis (1998), Barker (1998, Appendix II)
cataclasite-series rock	Collective term for cataclastic rocks that maintained primary cohesion during deformation; includes protocataclasite, cataclasite, and ultracataclasite (Sibson, 1977). These subtypes are differentiated based on the fraction of the rock considered ‘matrix’. Matrix is broken mineral grains or rock fragments that are too small to be discernible (0.1 mm following definition of aphanitic).	Sibson (1977), Scholz (1990), Snoke and Tullis (1998)
cataclastic rock	“A rock, such as tectonic breccia, containing angular fragments that have been produced by the crushing and fracturing of preexisting rocks as a result of mechanical forces in the crust.” (Jackson, 1997). Criterion added here for database precision is >10% of rock volume composed of fragments bounded by fractures related to a secondary tectonic event. Use of the term ‘cataclastic’ denotes deformation in the absence of crystal plastic processes. [Mylonite-series rock is not classified here as a cataclastic rock, although it may contain subordinate cataclastic fabric.]	Jackson (1997)
Composite-origin rock	Rock with unspecified fabric, for which insufficient information is available to determine if it is cataclastic, impact-related, glassy, or metamorphic.	this report
contact metamorphic melt rock	Rock in which framework of rock is glassy mineral material that encloses rock and mineral fragments, and there is evidence that melting is related to contact metamorphism.	this report
fault breccia	Cataclastic rock lacking evidence for primary cohesion during deformation, in which fractures separate visible fragments (>= 0.1mm in diameter) that form >30% of rock mass, and are rotated relative to each other, and no evidence of impact metamorphism is observed. Composition modifiers refer to character of comminuted rock between fragments; composition of fragment protolith is assumed identifiable, and composition of that is indicated via protolith relationship.	Snoke and Tullis (1998), Barker (1998, Appendix II)
foliated cataclasite	Cataclastic rock that maintained primary cohesion during deformation, and consists of 50-90% matrix, and has a foliation. Matrix is broken mineral grains or rock fragments.	Snoke and Tullis (1998); Sibson (1977) modified by Scholz (1990)

Name	Definition	Source
foliated gouge	Cataclastic rock lacking evidence for primary cohesion during deformation, in which visible fragments (> 2 0.1 mm in diameter) constitute <30% of the rock mass, and having a foliation. Composition modifier refers to general character of comminuted matrix. Protolith of fragments assumed to be recognizable.	Snoke and Tullis (1998); Sibson (1977) modified by Scholz (1990)
foliated metamorphic rock	Any metamorphic rock that contains a foliation.	this report
foliated protocataclasite	Cataclastic rock that maintained primary cohesion during deformation, and consists of 10-50% matrix, and has a foliation. Matrix is broken mineral grains or rock fragments.	Snoke and Tullis (1998); Sibson (1977) modified by Scholz (1990)
foliated ultracataclasite	Cataclastic rock that maintained primary cohesion during deformation, and consists of 90-100% matrix, and has a foliation. Matrix is broken mineral grains or rock fragments.	Snoke and Tullis (1998); Sibson (1977) modified by Scholz (1990)
gneiss	General term for a foliated, phaneritic rock without well developed, continuous schistosity	Schmid and others (2002), Jackson (1997), Barker (1998, Appendix II)
gneissic mylonite	Mylonite that has continuous compositional layering, >5 mm thick. Continuous means that layers defining the foliation can be traced for >10 cm (length of lateral continuity), and are spaced at a distance ≤ the average length of lateral continuity. Monomineralic compositional modifiers do not apply, because if monomineralic, cannot develop gneissoid banding.	revised from IUGS (Brodie and others, 2002) and Robertson (1999)
gneissic protomylonite	Protomylonite that lacks well developed continuous schistosity, but displays continuous compositional banding >5 mm thick.	this report
gouge	Cataclastic rock lacking evidence for primary cohesion during deformation, in which visible fragments (> 0.1 mm in diameter) constitute <30% of the rock mass. Composition modifier refers to general character of comminuted matrix. Protolith of fragments assumed to be recognizable.	Sibson (1977), Snoke and Tullis (1998), Barker (1998, Appendix II)
granoblastic rock	Phaneritic metamorphic rock having granoblastic fabric and very little or no foliation or lineation. Specifically, <10% of the particles in the rock are planar or linear fabric elements with an aspect ratio □ 1.5:1. [Use of generic term granoblastic rock denotes that nothing is known about the rock fabric beyond that it is granoblastic.]	
granofels	Phaneritic metamorphic rock that has little or no foliation or lineation. Specifically, <10% of the particles in the rock are planar or linear fabric elements with an aspect ratio ≥ 1.5:1. In this sense, granofels is the phaneritic equivalent of hornfels.	adapted from Goldsmith (1959), Robertson (1999), Barker (1998, Appendix II), and IUGS (Schmid and others, 2002; Brodie and others, 2002)

Name	Definition	Source
hornfels	Aphanitic metamorphic rock that has little or no foliation or lineation Although hornfels is typically a product of contact metamorphism, that genesis is not a requirement of this descriptive definition. Hornfels, in this sense, is the aphanitic equivalent of granofels.	Winkler (1967) in Jackson (1997), Winkler (1979)
impact breccia	Breccia (as generally defined) containing fragments that show unequivocal evidence of shock metamorphism; typically occurring "around, inside, and below impact craters" (Stöffler, 2001c); subclasses are monomict impact breccia, polymict impact breccia, and suevite.	Stöffler (2001c), Stöffler and Grieve(2001)
impact melt rock	Crystalline, semi-glassy, or glassy rock in which >=50% of the rock volume is solidified from impact melt (implying <50% non-melt inclusions). Framework of rock is glassy mineral material and evidence of impact is observed.	Stöffler (2001c), Stöffler and Grieve(2001).
impactite (impact metamorphic rock)	Rock that shows evidence of impact metamorphism. General term for rocks affected by impact resulting from the collision of planetary bodies.	Stöffler (2001c), Stöffler and Grieve (2001).
incohesive cataclastic rock	Cataclastic rock for which evidence for primary cohesion during deformation is lacking or not specified, and evidence for impact metamorphism is lacking or not specified.	Snoke and Tullis (1998); Sibson (1977) modified by Scholz (1990)
layered gneiss	Foliated, phaneritic rock that lacks well developed, continuous schistosity and has laterally continuous compositional layering > 5 mm thick. Laterally continuous means that layers defining the foliation can be traced for >10 cm (length of lateral continuity), and are spaced at a distance ≤ the average length of lateral continuity.	modified from IUGS (Schmid and others, 2002; Brodie and others, 2002), and Robertson (1999)
metamorphic glass	Rock with framework of glassy material that is the product of metamorphic event.	this report
metamorphic rock	A metamorphic rock is any rock derived from pre-existing rock by mineralogical, chemical, or structural changes, essentially in the solid state (based on Jackson, 1997). In order to be considered a metamorphic rock, there must be observable features in the rock that document change after the original formation of the rock as a rock, under physical or chemical conditions that differ from conditions normally occurring at the surface of the Earth and in zones of cementation and diagenesis below the surface (Smulikowski and others, 1997).	Jackson (1997), Smulikowski and others (1997)
migmatite [recommended for text field only]	A heterogeneous composite rock mass consisting of irregular and discontinuous interleaving of leucocratic granitoid material (leucosome) and residual high-grade metamorphic material (restite) (Barker, 1998, Appendix II: Glossary). *Migmatite is not used as a root name in this classification for reasons discussed in the text.* Here, the adjective "migmatitic" is applied to a fabric term, as in migmatitic gneiss, where the granitoid part makes up >10% of the rock volume.	paraphrase of Barker (1998, Appendix II), (Wimmenauer and Bryhni, 2002)

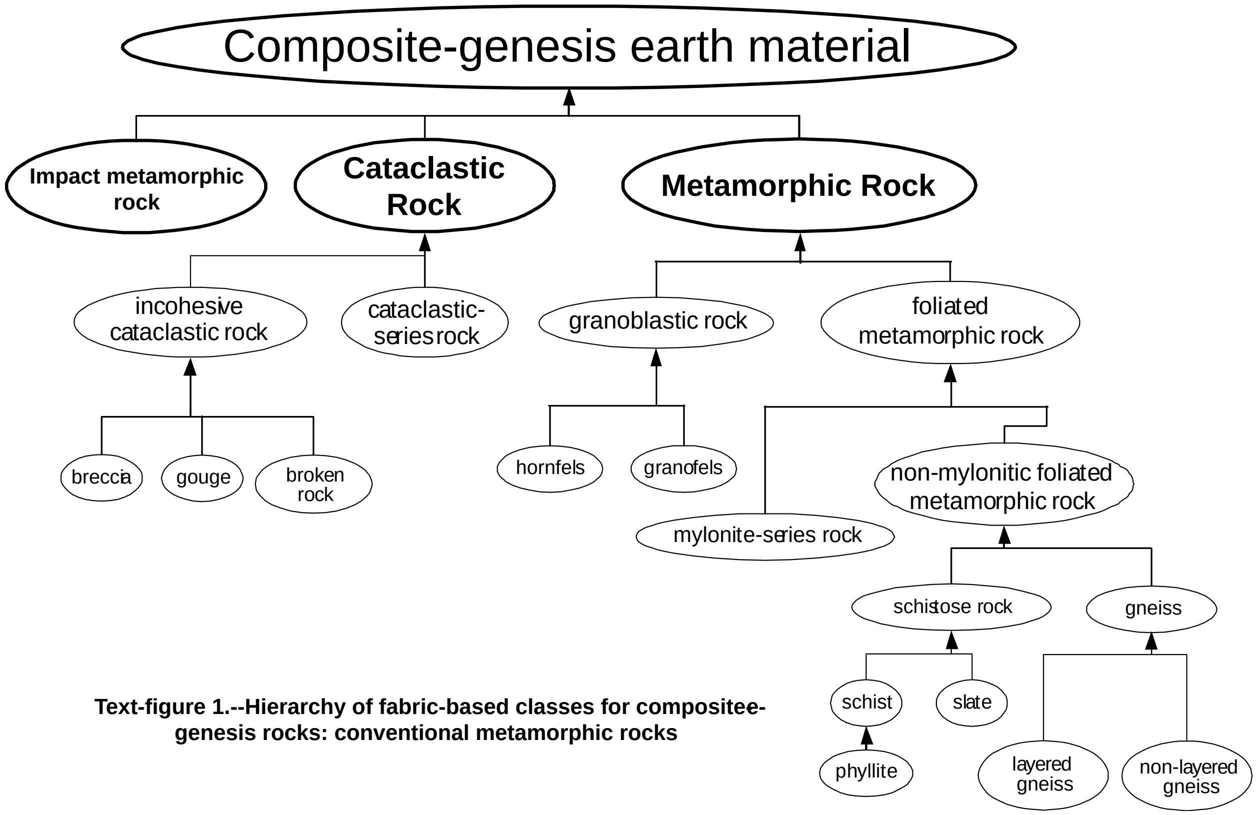
Name	Definition	Source
migmatitic gneiss	Foliated, phaneritic rocks without well developed, continuous schistosity that is megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance. The granitoid phase makes up >10% of the rock volume.	composite from Jackson (1997) and Robertson (1999)
migmatitic granofels	Non-foliated, phaneritic rock that is megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance. The granitoid phase makes up >10% of the rock volume. Example -- 'opthalmic' or patch migmatite of Mehnert (1968).	composite from Jackson (1997) and Robertson (1999)
migmatitic layered gneiss	Foliated, phaneritic rock without well developed, continuous schistosity that has continuous compositional layering, > 5 mm thick, and is megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance. The granitoid phase makes up >10% of the rock volume.	composite from Jackson (1997) and Robertson (1999)
migmatitic non-layered gneiss	Foliated, phaneritic rock without well developed, continuous schistosity or continuous compositional layering that is megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance. The granitoid phase makes up >10% of the rock volume.	composite from Jackson (1997) and Robertson (1999)
migmatitic schist	Foliated, phaneritic rock that has well developed, continuous schistosity that is megascopically composite, consisting of two or more petrographically different parts, one of which is the country rock in a more or less metamorphic state, the other is of pegmatitic, aplitic, or granitic appearance. The granitoid phase makes up >10% of the rock volume.	composite from Jackson (1997) and Robertson (1999)
monomict impact breccia	Impact breccia free of impact melt in which all of the fragments (100%) have essentially the same composition.)	Stöffler (2001c), Stöffler and Grieve(2001).
mylonite	Mylonite-series rock consisting of 50-90% matrix showing evidence of tectonic grain size reduction. Equivalent to "orthomylonite" of Wise and others (1984) and "mesomylonite" of Brodie and others (2002)	Sibson (1977), Hanmer (1987), Passchier and Trouw (1996), Snoke and Tullis (1998)

Name	Definition	Source
mylonite-series rock	A collective term for the "mylonite series" rocks of Sibson (1977), including protomylonite, mylonite, ultramylonite, and phyllonite. Equivalent to Brodie and others' (2002) broader usage of "mylonite" for "A fault rock which is cohesive and characterized by a well developed [foliation] resulting from tectonic reduction of grain size, and commonly containing rounded porphyroclasts and lithic fragments of similar composition to minerals in the matrix." Additional criteria introduced here for precision in databases include a foliation defined by deformed mineral grains or grain aggregates having aspect ratio > 1.5:1, and >10% of rock consisting of 'matrix' . Matrix is an aggregate of new mineral grains (not present in the protolith, but may be same mineral species) that are significantly smaller (1% of diameter) than the original size of mineral grains, and are the product of non-cataclastic deformation. Non-cataclastic deformation is deformation in which the material continuity of the deformed volume is maintained on the scale of observation, indicated by the absence of thoroughgoing fractures in the volume. The definition is meant to identify a fabric in the rock due to crystal plastic and/or other types of non-cataclastic deformation.	Sibson (1977), Snoke and Tullis (1998), Brodie and others (2002)
non-layered gneiss	A foliated, phaneritic rock that lacks well developed, continuous schistosity and laterally continuous compositional layering > 5 mm thick. "Laterally continuous" here means that layers defining the foliation can be traced > 10 cm (length of lateral continuity). Foliated means that ≥ 10% of mineral grains in the rock are fabric elements.	IUGS (Schmid and others (2002; Brodie and others, 2002)
non-mylonitic foliated metamorphic rock	Metamorphic rock that is not granoblastic and does not have a mylonitic fabric.	this report
phyllite	Rock that has a well developed, continuous schistosity, an average grain size (excluding porphyroblasts) <0.25 mm and >0.1 mm, and a silvery sheen on cleavage surfaces.	Jackson (1997), Barker (1998, Appendix II)
phyllonite	Phyllosilicate-rich mylonite-series rock of phyllitic appearance (having a silvery sheen on cleavage surfaces); "sometimes (erroneously) used for ultramylonite" (Passchier and Trouw, 1996). Criterion added here for precision is having >40% phyllosilicate minerals (e.g., mica, chlorite).	Sibson (1977), Passchier and Trouw (1996), Snoke and Tullis (1998), Robertson (1999), Brodie and others (2002)
polymict impact breccia	Impact breccia that contains fragments of different composition and is free of impact melt particles.	Stöffler (2001c), Stöffler and Grieve(2001).
protocataclasite	Cataclastic rock that maintained primary cohesion during deformation, and consists of 10-50% matrix. Matrix is broken mineral grains or rock fragments.	Snoke and Tullis (1998): Sibson (1977) modified by Scholz (1990)

Name	Definition	Source
protomylonite	Mylonite-series rock consisting of 10-50% matrix showing evidence of tectonic grain size reduction.	composite from Robertson (1999), Jackson (1997), Snoke and Tullis (1998), Barker (1998, Appendix II), Passchier and Trouw (1996)
pseudotachylite	"Ultrafine-grained vitreous-looking material, usually black and flinty in appearance, occurring as thin planar veins, injection veins or as a matrix to pseudo-conglomerates or breccias, which infills dilation fractures in the host rock" (Brodie and others, 2002). [see "impact pseudotachylite"]	Spray,(1995), Passchier and Trouw (1996), Snoke and Tullis (1998), Brodie and others (2002)
schist	Phaneritic metamorphic rock having a well developed schistosity. Well developed schistosity is defined to mean that >50% of rock consists of mineral grains having a tabular, lamellar, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric (following Jackson, 1997). Continuous is defined on a hand sample-scale, and in quantitative terms to mean that domains lacking the fabric are <1 cm thick if they are layers, and <5 cm in diameter if they are irregular patches, and constitute < 25% of the rock.	Jackson (1997), Barker (1998, Appendix II)
schistose mylonite	Mylonite that has a well developed continuous schistosity	modified from Snoke and Tullis (1998), Sibson (1977)
schistose protomylonite	Protomylonite that has a well developed schistosity	modified from Snoke and Tullis (1998), Sibson (1977)
shocked rock	non-brecciated rock which shows unequivocal effects of shock metamorphism exclusive of whole-rock melting (Stöffler (2001c). Specifically, <= 30% of the rock is fracture-bounded fragments, or if fragments form >30% of rock, they are not rotated relative to each other.	Stöffler (2001c), Stöffler and Grieve (2001)
slate	Aphanitic rock that has well developed schistosity An average grain size <0.1mm (excluding porphyroblasts) is specified here for precision.	Jackson (1997), Robertson (1999), Brodie and others (2002)
suevite	Impact breccia that contains impact melt particles (>0 and <50%))	Stöffler (2001c), Stöffler and Grieve (2001)
ultracataclasite	Cataclastic rock that maintained primary cohesion during deformation, and consists of 90-100% matrix. Matrix is broken mineral grains or rock fragments.	Snoke and Tullis (1998): Sibson (1977) modified by Scholz (1990)
ultramylonite	Mylonite-series rock consisting of 90-100% matrix showing evidence of tectonic grain size reduction.	composite from Robertson (1999); Jackson (1997), Snoke and Tullis (1998), Passchier and Trouw (1996), Barker (1998, Appendix II)

5.3 Metamorphic (including hydrothermally altered) rock

SLTTM_1.0 recognizes the following classes of metamorphic rock (including hydrothermally altered rock) based on fabric: (1) granoblastic rock including granofels and hornfels, and (2) non-mylonitic foliated metamorphic rock including schistose rock (schist, phyllite, slate) and gneiss (layered gneiss and non-layered gneiss), and (3) mylonitic rock.



Text-figure 1.--Hierarchy of fabric-based classes for compositee-genesis rocks: conventional metamorphic rocks

5.3.1 Granoblastic rock

5.3.1.1 Granofels

Granofels was introduced by Goldsmith (1959) for “medium- to coarse-grained granoblastic metamorphic rock with little or no foliation or lineation” (Jackson, 1997). The British Geological Survey (Robertson, 1999) and provisional IUGS nomenclature (Brodie and others, 2002; Schmid and others, 2002) use the term regardless of grain size.

SLTTM_1.0 defines **granofels** as *a phaneritic metamorphic rock that has little or no foliation or lineation,* implying that that <10% of the particles in the rock are fabric elements. To be a fabric element, a particle must have an inequant shape with an aspect ratio ≥ 1.5:1, and be aligned with other particles as part of a fabric. In this sense, granofels is the phaneritic equivalent of hornfels.

5.3.1.2 Hornfels

The *Glossary of Geology* (Jackson, 1997) cites an earlier edition (1967) of Winkler (1979) in defining hornfels as “A fine-grained rock composed of a mosaic of equidimensional grains without preferred orientation and typically formed by contact metamorphism. Porphyroblasts or relict phenocrysts may be present in the characteristically granoblastic (or decussate) matrix.” A genetic connotation of contact metamorphism is required by the British Geological Survey definition (Robertson, 1999, p. 12) of hornfels as “a specific variant of granofels” to be used as a root name where ”features of the original rock have been modified by contact metamorphism…Robertson (1999) states that "a massive, compact, fine-grained rock should be classified as a fine-grained granofels (Goldsmith, 1959) and not a hornfels if there is no direct evidence for contact metamorphism." Alternatively, Winkler (1976, p. 327) states that "Hornfelses are typically produced by contact metamorphism…and *occasionally by regional metamorphism* [italics added]."

SLTTM_1.0 defines hornfels as a non-foliated aphanitic rock having granoblastic fabric. The term hornfels does not necessarily denote a contact metamorphic origin (although that is most commonly the case). This is consistent with the goal of keeping this terminology as descriptive as possible. Hornfels, in this sense, is the aphanitic equivalent of granofels.

5.3.2 Non-mylonitic foliated metamorphic rock

5.3.2.1 Historical usage of schist and gneiss

The term "gneiss" is used inconsistently in the geological literature. Some reports distinguish gneiss and schist based on layering whereas others use mineral percentages (e.g., mica vs. feldspar + quartz). Note the etymology of 'gneiss': "alteration of Middle High German *gneiste* spark" [Merriam-Webster's Dictionary, 2004, http://www.m-w.com/cgi-bin/dictionary], suggesting the term originally had more to do with composition than with foliation.

Definitions of gneiss:

1. Medium- to coarse-grained rock having a gneissic fabric, i.e. "it splits parallel to 's' generally along mica or hornblende layers, into plates and angular blocks, a few centimeter to tens of centimeters in thickness, or parallel to 'B' into cylindrical bodies (pencil gneiss). The prevalent light-colored constituents (quartz+feldspar) have interlocking boundaries and provided, as compared to schists, a better coherence and a coarser fissility to the rock; nevertheless the fissility in many cases creates an almost perfect plane" (Wenk, 1963, quoted in Winkler, 1979)
2. Rock having recognizable parallel structure consisting predominantly of quartz and feldspar (feldspar >20%, and mica >10%) Fristch and others, 1967, quoted in Winkler, 5th edition, 1979, p. 342).
3. A medium- to coarse-grained irregularly "banded" rock that has fairly poor schistosity because of the preponderance of quartz and feldspar; equivalent or higher regional metamorphic grade than a schist (Hyndman, 1972).
4. Rock composed chiefly of quartz and feldspar; medium- to coarse-grained phaneritic, granoblastic to lepidoblastic; compositional layering expressed by varying modal proportions of quartz, feldspar, mica and hornblende usually evident, but in some granitic gneisses layering is quite subtle or even absent and a weak foliation is expressed by preferred orientation of inequant mineral grains or grain aggregates. (Best, 2002).
5. Banded rock that does not break along a preferred plane (Blatt and Tracy, 1996). A gneiss has large grains and is foliated i.e. quartz and feldspar rich layers separated from micaceous or mafic layers (Yardley, 1989). Types of Occurrences: Silicic: light colored minerals such as quartz and feldspar make up the majority of the rock; Intermediate: equal amounts of light and dark minerals; Mafic: ferromagnesian minerals make up most of the rock; Undifferentiated (http://www.geol.lsu.edu/rkd_dir/gneiss.html)
6. A foliated rock formed by regional metamorphism, in which bands or lenticles of granular minerals alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits predominate; generally <50% of minerals show preferred parallel orientation; although commonly feldspar+quartz rich, mineral composition is not an essential factor in its definition (Jackson, 1997).

7. A rock (regardless of protolith and modal composition) that is medium- to coarse-grained, inhomogeneous, and characterized by a coarse foliation or layering and some layers >5 mm thick (Robertson, 1999).

8. Gneiss is a roughly foliated or banded metamorphic rock consisting largely of granular minerals such as quartz (http://www.cst.cmich.edu/users/dietr1rv/gemrxD-K.htm , gem rock definitions)

9. A rock that has alternating bands of granular and flaky (or elongate) minerals. Generally less than 1/2 the minerals show a preferred parallel orientation. (http://forestry.about.com/library/glossary/blforgll.htm) forestry terms.

10. A metamorphic rock displaying a gneissose structure (A type of foliation on the hand specimen scale, defined by (a) irregular or ill-defined layering, or (b) augen and/or lenticular aggregates of mineral grains (augen structure, flaser structure), or (c) inequant mineral grains which are present, however, only in small amounts or which display only a weak preferred orientation, thus defining only a poorly developed schistosity.). The term gneiss may also be applied to rocks displaying a dominant linear fabric rather than a gneissose structure, in which case the expression "lineated gneiss" is applied. The term gneiss is used almost exclusively for rocks containing abundant feldspar +/- quartz, but may be used in exceptional cases for other compositions, in which case the exact mineralogy should be given (e.g. feldspar and quartz- free cordierite-anthophyllite-gneiss). (http://web.met.unimelb.edu.au/TeachingSupport/625-224/224practerms.pdf , definitions of technical terms for Roger Powell's Metamorphism class).

Definitions of schist:

1. A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs due to the well developed parallelism of more than 50% of the minerals present, particularly those of lamellar or platy habit, e.g. mica and hornblende. The mineral composition is not an essential factor in its definition unless specifically included in the rock name (Jackson, 1997).
2. Metamorphic rock "Characterised by parallel alignment of moderately coarse grains, usually clearly visible with the naked eye…This type of fabric is known as schistosity…" (Yardley, 1991, p. 22).
3. "Metamorphic rock commonly of pelitic composition, with a well developed schistosity." (Barker, 1998, p. 242).
4. "A metamorphic rock displaying schistose structure. For phyllosilicate-rich rocks the term schist is reserved for medium- to coarse-grained varieties, whereas finer-grained rocks are termed slates or phyllites." (Schmid and others, 2002).
5. The main characteristic of "schist" is a well-developed *schistosity*. Schistosity has been defined as:
6. "The foliation in schist or other coarse-grained, crystalline rock due to the parallel alignment of platy mineral grains (mica) or inequant crystals of other minerals" (Jackson, 1997). [This definition is preferred here because the distinction between foliation related to crystallographic orientation of tabular or elongate crystals (schistosity) and grain-shape fabric is important in interpreting the fabric genesis.]
7. "A preferred orientation of inequant mineral grains or grain aggregates produced by metamorphic processes." (Schmid and others, 2002).
8. "A foliation or lineation which allows the rock to be split easily along planes. Constituent minerals can be seen with the unaided eye." (Robertson, 1999, p. 13)
9. A "secondary foliation defined by preferred orientation of inequant fabric elements in a medium to coarse grained rock. Individual foliation-defining elements are visible with the naked eye" (Passchier and Trouw, 1996). [This definition allows a schistosity to be defined by the grains that are inequant due to plastic deformation—thus a pure quartz tectonite that has a grain shape fabric defined by tectonically flattened quartz grains would have a schistosity under this definition.]

Based on the various definitions of schist and gneiss, the criteria used to distinguish these rock types are:

- Presence of compositional banding
- Thickness of compositional banding
- Homogeneity of the rock
- Modal abundance of mica
- Modal abundance of quartz +feldspar
- Degree of fissility (how thinly can the rock be parted along the 'schistosity')
- Grain size

In the IUGS proposal of Brodie and others (2002), a "schistose structure" is characterized by a "schistosity which is well developed, either uniformly through the rock or in narrowly spaced repetitive zones such that the rock will <u>split on a scale of one cm or less</u>" and a "gneissose structure" is characterized by a "schistosity which is either poorly developed throughout the rock or, if well developed, occurs in broadly spaced zones such that the rock will split on a scale of more than one cm."

In practical terms, spitting may be influenced by extraneous variables such as later foliation-parallel joints and weathering. The thickness of sheets split along the foliation in unweathered rocks cannot be used to classify the weathered rocks commonly encountered in the field. Classification would thus be a function of weathering—an undesirable side effect. Criteria based on the thickness of visible layering would not suffer from dependence on the degree of weathering.

5.3.2.2 Schistose rock (schist, phyllite, and slate)

Schistose rock—Any metamorphic rock that has a well developed, continuous schistosity. "Well developed" schistosity is defined to mean that >50% of the rock consists of mineral grains having a tabular, lamellar, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric (following Jackson, 1997), and "continuous" schistosity is defined on a hand-sample scale, and in quantitative terms, to mean that domains lacking the fabric are <1 cm thick if they are layers, and <5 cm in diameter if they are irregular patches, and constitute <25% of the rock.

SLTTM_1.0 subdivides rocks that have well developed continuous schistosity (schistose rocks) into the following:

Schist—phaneritic rock having average grain size >.25 mm). Schist may have compositional layering at any scale.

Phyllite—phaneritic rock but finer-grained than schist, having average grain size <0.25 mm but >0.1 mm and typically a silvery sheen on cleavage surfaces.

The term phyllite is widely used and generally understood to describe a fine-grained schistose micaceous rock. Robertson (1999) discusses the term as follows:

> "The term phyllite has previously been used for rocks possessing a silky or lustrous sheen on foliation surfaces imparted by fine-grained (< 0.1 mm) white mica (including muscovite, paragonite and phengite) orientated parallel to the foliation in the rock. Individual mica flakes can be seen with the naked eye in contrast to slates where they cannot be distinguished. Most are probably derived by the low- to medium-grade metamorphism of mudstones although some rocks that have been described as phyllites may have been confused with phyllonites…Here 'phyllite' is classified as a specific variant of schist. It is therefore not permissible as a root name but may be used as a specific qualifier, namely *phyllitic*, for example *phyllitic* semipelite." (Robertson, 1999, p. 12).

Slate—aphanitic rock, implying average grain size <0.1 mm. In the system proposed here, the term slate is restricted to schistose rocks that are aphanitic except for porphyroblasts. This definition is essentially equivalent to that of Brodie and others [2002].

Because "phyllite" and "slate" are widely used on geologic maps in North America, SLTTM_1.0 differs from Robertson (1999) and advocates retaining them as rock names. In order for the terms to be useful and unambiguous, criteria for uniquely distinguishing phyllite from schist and slate must be established.

The definition of slate as an aphanitic rock displaying a well developed continuous schistosity is consistent with the provisional IUGS definition (Brodie and others, 2002). In addition, it requires that >50% of the rock consists of mineral grains having a tabular, lamellar, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric. In an aphanitic rock this determination is generally based on indirect evidence, which is typically the presence of slaty cleavage, and the sheen observed on parting surfaces due to alignment of tiny phyllosilicate grains. An average grain size that is aphanitic (<0.1 mm), except for porphyroblasts, is specified here for precision, and the North American spelling of *slaty* (rather than *slatey*; Jackson, 1997) is preferred for use in North America.

5.3.2.3 Layered gneiss and non-layered gneiss

Gneiss does not have continuous schistosity on a hand sample scale as defined above, but it may have schistose layers separated by non-schistose layers. The boundary of gneiss and schist in this logic is placed where the mineral grains that define the schistosity are distributed such that the schistosity is deemed "continuous.". SLTTM_1.0 defines gneissose rocks in the following way:

Gneiss—a foliated phaneritic metamorphic rock that does not have "well developed" continuous schistosity. This follows the spirit of the proposed IUGS classification scheme (Schmid and others, 2002; Brodie and others, 2002). Classified into **layered gneiss** and **non-layered gneiss**.

Layered gneiss—a foliated, phaneritic rock that lacks well developed, continuous schistosity and has laterally continuous compositional layering > 5 mm thick.

Non-layered gneiss—

5.3.2.4 Migmatitic rocks as subclasses

The IUGS proposed definition of migmatite (Wimmenauer and Brynghi, 2002, p. 2) is "A composite silicate rock, pervasively heterogeneous on a meso- to megascopic scale. It typically consists of darker and lighter parts. The darker parts usually exhibit features of metamorphic rocks while the lighter parts are of plutonic appearance…" Wimmenauer and Brynghi (2002) use "migmatite" as a superclass for any rock that has these characteristics.

Numerous terms have been employed for varieties of migmatite (Mehnert, 1968), but most are either genetic or difficult to apply on a hand-specimen scale. In the BGS classification, "'Migmatite' is not permissible as a root name…as it is not a single rock type. However, migmatitic may be used as a specific textural modifier" (Robertson, 1999, p. 11). Another problem is that "the scale of migmatitic structures is such that they mainly require definitions, which refer to rock masses greater than the preferred hand specimen size" (Wimmenauer and Bryngi, 2002). The IUGS (Wimmenauer and Brynghi, 2002) recommends 'migmatite' as the "main term" for these rocks as well as "special terms" (equated to recommended rock names) for parts of a migmatite (such as leucosome and restite), genetic types (such as anatexite and veinite), and three descriptive types (agmatite = breccia-like; phlebite = veined, nebulite = having diffuse relics of pre-existing rock). The terms for parts of a migmatite represent roles in a relationship, and are thus not suitable as kinds of rock.

The system proposed here specifically avoids use of genetic terminology where possible, and the genetic classification of migmatitic rocks is thus outside the scope of the system. The descriptive terms are logically equivalent to other terms in the classification e.g. agmatite = migmatitic granofels (in most cases), and are thus not included as separate terms. Any of these names could be used in an uncontrolled rock name field in a database.

Rather than using "migmatite" as a root term or superclass as proposed by Wimmenauer and Brynghi (2002) for IUGS, the classification here follows the British Geological Survey rationale and precedent (Robertson, 1999), which applies "migmatitic" as an adjective modifier to terms such as gneiss and schist. For precision in database applications, this classification requires that the lighter colored, granitoid phase must form >10% of the rock volume.

5.3.3 Mylonite-series rock

A rock is here classified as a **mylonite-series rock** if the rock displays a foliation defined by the shapes of deformed mineral grains or grain aggregates having aspect ratios > 1.5:1, >10% of the rock is composed of "matrix" showing evidence of tectonic reduction in grain size, and the foliation and matrix are interpreted to be the product of continuous, crystal-plastic deformation processes. Deformation in faults and shear zones occurs in a continuum of environmental conditions from near the Earth's surface, where discontinuous/brittle processes dominate, to high temperature conditions deep in the Earth where continuous deformation and crystal-plastic processes dominate (Sibson, 1977; Passchier and Trouw, 1996). Foliated, deformed rocks formed in the crystal-plastic regime are included in the mylonite-series.

Mylonite-series rocks are commonly lineated. They typically contain fabric elements such as quartz ribbons, mica fish, asymmetric porphyroclasts, S-C composite planar fabrics, and microstructures indicative of crystal-plastic deformation (e.g. recovery and recrystallization, see Sibson, 1977; Passchier and Trouw, 1996; Snoke and Tullis, 1998). The matrix consists of new or recrystallized mineral grains that are interpreted to be smaller than the mineral grains in the original, undeformed protolith. In cases where the protolith was very fine-grained or is unknown, problems in applying this definition may be overcome to some extent by observing the progressive development of fabric and grain-size reduction along the margins of high-strain zones. The distinction between relatively high-temperature cataclastic rocks and mylonite-series rocks is based on the presence of a foliation produced by aligned mineral grains whose shape has been modified by crystal-plastic deformation in mylonite-series rocks.

Standard classification schemes for mylonite-series rocks are based on the degree of deformation-related grain-size reduction, which is quantified as the percentage of matrix produced by tectonic reduction in grain size (Sibson, 1977; Wise and others, 1984; Scholz, 1990; Passchier and Trouw, 1996; Snoke and Tullis, 1998). Snoke and Tullis (1998, Table 0.1) endorsed Scholz's (1990, Table 3.1) slightly modified version of Sibson's (1977) classification of fault rocks. We adopt that classification here with minor modifications for database applications. The mylonite-series rocks, as used here, are equivalent to the "mylonite series" of Sibson (1977), which is subdivided into **protomylonite** (having 10-50% matrix), **mylonite** (having 50-90% matrix), and **ultramylonite** (having 90-100% matrix).

Phyllonite is a common term for phyllosilicate-rich mylonite-series rock of phyllitic appearance, i.e. having a silvery sheen on cleavage surfaces (Sibson, 1977; Passchier and Trouw, 1996; Snoke and Tullis, 1998; Robertson, 1999, Brodie and others, 2002). SLTTM-1.0 also specifies >40% phyllosilicate minerals (e.g., mica, chlorite) and a *well developed continuous schistosity* as defined in Appendix 2.

Under some conditions, recrystallization during deformation may lead to an increase in grain size relative to the protolith of a highly strained rock. Such rocks commonly have equant polygonal mineral grains and a foliation defined by composition or grain-size variations. These rocks are sometimes called "blastomylonite," but SLTTM_1.0 would classify them as "layered gneiss" or possibly as "non-layered gneiss" if the foliation is defined by flat mineral grains without layering.

5.4 Cataclastic rock

A rock is here classified as a cataclastic rock if >10% of the volume consists of fragments bounded by fractures related to deformation that occurred after the formation of the protolith. Cataclastic rocks typically include fault rocks formed in the brittle regime, although that origin is not required by the descriptive definition. Deformation in faults and shear zones occurs in a continuum of environmental conditions from near the Earth's surface, where discontinuous brittle processes dominate, to high temperature conditions deep in the Earth where continuous deformation and crystal-plastic processes dominate (Sibson, 1977; Passchier and Trouw, 1996). Cataclastic rocks are further classified based on the presence or absence of primary cohesion, the percentage of broken fragments large enough to be visible, and the amount of fragmental cataclastic matrix (Sibson, 1977; Snoke and Tullis, 1998).

Some cataclastic rocks are foliated, but where this is the case, the foliation is defined by aligned aggregates of rock fragments, rather than oriented mineral grains. Minerals in the same rock may deform by different mechanisms, and loss of material continuity across slip surfaces may vary, resulting some rocks that are transitional between cataclastic rocks and mylonite-series rocks.

SLTTM_1.0 adapts Sibson's (1977) widely used classification of cataclastic rocks, as slightly modified by Scholz (1990, Table 3.1) and endorsed by Snoke and Tullis (1998, Table 0.1). The cataclastic rocks are initially subdivided based on the presence or absence of primary cohesion (cohesion during the deformation). Those having evidence of primary cohesion ('**cataclasite series**' of Sibson) are subdivided into **protocataclasite** (having 10-50% matrix), **cataclasite** (having 50-90% matrix), and **ultracataclasite** (having 90-100% matrix). Fluid flow along fault zones commonly re-cements rocks that have lost cohesion during deformation, obscuring evidence for the presence or absence of primary cohesion during deformation. **Incohesive cataclastic rocks** are those that lack evidence of primary cohesion. These include **fault breccia** (having visible fragments make up >30% of the rock) and **gouge** (having visible fragments <30% of the rock). Cataclastic rocks are further subdivided based on the presence or absence of foliation. **Pseudotachylite**, as discussed below under composite-genesis melt rock, is also regarded as a special type of cataclastic rock. Distinctions between cataclastic rock and **broken rock** related to mass wasting (e.g., landslides, rock avalanche, caldera collapse) are based on the geologic setting.

5.5 Composite-genesis melt rock

5.5.1 Definition

Composite-genesis melt rock—a rock that solidified from melt (liquid) of a preexisting rock under conditions outside the domain of typical igneous rocks.

Examples of composite-genesis melt rock include contact-metamorphic melt rock (melt under contact metamorphic conditions), impact melt rock (also classified as impact-metamorphic rock and discussed under that heading), and pseudotachylite.

Pseudotachylite (also spelled pseudotachylyte) is typically a dark, glassy-looking rock that occurs as veins and dike-like injections in fault systems, and it is commonly interpreted as a product of frictional melting along faults (Spray, 1995; Snoke and Tullis, 1998). The IUGS provisional definition for **pseudotachylite** is "Ultrafine-grained vitreous-looking material, usually black and flinty in appearance, occurring as thin planar veins, injection veins or as a matrix to pseudo-conglomerates or breccias, which infills dilation fractures in the host rock" (Brodie and others, 2002). SLTTM_1.0 modifies this definition slightly for internal consistency, and to avoid introduction of new terminology:

Pseudotachylite—an aphanitic, vitreous or flinty material that occupies dilatent fractures associated with fault zones or impact craters, and is interpreted to be related to frictional melting associated with seismic or shock events. It typically contains abundant fractured-rock inclusions and occurs within larger bodies of broken or brecciated rock.

"Impact pseudotachylite" is regarded here as a special occurrence of pseudotachylite as discussed below under "impact-metamorphic rock."

5.6 Impact-metamorphic rock

Impact-metamorphic rock is defined (unavoidably) by genesis and subdivided based on descriptive fabric criteria. In the strictest sense, i**mpact metamorphism** is "caused by the passage of a shock wave due to impact of a planetary body (projectile or impactor) on a planetary surface (target)" whereas "shock metamorphism" is "caused by shock wave compression due to impact of a solid body or due to the detonation of high-energy chemical or nuclear explosives"

(Stöffler, 2001c). Impact metamorphic rocks display evidence of shock metamorphism, such as microscopic planar deformation features within grains or shatter cones (Stöffler and Grieve, 2001). Many rocks classified as impact metamorphic rocks are interpreted as such based on field relationships (such as a crater), and such interpretations can be subject to debate.

The field classification of impact-metamorphic rocks can be problematic, because of their similarity to some sedimentary or fault-related breccias, and to various fragmental volcanic or pyroclastic rocks in other situations. Where impact metamorphic rocks would meet the descriptive criteria for cataclastic rocks, the distinction of an impact metamorphic rock is based on observable features attributed to shock metamorphism, or by interpretation of field relations at the sample location. The essential feature that identifies an impactite (impact metamorphic rock) is the presence of microscopic planar deformation features that are unequivocally the result of shock metamorphism (Stöffler and Grieve, 2001).

Stöffler and Grieve (2001) and Stöffler (2001a, 2001b, 2001c) proposed a threefold IUGS classification of impactites resulting from a single impact event as (i) shocked rock, (ii) impact melt rock, and (iii) impact breccia. The definitions, as slightly modified and adapted for use in this classification, are:

shocked rock—non-brecciated rock which shows unequivocal effects of shock metamorphism exclusive of whole rock melting.

impact melt rock—crystalline, semi-glassy, or glassy rock in which >=50% of the rock volume is solidified from impact melt (implying <50% non-melt inclusions).

impact breccia—breccia, as generally defined, that has unequivocal evidence of shock metamorphism.

"Impact breccia" is further divided into three subclasses, slightly modified from Stöffler and Grieve (2001) and Stöffler (2001a, 2001b, 2001c), which are: (i) **suevite** [impact breccia that contains impact melt particles (>0 and <50%)]; (ii) **polymict impact breccia** [impact breccia that contains fragments of different composition and is free of impact melt particles, and (iii) **monomict impact breccia** [impact breccia free of impact melt in which all of the fragments (100%) have essentially the same composition."].

Pseudotachylite, in addition to being associated with regional faults (see Cataclastic Rocks), occurs in impact structures such as the Vredefort structure in South Africa, where pseudotachylite was first described (discussion and references in Snoke and Tullis, 1998). Pseudotachylite is here classified as a cataclastic rock, whether or not the associated fault or fracture zone happens to be part of an impact structure. "Impact pseudotachylite" as used by Stöffler (2001c) is not distinguished in this classification and, instead, is regarded as a special occurrence of pseudotachylite.

Further subdivisions of impact metamorphic rock, including those from multiple impacts as known from the Moon (Stöffler and Grieve, 2001), are not considered here. More specific terms can be used in a text field where desirable. In the case of "shocked rock," the dual use of a protolith classification (sedimentary, igneous, or metamorphic) can be applied. In a similar fashion, the dual use of an igneous rock classification can provide more information on the composition and texture of "impact melt rock" at places such as Sudbury, Ontario.

5.7 Term of last resort in absence of fabric class

'Rock' is used as a root name of last resort only where the fabric of the rock is unknown and therefore unspecified. Potential applications may be necessary where geologic map units are inferred from geophysical data or compiled from sources based on other criteria such as age or formation name. If the fabric is known, a more informative term such as schist, gneiss, or granofels should be used. A composition qualifier could be added to rock (e.g., calc-silicate rock, quartzofeldspathic rock, ultramafic rock).

6 CLASSIFICATION BY COMPOSITION (QUALIFIER TERMS)

Selection of composition qualifiers is based on the modal mineralogy of a metamorphic rock. Compositional classification is based on classification of mineral species into groups based on general chemical similarity. Definitions of the mineral groups that serve to identify the various composition types are thus fundamental.

6.1 Definition of rock-forming mineral groups in this classification

Ferromagnesian minerals. Omphacite (jadeitic pyroxene), chlorite, dark-colored amphibole, dark-colored pyroxene, biotite, serpentine, pyrope garnet, talc.

Quartz-feldspar (quartzofeldspathic) minerals: quartz, plagioclase, K-feldspar.

Calcsilicate minerals: minerals that contain significant amounts of Ca ± Mg and Si and include diopside, epidote, grossularite and uvarovite garnet, calcic-amphiboles, titanite, wollastonite, vesuvianite and calcic plagioclase. Mg-rich minerals such as forsterite and phlogopite are also common constituents of calcsilicate-rocks. As a general rule, plagioclase may be considered a calcsilicate mineral if it has >50% anorthite content (Robertson, 1999).

Carbonate minerals: calcite, dolomite, siderite.

Aluminous minerals: aluminosilicates, muscovite, kaolinite, garnet (associated with feldspar), corundum, pyrophyllite.

Phyllosilicate minerals: mica group, chlorite group

Garnets occur in aluminous, ferromagnesian, and calcsilicate rocks. Cordierite, staurolite, brucite, and periclase are not useful for compositional rock classification without more detailed knowledge of their mineral associations or compositions.

Table 2. Summary of composition terms

Qualifier	definition	source	kind
amphibolite	Rock that consists of >75% green, brown, or black amphibole plus plagioclase (including albite) and amphibole >30% (modal) of whole rock, and amphibole >50% of total mafic constituents.	Coutinho and others (2002)	common
argillic	use for apparently clay-rich aphanitic rocks	based on Jackson, 1997	standard chemical
calcareous	When mineralogy cannot be identified (aphanitic rocks), means that rock reacts to form bubbles when hydrochloric acid is applied.	Jackson (1997); criteria proposed by this report	standard chemical
calcareous quartzo-feldspathic	rock consists of 10%-50% carbonate or calcsilicate minerals, and micaceous or aluminous minerals form <40% of non-(carbonate or calcsilicate) minerals and quartz forms <60% of the non-(carbonate or calcsilicate) minerals	Robertson (1999)	standard chemical
calcareous-pelitic	rock consists of 10%-50% carbonate or calcsilicate minerals, and micaceous or aluminous minerals form ≥ 40% of non-(carbonate or calcsilicate) minerals	Robertson (1999)	standard chemical

Qualifier	definition	source	kind
calcareous-quartzite	rock consists of 10%-50% carbonate or calcsilicate minerals, and micaceous or aluminous minerals form <40% of non-(carbonate or calcsilicate) minerals, and quartz forms ≥ 75% of the non-(carbonate + calcsilicate) minerals	Robertson (1999)	standard chemical
calcareous-semi-pelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%, and quartz+ feldspar < 60% and carbonate + calcsilicate minerals > 10%	Proposed, this report	standard chemical
calcite marble	carbonate minerals form > 75% of rock, and calcite forms >75% of carbonate minerals.	modified from Robertson (1999)	common
calcsilicate	rock consists of ≥ 50% calcsilicate or carbonate minerals and carbonate minerals ≤ calcsilicate minerals in mineral mode. When used for aphanitic rocks, indicates quartz or feldspar is significant in the mineral mode, and the rock does not meet calcareous.	Barker (1998, Appendix II), Robertson (1999)	standard chemical
dark-colored	use for dark-colored aphanitic rocks about which other information not available	descriptive	color
dolomite marble	carbonate minerals form > 75% of rock, and dolomite forms >75% of carbonate minerals.	modified from Robertson (1999)	common
eclogite	Rock composed of >75% garnet (almandine-pyrope) and sodic pyroxene (omphacite).	Carswell (1990), Barker (1998, Appendix II), modified from Jackson (1997)	common
epidosite	Rock consisting of >75% epidote, and >50% of non-epidote mineral is quartz.	modified from Jackson (1997)	monomineralic
ferromagnesian	rock having >40% dark ferromagnesian minerals. Standard term defined by Bates and Jackson (1987) to mean "containing iron and magnesium"	Usage proposed, this report	superclass
greisen	Hydrothermal rock consisting of >70% quartz + muscovite or lepidolite, and having accessory (>1%) topaz or tourmaline (or other fluorine-bearing phase). In a hierarchy based purely on description, would be a kind of semi-pelitic rock (10-40% aluminous minerals; <60% quartz + feldspar) or quartz-feldspathic (<40% aluminous and >60% quartz + feldspar)	modified from Jackson (1997)	common
impure marble	rock consists of >50% calcsilicate or carbonate minerals and relative proportion of calcsilicate and carbonate minerals is unknown or not specified	Usage proposed, this report	superclass
light-colored	use for light-colored aphanitic rocks about which other information not available	descriptive	color
mafic	rock consists of ≥ 40% and <90% ferromagnesian minerals.	modified from Robertson (1999)	standard chemical
magnesian	No definition at present., but may be useful?		

Qualifier	definition	source	kind
marble	rock in which carbonate minerals form > 75% of rock	Barker (1998, Appendix II), Robertson (1999)	common
metacarbonate	rock consists of >50% calcsilicate or carbonate minerals and carbonate minerals > calcsilicate minerals in mineral mode.	Robertson (1999)	standard chemical
monomineralic	Rock that consists of >75% of a single mineral species and does not meet any of the other composition terms (e.g. quartzite, calcite marble, dolomite marble, serpentinite…)	for consistency with Robertson (1999)	superclass
None	Composition not specified	this scheme	superclass
pelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%, and aluminous mineral + mica content is ≥ 40%.	modified from Robertson (1999)	standard chemical
quartz-feldspar-pelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%	Usage proposed, this report	superclass
quartzite	Rock that consists of ≥ 75% quartz	Robertson (1999), revised to be consistent with other monomineralic rocks.	common
quartzo-feldspathic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%, and quartz + feldspar >60%.	revised from Robertson (1999)	standard chemical
semi-pelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%, and quartz+ feldspar < 60%.	revised from Robertson (1999)	standard chemical
serpentinite	Rock that consists of >75% serpentine.	Barker (1998, Appendix II), Jackson (1997), revised to be consistent with other monomineralic rocks.	monomineralic
silicic	Use for apparently siliceous aphanitic rocks. Bates & Jackson (1987) include denotation of igneous origin. For this classification, should be considered to mean "appears to consist largely of quartz and feldspar", generally is aphanitic with hardness ≥ 6, and the rock does not meet calcareous or calcsilicate.	Usage proposed, this report	standard chemical
skarn	Not recommended. Usage too problematic; distinction from calcsilicate hornfels or calc-silicate granofels not clear.	Einaudi (1982), Einaudi and Burt (1982), Barker (1998, Appendix II)	common

Qualifier	definition	source	kind
special composition	Rock that has a mineral composition that doesn't fit in any defined composition class. A modal mineral description is essential. The rock consists of <40% ferromagnesian minerals and <50% carbonate + calcsilicate minerals and <70% Q+Fs + mica + aluminous minerals.	Usage proposed, this report	superclass
ultramafic	Rock that consists of >90% ferromagnesian minerals.	Robertson (1999)	standard chemical
whiteschist	Not recommended. Use pelitic rock if kyanite + garnet + white mica + quartz >70%, and ky + garnet + white mica must be ≥ 40%, otherwise whiteschist is a kind of special composition metamorphic rock. Whiteschist is defined as a rock consisting of talc, kyanite, white mica (paragonite), garnet, or (sodic whiteschist) jadeite, Mg-glaucophane, kyanite, quartz, and garnet. Desmons and others' (2002) IUGS proposal notes that "Whiteschist is defined in a loose descriptive manner, in a similar way to blueschist…More precise rock terms should be used wherever possible (e.g., kyanite-talc-phengite schist)."	Schreyer (1973, 1977), Meyre and others (1999); Desmons and others (2002)	common

6.2 Quartz-feldspar-pelitic rocks

Pelite has three definitions in the *Glossary of Geology* (Jackson, 1997): (1) "a sediment or sedimentary rock composed of clay- or mud-sized particles," (2) "a fine-grained sedimentary rock composed of more or less hydrated aluminum silicates with which are mingled small particles of various other minerals; an aluminous sediment," and (3) "the metamorphic derivative of a lutite, such as the metamorphosed product of a siltstone or mudstone (as commonly used a pelite means an aluminous sediment metamorphosed, but if used systematically, it means a fine-grained sediment metamorphosed)." Since Al-rich clays are a major component of most clay-sized sediment, the distinction between the meaning of "pelite" as a grain size and the compositional connotation has become blurred. The term "pelite" has a strong connotation of aluminous composition when used to describe metamorphic rocks, and the British Geological Survey classification of metamorphic rocks uses it in that sense (Robertson, 1999).

SLTTM_1.0 follows the British Geological Survey's lead in emphasizing the aluminous composition of pelite, but differs in using the adjective form "pelitic-" as a compositional qualifier prefix to a fabric term as in "pelitic-schist." We use the following classification categories (Table 2):

Pelitic—a rock composition having modal percentages of quartz + feldspar + mica + aluminous minerals ≥ 70% is here classified as if aluminous minerals + mica ≥ 40%.

Semipelitic—quartz +feldspar <60%

Quartzofeldspathic—quartz + feldspar >60%.

SLTTM_1.0 does not consider biotite mica to be an aluminous or "pelitic" mineral.

6.3 Monomineralic rocks

Rocks are considered to be monomineralic if they consist predominantly of a single mineral or closely related mineral group. Common monomineralic rocks such as marble (>75% carbonate), quartzite (>75% quartz), and serpentinite (>75% serpentine) are defined individually in the classification. Otherwise, “monomineralic” in the SLTTM_1.0 classification system is used as a general prefix to avoid including separate “-ite” names for nearly every mineral. Metamorphic rocks consisting predominantly (>75%) of a single mineral are classified as monomineralic-granofels, monomineralic-hornfels, monomineralic-schist, etc., depending on the fabric. If someone is interested in a specific monomineralic rock, the query would search the modal-mineralogy description for >75% of mineral Z. The user interface could have rock names such as hornblendite, biotitite, and tourmalinite stored in the database as ‘monomineralic metamorphic rock (or granofels, schist, hornfels)’ and specify modal mineralogy >75% of the appropriate mineral.

6.4 Calcsilicate and metacarbonate rocks

Calcsilicate and metacarbonate rocks are rocks that are composed of ≥50% calcsilicate or carbonate minerals. The term **marble** implies that a significant percentage of the rock consists of carbonate mineral. This follows the definition in Jackson (1997): “a metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite or dolomite, usually with a granoblastic, saccharoidal texture”.

SLTTM_1.0 defines **marble** as a monomineralic rock in which carbonate minerals form > 75% of rock. For rocks that meet the mineralogical definition of marble, but do not have a granoblastic fabric, the term marble becomes a strictly compositional modifier. Although a marble may consist of several different minerals (calcite, dolomite, siderite…), it is considered monomineralic because they all belong to the samel , closely related mineral carbonate minerals group. The name **impure marble** is suggested as a general term for rocks that consist of >50% but ≤75% carbonate and calc-silicate minerals, and **metacarbonate rock** for an **impure marble** in which carbonate minerals are more abundant than calc-silicate minerals.

6.5 Ferromagnesian rocks

Ferromagnesian rocks are those that consist of >40% dark ferromagnesian minerals. Rocks included in this group include eclogite, mafic and ultramafic metamorphic rocks, and amphibolite.

The *Glossary of Geology* (Jackson, 1997) defines **amphibolite** as “A crystalloblastic rock consisting mainly of amphibole and plagioclase with little or no quartz. As the quartz content increases, the rock grades into hornblende-plagioclase gneiss.” A wide range of accessory minerals can be present.

Most amphibolites are metamorphosed mafic igneous rocks (ortho-amphibolites) but some may be metamorphosed calcareous sediments (para-amphibolites) (Yardley, 1991). Coutinho and others (2002) compiled the modal mineralogy of numerous rocks described as “amphibolite” from different localities, noting that they fit the common definition of amphibolite as a hornblende + plagioclase rock. Their data show that most amphibolites contain >50% amphibole although 30% to 50% is not unusual, that the amphibole + plagioclase is mostly >90% and less commonly as low as 75%, and that most of the rocks described as amphibolite have <10% quartz. Based on these and other data, Coutinho and others (2002) proposed the following IUGS definition:

> “Amphibolite is a gneissose or granofelsic metamorphic rock mainly consisting of green, brown, or black amphibole and plagioclase (including albite), which combined constitute more than 75% of the rock. The amphibole constitutes more than 50% of the total mafic constituents and is present in an amount more than 30% [italics added]. Other common minerals include quartz, clinoproxene, garnet, epidote-group minerals, biotite, titanite, and scapolite. Orthopyroxene is absent.”

Members of the SLTT Subgroup on Metamorphic Rocks object to the exclusion of orthopyroxene, which can be present in these rocks at uppermost amphibolite facies, and to the inclusion of scapolite as a "common" mineral. Scapolite may occur in amphibolites of calc-silicate affinity but it is not "common." The main part of Coutinho and others' (2002) proposed IUGS definition shown in italics is adopted here, without requiring the absence of orthopyroxene.

SLTTM_1.0 defines **amphibolite** as a metamorphic rock composed mostly of green, brown, or black amphibole and plagioclase (including albite) so that amphibole + plagioclase >75% and amphibole >30% (modal percent) of the whole rock, and amphibole >50% of the total mafic constituents.

6.6 Special-composition rocks

Special non-systematic rock names such as whiteschist, rodingite, fenite, skarn, gondite, coticule, and greisen are commonly used in some settings. Their definitions typically are based on modal mineralogy, but not fabric, and as such may generally be considered as composition qualifier terms. This classification leans towards a minimum of special rock names for rocks of unusual composition, and relies on the presence of a modal-mineralogy description included in the database to provide a mechanism to describe and search for such rocks. Thus, many of these special rocks would be assigned a composition qualifier 'special composition'. The uncontrolled rock name field in the database is available to assign any special rock name the geologist may prefer.

Some of these special-composition rock names may be added as subtypes of special-composition rock, which are identified by decision switches near the top of the classification decision tree. The problem posed by many of these special names is that their definitions overlap other composition-qualifier classes. For example, in the composition-qualifier hierarchy, greisen is a subclass of quartz-feldspar-semipelitic rock but may overlap semipelitic rock, quartzofeldspathic rock, or quartzite, depending on the specific modal mineralogy. Thus, placement of these special terms in the same class hierarchy results in ambiguous classification (should the rock be classified as greisen or as semi-pelitic granofels?), unless a modal mineral analysis description is included. Use of special rock names must be constrained by requiring that a modal-mineral description be provided for any rock for which classification using the special name results in ambiguous placement in the composition qualifier hierarchy. Again, this classification scheme avoids such special terms as much as possible. Such names are better used in the uncontrolled lithology name field of the database.

7 CLASSIFICATION BY PROTOLITH

Two groups that have recently developed or are in the process of developing terminology for metamorphic rocks (Robertson, 1999; Schmid and others, 2002) include protolith as an important classification criterion in cases where protolith is clearly identifiable. In many metamorphic terranes the protolith for metamorphic rocks is obvious, and in such terranes (e.g. Canadian Shield), rocks are commonly mapped based on protolith, and named by adding the prefix ‘meta’ to the protolith name to indicate that the rock has been metamorphosed. For many users, such as mineral explorationists and resource appraisers, protolith is the most important (commonly the only important) feature of these rocks, and any useful geologic map database must represent the protolith identification. Why not include protolith-based names (e.g., metabasalt, metagranite, metaconglomerate) in this classification?

We acknowledge that, for rock-naming purposes, use of the ‘meta’ prefix has been and no doubt will continue to be very useful as a way for geologists to (informally) communicate information about metamorphic rocks. However, we are concerned that, for incorporation into geoscience databases where fabric and composition are clearly key attributes of rock description, the tri-fold naming scheme that includes protolith in the rock name (e.g., metabasalt, metaquartzite, metalimestone) clogs up the works and introduces a highly subjective element of genetic interpretation into an exercise that we are trying to keep as descriptive as possible. The classification system proposed here is designed for databases (automated knowledge representation), and in this context, use of the ‘meta’ prefix is equivalent to dual classification--a protolith classification using the appropriate system for the determined protolith, and classification as 'metamorphic rock' in our proposed composite-genesis classification. The usage tells nothing about what kind of metamorphic rock the material is, beyond whatever connotations the protolith rock name has for composition. Accordingly, SLTTM_1.0 recommends that rock-name terms in the form ‘meta(*some rock name*)’ are to be placed in an uncontrolled rock name field, designed to allow the geologist to assign the name that is most meaningful for local or traditional use. Such terms also can appear in a user interface for classifying rocks by having underlying software that maps the name assignment to the implied dual classification. To keep the meaning of the classification clear, a metamorphic rock must be classified based on the aspects of the rock that make it a metamorphic rock, i.e., fabric and composition.

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9 APPENDIX 1. PRELIMINARY REPORTS OF THE IUGS SUBCOMMISSION ON THE SYSTEMATICS OF METAMORPHIC ROCKS (SCMR)

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10 APPENDIX 2. SELECTED FABRIC TERMS AND DEFINITIONS

Aphanitic—“Individual grains not visible with the unaided eye (ca. <0.1 mm)” (Schmid and others, 2002) [“Said of the texture of an igneous rock in which the grains are too small to distinguish with the unaided eye…” (Jackson, 1997) and extended to metamorphic rocks by Schmid and others (2002).]

Cataclastic—“Pertaining to the structure produced in a rock by the action of severe mechanical stress during dynamic metamorphism; characteristic features include the bending, breaking, and granulation of minerals. Also said of the rocks exhibiting such structures.” (Jackson, 1997)

Cataclastic rock --“A rock, such as tectonic breccia, containing angular fragments that have been produced buy the crushing and fracturing of preexisting rocks as a result of mechanical forces in the crust.” (Jackson, 1997). Mylonite-series rock is not classified here as a cataclastic rock, although it may contain subordinate cataclastic fabric.

Cleavage—“The property of a rock to split along a regular set of parallel or sub-parallel closely spaced surfaces” (Brodie and others, 2002).

Continuous foliation –Foliation in which the fabric elements are uniformly distributed. For precision, *continuous* is here defined on a hand sample-scale, and in quantitative terms to mean that domains lacking the fabric are <1 cm thick if they are layers, and <5 cm in diameter if they are irregular patches, and constitute <25% of the rock. Distinct from spaced foliation (Passchier and Trouw, 1996, p. 64-65).

Compositional layering--Non-genetic term for foliation defined by layers of different composition (Passchier and Trouw, 1996). Compositional layering is here considered to be *laterally continuous* if layers can be traced >10 cm.

Fabric element-- Part of a rock fabric such as a foliation, lineation, etc. (Jackson, 1997; Passchier and Trouw, 1996). Any of the elementary parts of an aggregate whose orientation and geometry can be described; only structures that are penetrative on the scale of the domain contribute to the fabric (Turner and Weiss, 1963).

Fabric--The complete spatial and geometrical configuration of all those components that are contained in a rock and that are penetratively and repeatedly developed throughout the volume of rock under consideration; the shapes and characters of individual parts of a rock mass and the manner in which these parts are distributed and oriented in space (paraphrase of Passchier and Trouw, 1996, and Jackson, 1997), both of which cite Hobbs and others (1976, p. 73). [English translation of German word *Gefüge* used by Sander (1930) to denote the internal ordering of both geometric and physical spatial data in an aggregate (Turner and Weiss, 1963). In a non-crystal, the internal geometric configuration of the elementary parts and of any characteristic features to which the arrangement of these parts gives rise [paraphrase from, Paterson & Weiss (1961, p. 854) quoted in Turner & Weiss (1963, p. 19).]

Foliation—Planar fabric in a rock that is penetrative on a mesoscopic scale (Turner and Weiss, 1963; Passchier and Trouw, 1996; Brodie and others, 2002).

Grain-shape fabric--Fabric defined by shape-preferred orientation of mineral grains or mineral grain aggregates (Passchier and others, 1990; Passchier and Trouw, 1996, p.74).

Gneissosity—“General term for foliation in a gneiss. Use of this term is discouraged because of its vague connotation; several types of foliation (layering, schistosity) may occur in the same gneiss.” (Passchier and Trouw, 1996, Glossary)

Granoblastic--Fabric dominantly formed by equidimensional crystals. An example is a foam structure…in which platy or acicular mineral shapes are absent, and most grains have equant shape. (Passchier and Trouw, 1996, Glossary)

Migmatitic--Having the characteristics of migmatite, which is "A coarse-grained heterogeneous rock type characteristically with irregular and discontinuous interleaving of leucocratic granitoid material (leucosome) and residual high-grade metamorphic material (restite). (Barker, 1998, Appendix II: Glossary)

Mylonite-series rock--A collective term for the "mylonite series" rocks of Sibson (1977), including protomylonite, mylonite, ultramylonite, and phyllonite. Equivalent to Brodie and others' (2002) broader usage of "mylonite" for "A fault rock which is cohesive and characterized by a well developed [foliation] resulting from tectonic reduction of grain size, and commonly containing rounded porphyroclasts and lithic fragments of similar composition to minerals in the matrix." By this usage, mylonite-series rock is not a cataclastic rock; cataclastic fabrics, if present, are subordinate.

Penetrative—Repeated at distances so small, compared with the scale of the whole…that they can be considered to pervade it uniformly and be present at every point (paraphrase of Turner and Weiss, 1963, p. 21).

Penetrative fabric element--A fabric element that occurs penetratively throughout a rock at the scale of observation (Passchier and Trouw, 1996).

Phaneritic—"Individual grains visible with the unaided eye (ca. >0.1 mm)" (Schmid and others, 2002). ["Said of the texture of an igneous rock in which the grains are large enough to distinguish with the unaided eye, i.e. megascopically crystalline" (Jackson, 1997) and extended to metamorphic rocks by Schmid and others (2002).]

Schistosity--Foliation in a rock due to the parallel, planar arrangement of mineral grains of the platy, prismatic or ellipsoidal types, usually mica (Jackson, 1997). *Well developed schistosity* is here defined to mean that >50% of the rock consists of mineral grains having a platy, lamellar, tabular, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric (following Jackson, 1997). *Continuous* is here defined on a hand sample-scale, and in quantitative terms to mean that domains lacking the fabric are <1 cm thick if they are layers, and <5 cm in diameter if they are irregular patches, and constitute <25% of the rock.

Slaty cleavage—A "well developed planar schistosity in a rock in which the individual grains are too small to be seen by the unaided eye and the schistosity is developed on the grain scale." (Brodie and others, 2002)

Spaced foliation—Foliation in which the fabric elements are separated by domains that lack the foliation; not "continuous" as defined above. Discussion in Passchier and Trouw (1996, p. 65).

11 APPENDIX 3. METAMORPHIC FACIES AND TYPES

This appendix presents recommendations (initially proposed by Subgroup members Hoisch and Williams) for the classification of metamorphic facies and types of metamorphism. These recommendations assume as a prerequisite that any rock should fit into only one facies and only one type of metamorphism. We exclude the hornfels and sanidinite facies, as done by Spear (1993) because the mineral assemblages are no different than in the higher-pressure facies. The only distinction appears to be textural, and that will appear in other attribute lists (rocks called hornfels or hornfelsic). "Sanidinite facies" is essentially synonymous with pyrometamorphism and consequently is not considered a true facies. We suggest including it in the granulite facies. Common usage for pyrometamorphism includes ultra-high temperature contact metamorphism, which poses the problem of a non-unique definition, unless it is confined to metamorphism by burning coal seams. That seems appropriate, since the root "pyro" means fire. It is an uncommon but spectacular type of metamorphism. The term "ultrametamorphism" means partially melted, but this overlaps both the upper amphibolite and granulite facies, and so we exclude it here. Lithologic terminology for partially melted rocks should follow the IUGS recommendations of Wimmenauer and Bryhni (2002) as much as possible.

We do not define the metamorphic facies, at this stage, because that would involve numerous debates on their boundaries. If we absolutely must define them, then some general statements can be added.

The lists below are recommendations for consideration by others. There is quite a range of published opinion. We tried not to make arbitrary decisions, but it is unlikely that any set of recommendations will please everyone.

Types of metamorphism:

1) **Contact metamorphism**--Metamorphism of country rock at the contact of an igneous body.

2) **Regional metamorphism**--Metamorphism not obviously localized along contacts of igneous bodies; includes burial metamorphism and ocean ridge metamorphism.

3) **Hydrothermal metamorphism (metasomatism)**--Metamorphism involving significant changes in a rock's bulk chemistry as a result of interaction with chemically reactive fluids.

4) **Shock (impact) metamorphism**—Shock metamorphism is “caused by shock wave compression due to impact of a solid body or due to the detonation of high-energy chemical or nuclear explosives” (Stöffler, 2001c). Impact metamorphism is “caused by the passage of a shock wave due to impact of a planetary body (projectile or impactor) on a planetary surface (target). It includes melting and vaporization of the target rock(s)” (Stöffler, 2001c).

5) **Pyrometamorphism**--Ultra-high temperature metamorphism at shallow depths caused by burning coal seams.

Metamorphic facies:

1) Zeolite

2) Prehnite-pumpellyite

3) Greenschist

4) Epidote amphibolite

5) Amphibolite

6) Granulite

7) Blueschist (glaucophane schist)

8) Eclogite

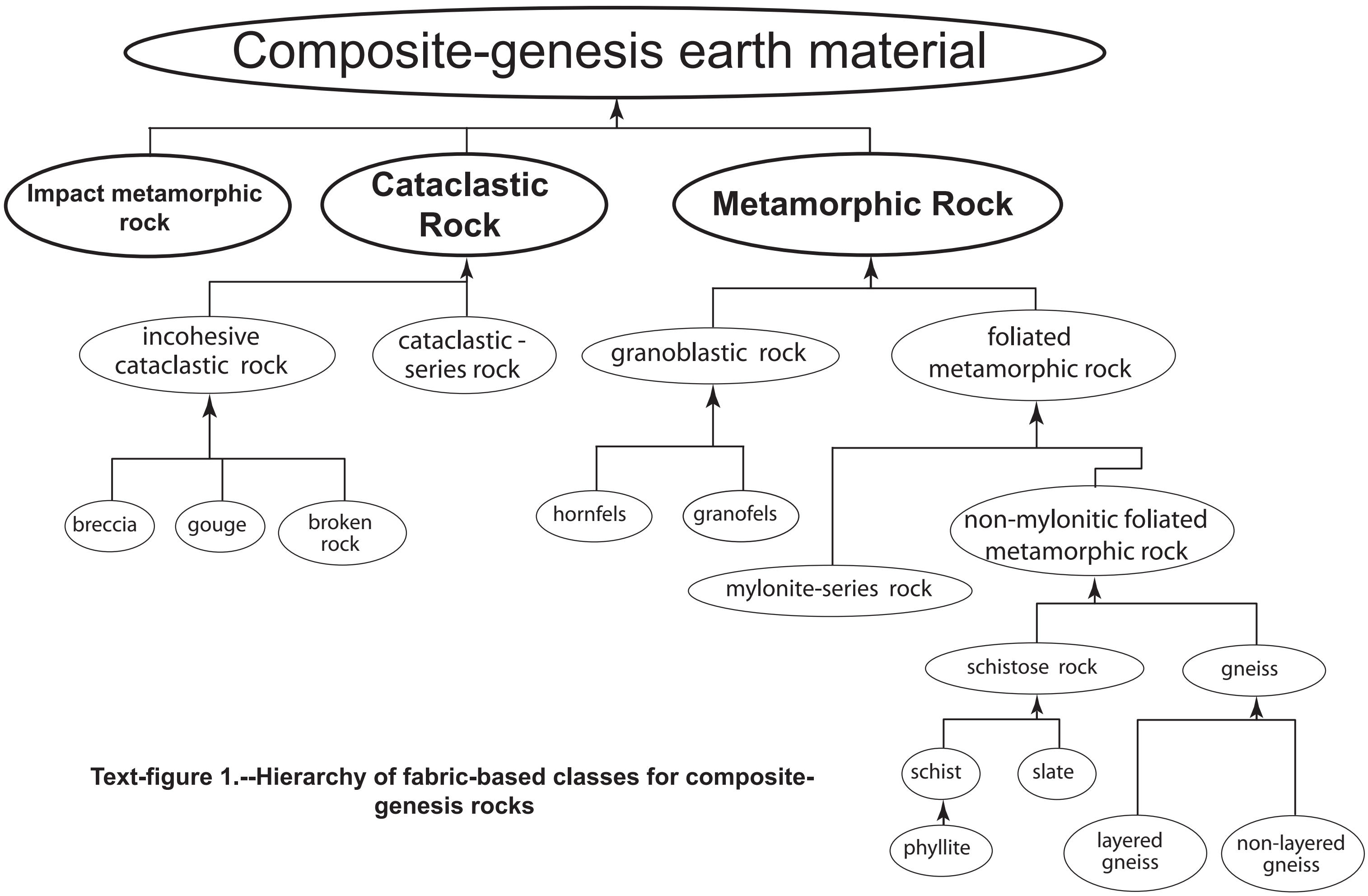
9) Ultra-high pressure

This proposed list of metamorphic facies differs from the IUGS recommendations of Smulikowski and others (1997), who also include the sanidinite facies (here included in granulite facies) and pyroxene hornfels facies. The glaucophane schist facies as used by Smulikowski and others (1997) is another name for the blueschist facies as listed here.

12 APPENDIX 4. GLOSSARY OF METAMORPHIC ROCK TERMS AND PARENT-CHILD RELATIONSHIPS (DATABASE)

Glossary is included in accompanying Microsoft Access database.

Figure 1



Text-figure 1.--Hierarchy of fabric-based classes for composite-genesis rocks

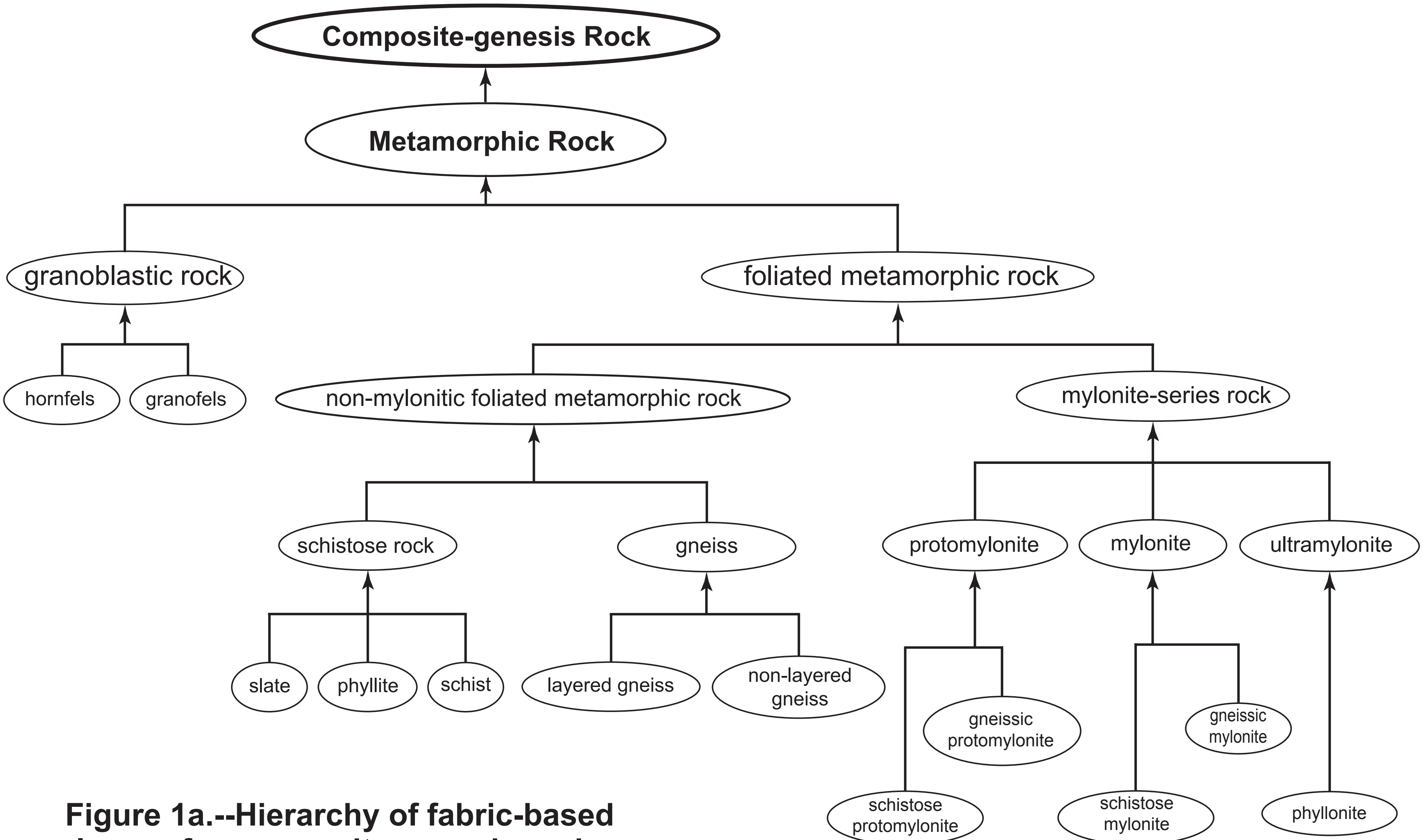


Figure 1a.--Hierarchy of fabric-based classes for composite-genesis rocks: conventional metamorphic rocks

Figure 1b

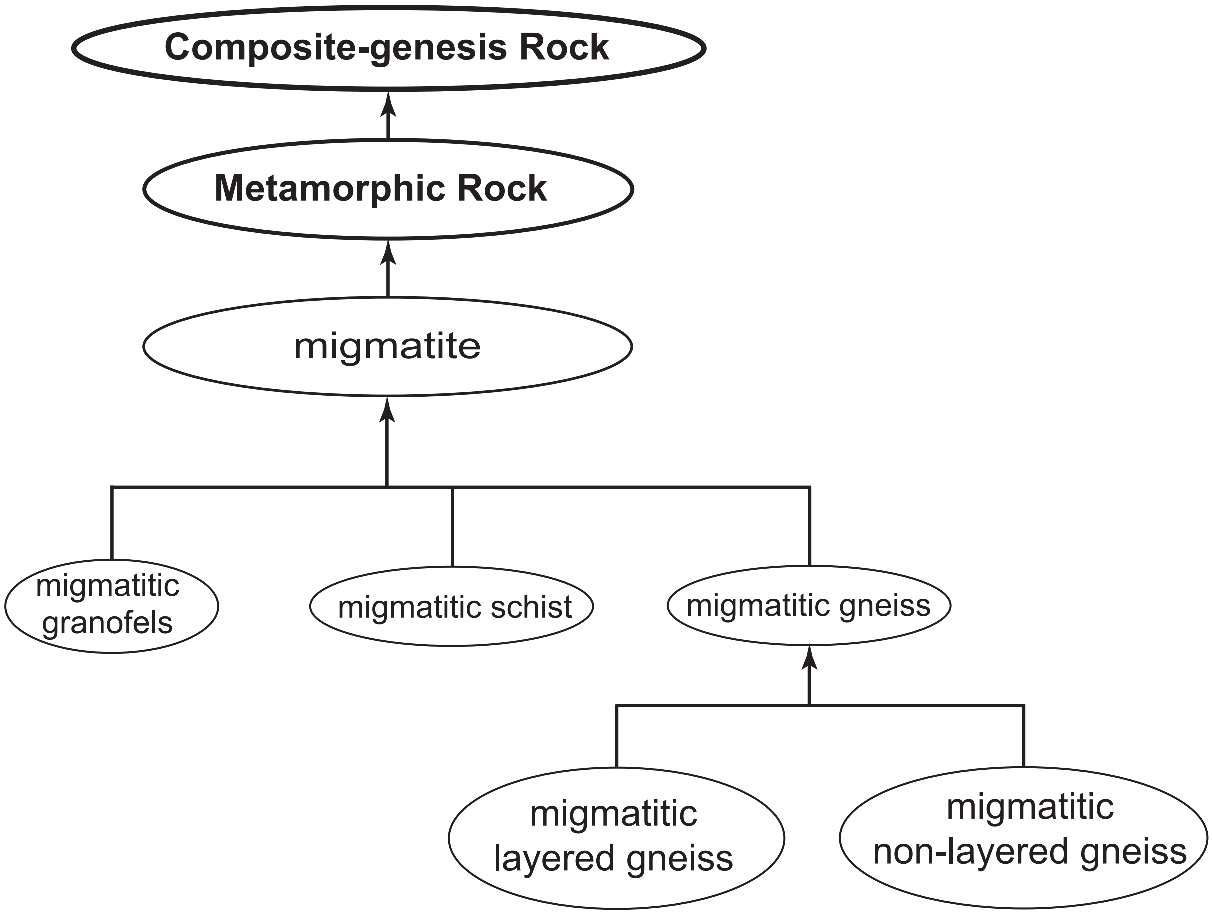


Figure 1b.--Hierarchy of fabric-based classes for composite-genesis rocks: migmatitic metamorphic rocks

Figure 2

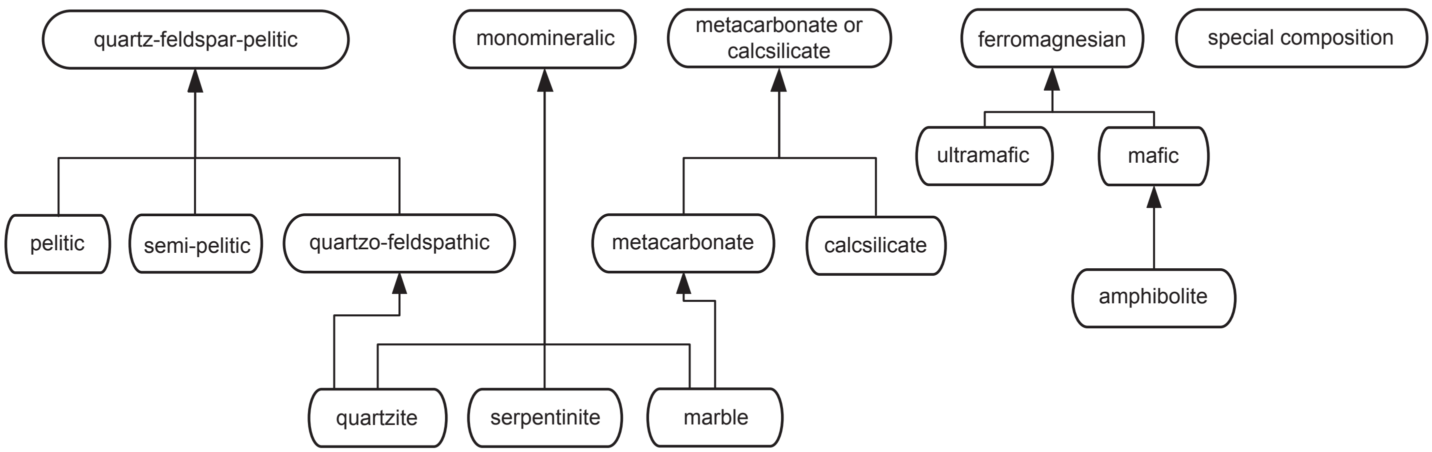


Figure 2.--Hierarchy of composition qualifier terms for composite genesis rocks

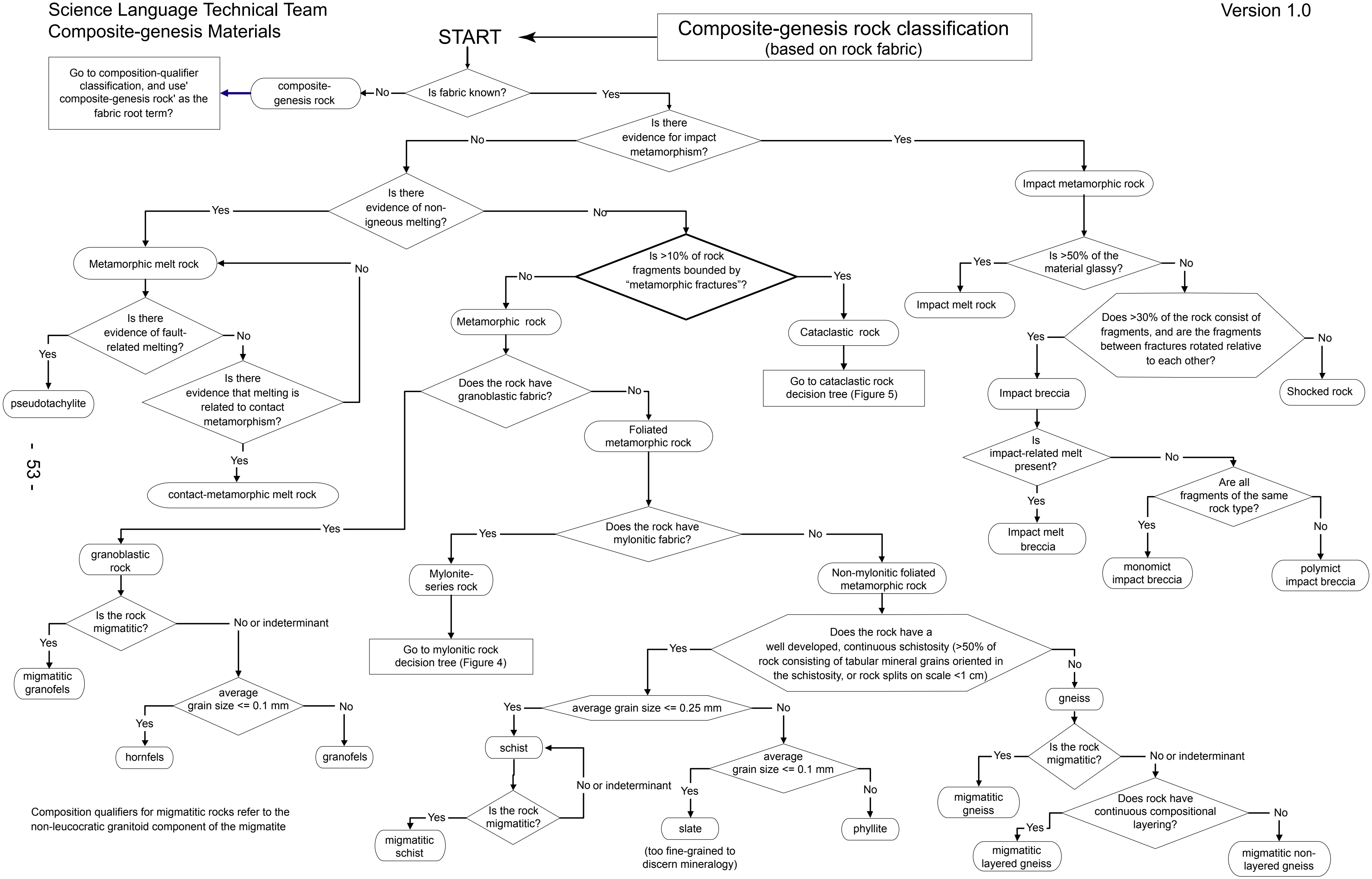


Figure 3.--Decision tree for classifying composite-genesis rocks based on fabric

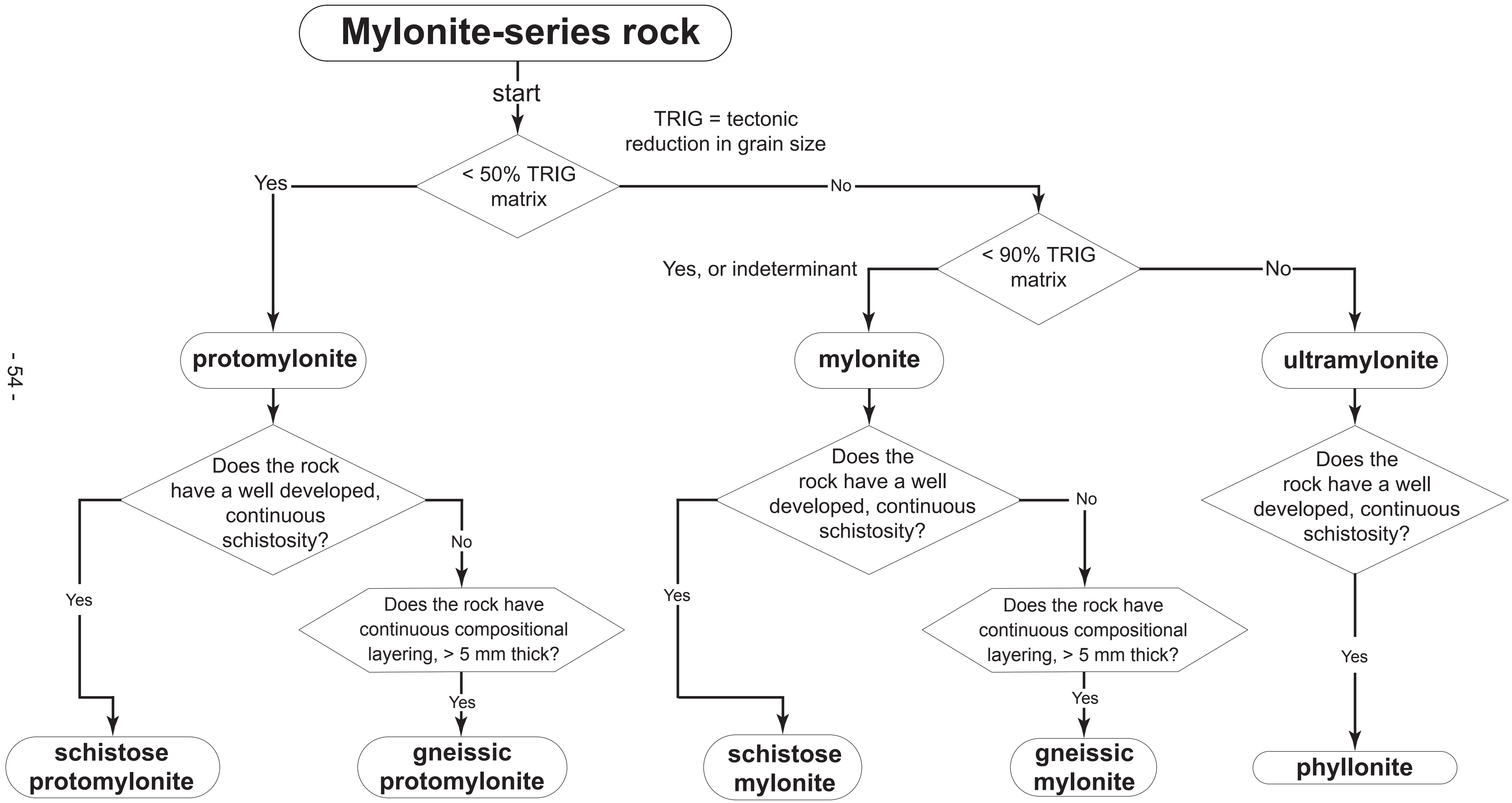


Figure 4.--Decision tree for mylonite-series rocks

Figure 5

These rocks need a special treatment for composition. The composition will in general be inherited from the protolith, which should also be classified, except in cases (gouge, ultracataclasite) where the protolith cannot be identified. Thus, compositional modifiers are only necessary for these. The fragmental rocks may have cement that is made of mineral materials not present in the protolith.

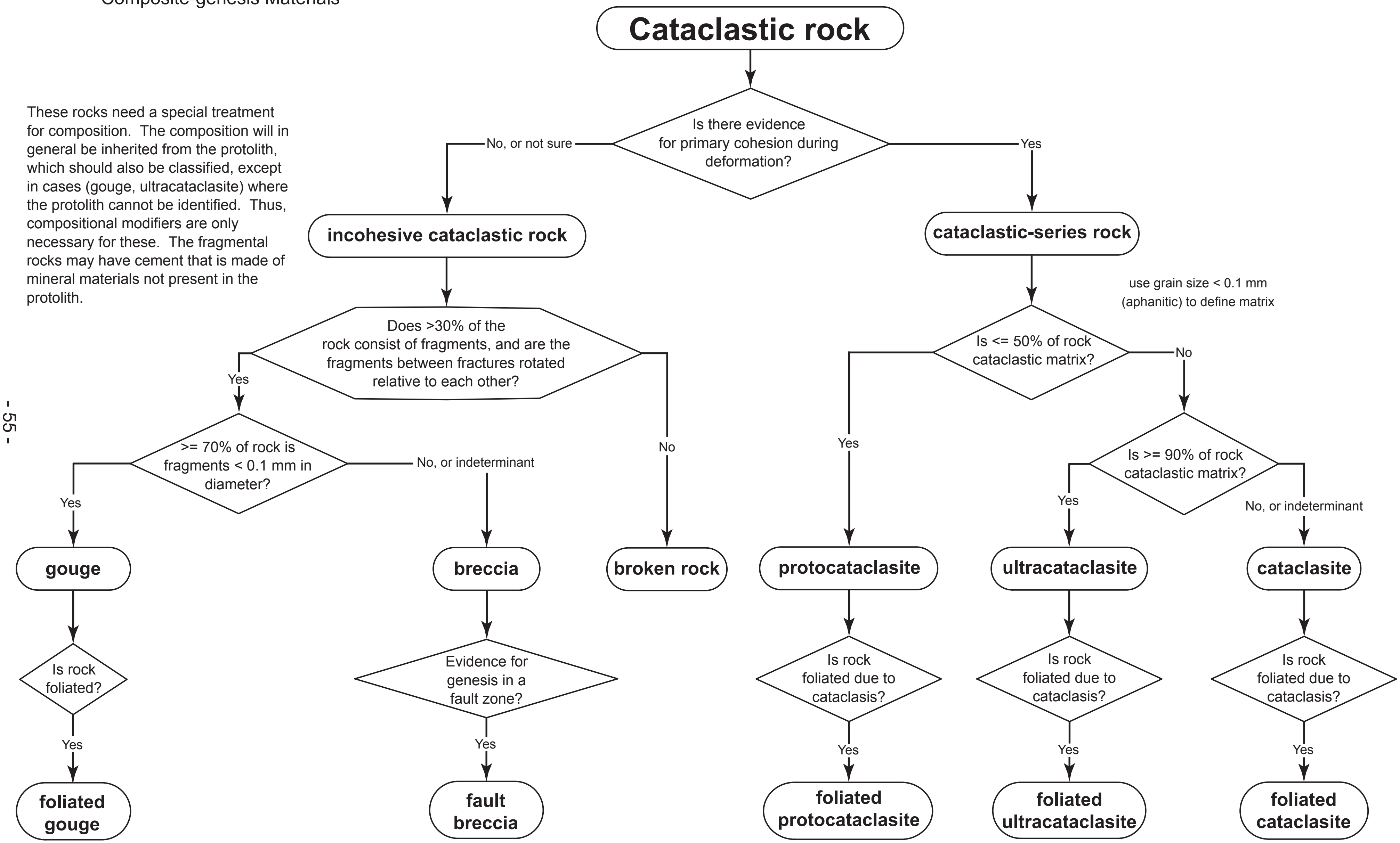


Figure 5.--Decision tree for cataclastic rocks

North American Data Model Steering Committee
Science Language Technical Team
Composite-genesis Materials

Compositional qualifiers for
composite-genesis rocks
Version 1.0

For rocks that have special names, if the special name denotes the rock fabric (typically granoblastic) then that rock name is used as a composition and fabric term; if a rock of that mineralogy has a different fabric from the denoted fabric, or the name does not denote a fabric, then use the special name as the composition modifier for an appropriate fabric term (e.g., marble gneiss, amphibolite schist, epidosite gneiss).

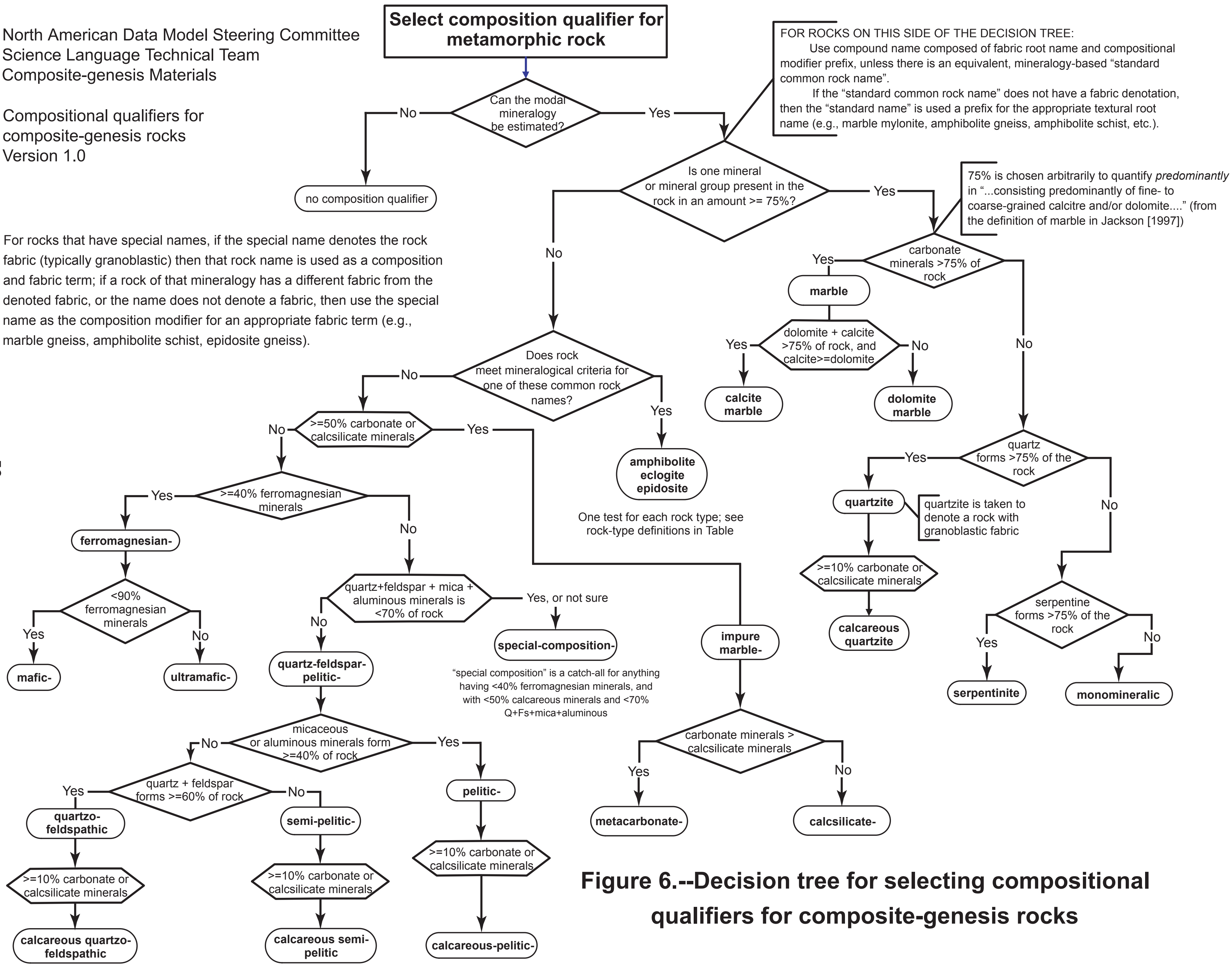


Figure 6.--Decision tree for selecting compositional qualifiers for composite-genesis rocks