Report on Progress to develop a North American Science-Language Standard for Digital Geologic-Map Databases

North American Geologic Map Data Model Steering Committee
Science Language Technical Team
http://nadm-geo.org/sltt/

INTRODUCTION

With the increasingly widespread production and use of digital geologic-map databases it has become clear that, to more effectively serve their constituencies, geoscience agencies need to develop several vital pieces of digital infrastructure:

1. A standard conceptual model for describing geologic phenomena, and for manipulating related data in a database environment,
2. Standardized science language that allows geologic materials and geologic structures to be described, classified, and interpreted,
3. Software tools for entering data into a standardized database and for retrieving the information according to user's needs, and
4. Methodologies and techniques for exchanging data sets having different structures and formats.

A single uniform language to classify and describe earth materials and their genesis is especially needed because users of geoscience information apply names, terms, and icons to communicate information about geologic objects and concepts. To the extent possible in a world where words are used diversely and inconsistently, standardized terminology is useful to facilitate information exchange among these users.

To address development of the infrastructure noted above, public-sector geologic-mapping entities in the United States and Canada formed a partnership called the North American Geologic Map Data Model Steering Committee (NADMSC, http://nadm-geo.org). NADMSC is sponsored by cooperative agreements between the U.S. Geological Survey (USGS) and the Association of American State Geologists (AASG), and between USGS and the Geological Survey of Canada (GSC). In the United States, NADMSC is linked to the database and standards development activities of the USGS National Geologic Map Database (http://ngmdb.usgs.gov/); in Canada, NADMSC is linked to database-development activities under the auspices of the Canadian Geoscience Knowledge Network.

The NADMSC chartered technical teams to develop resources and prototype standards for geologic map databases. These include: 1) the Data Model Design Team, which recently published the design for a conceptual data model (NADM DMDT, 2004); 2) the Data Interchange Technical Team, which provides in these Proceedings a report of progress (Boisvert and others); and 3) the Science Language Technical Team (SLTT), whose work is the subject of this report.

Between April 2000 and November 2004, the SLTT developed a prototype science language for the naming and describing of earth materials in geologic map databases produced by public-sector entities in North America. When the SLTT began its work, the intention was to produce a draft standard that could be evaluated, revised, and adopted by agencies and geologists working in North America. By the end of this process it became clear that, although this goal might be ultimately attainable, over the short term the SLTT's resources and lack of administrative authority prevent it from facilitating and executing the ambitious scope it originally envisioned.

Some committee members have proposed that the SLTT documents be published in a peer-reviewed venue. This is a logical suggestion, considering that the science-language reports are a comprehensive resource. However, this would require that the documents undergo an extensive review, and the NADMSC neither had the resources to conduct such a process nor does it have the formal mandate or permanent mechanism for archiving its documents. Therefore, in December, 2004, the SLTT posted the prototype science language as a set of "working documents" (see http://nadm-geo-org). Geologists and agencies are encouraged to evaluate and use the documents, to modify them as necessary for their purposes, and to offer recommendations for their modification.

In lieu of formal publication, the working documents are included in this open-file report in order to allow them to be permanently archived. The body of this report is an abbreviated summary of the SLTT's results. The Team's administrative procedures and the general nature of the science language classification were documented in a progress report at DMT'03 (NADM SLTT, 2003), and so are not repeated here. The appendices include the working documents and the executive summary from which this report was adapted. Because of their significant length, the appendices are available only in the web version of this open-file report.

The SLTT

The SLTT was formed in 2000, to identify and/or develop science language that allows information about geologic materials and geologic structures to be described in a standard way, and to promote wider use and more efficient exchange of geologic information. SLTT members were identified in the following ways:

1. Most participants from the U.S. Geological Survey were identified by Regional Geologic Executives from the USGS Western, Central, and Eastern Regions. This group includes representatives of the geologic-map editorial standards units of the regional publications groups. Additionally, some USGS scientists were appointed by Coordinators of USGS line-item science programs,
2. Scientists from the Geological Survey of Canada were identified by Canadian members of the NADMSC,
3. Scientists from State geological surveys were identified by the Digital Geologic Mapping Committee of the Association of American State Geologists (AASG),
4. Scientists from the U.S. Forest Service, National Park Service, U.S. Bureau of Land Management, and Natural Resources Conservation Service were selected by the committee chair, and
5. Scientists from academic institutions were selected by SLTT subcommittee co-chairs.

The assembled group (Table 1) represents a cross section of public-sector geologic map producers and users in the United States and Canada.

Table 1. NADMSC Science Language Technical Team committee members (Jonathan C. Matti, Chair)

Participant	Affiliation	SLTT Role
Lee Allison	Kansas Geological Survey	General scientific review
Brian Berdusco	Ontario Geological Survey	General scientific review
Richard C. Berg	Illinois State Geological Survey	Sedimentary subgroup
Thomas Berg	Ohio Geological Survey	General scientific review
Sam Boggs, Jr.	University of Oregon	Sedimentary subgroup
Eric Boisvert	Geological Survey of Canada	Sedimentary subgroup
Andrée Bolduc	Geological Survey of Canada	Sedimentary subgroup (co-chair)
Mark W. Bultman	U.S. Geological Survey	Sedimentary subgroup
William F. Cannon	U.S. Geological Survey	Metamorphic subgroup
Robert L. Christiansen	U.S. Geological Survey	Volcanic subgroup (co-chair)
Jane Ciener	U.S. Geological Survey	Geologic-map editorial standards
Stephen P. Colman-Sadd	Geological Survey of Newfoundland and Labrador	Metamorphic subgroup
Peter Davenport	Geological Survey of Canada	General scientific review
Ron DiLabio	Geological Survey of Canada	Sedimentary subgroup (co-chair)
Lucy E. Edwards	U.S. Geological Survey	Sedimentary subgroup
Robert Fakundiny	New York State Geological Survey	General scientific review
Kathleen Farrell	North Carolina Geological Survey	Sedimentary subgroup
Claudia Faunt	U.S. Geological Survey	Volcanic and sedimentary subgroups
Mimi R. Garstang	Missouri Department of Natural Resources	Sedimentary subgroup
Joe Gregson	National Park Service	General scientific review
Ardith K. Hansel	Illinois State Geological Survey	Sedimentary subgroup
Thomas D. Hoisch	Northern Arizona University	Metamorphic subgroup
J. Wright Horton, Jr.	U.S. Geological Survey	Metamorphic subgroup (co-chair)
David W. Houseknecht	U.S. Geological Survey	Sedimentary subgroup
Bruce R. Johnson	U.S. Geological Survey	Volcanic and metamorphic subgroups
Robert Jordan	Delaware Geological Survey	General scientific review
Ronald Kistler	U.S. Geological Survey	Plutonic subgroup (co-chair)
Alison Klingbyle	Geological Survey of Canada	Geologic-map editorial standards
Dennis R. Kolata	Illinois Geological Survey	Sedimentary subgroup
Elizabeth D. Koozmin	U.S. Geological Survey	Geologic-map editorial standards
Hannan LaGarry	Natural Resources Conservation Service	Sedimentary subgroup
Diane E. Lane	U.S. Geological Survey	Geologic-map editorial standards
Victoria E. Langenheim	U.S. Geological Survey	Plutonic and Sedimentary subgroups

Reed Lewis	Idaho Geological Survey	Plutonic and Volcanic subgroup
Stephen D. Ludington	U.S. Geological Survey	Volcanic subgroup (co-chair)
Jonathan C. Matti	U.S. Geological Survey	Sedimentary subgroup (co-chair)
James McDonald	Ohio Geological Survey	Sedimentary subgroup
David M. Miller	U.S. Geological Survey	Sedimentary subgroup (co-chair)
Andy Moore	Geological Survey of Canada	Sedimentary subgroup
Douglas M. Morton	U.S. Geological Survey	Plutonic subgroup
Patrick Mulvany	Missouri Department of Natural Resources	General scientific review
Carolyn Olson	Natural Resources Conservation Service	Sedimentary subgroup (co-chair)
Anne Poole	National Park Service	Plutonic and sedimentary subgroups
Stephen M. Richard	Arizona Geological Survey	Metamorphic subgroup (co-chair)
Andrew H. Rorick	U.S. Forest Service	Sedimentary subgroup
William Shilts	Illinois State Geological Survey	General scientific review
David R. Soller	U.S. Geological Survey	Sedimentary subgroup (co-chair)
Roy Sonenshein	U.S. Geological Survey	Sedimentary subgroup
William Steinkampf	U.S. Geological Survey	Volcanic and sedimentary subgroups
Douglas Stoeser	U.S. Geological Survey	Plutonic subgroup
Lambertus C. Struik	Geological Survey of Canada	General scientific review
John F. Sutter	U.S. Geological Survey	General scientific review
Harvey Thorsteinson	Minnesota State Geological Survey	Sedimentary subgroup
Robert J. Tracy	Virginia Polytechnic Institute and State University	Metamorphic subgroup
David Wagner	California Geological Survey	Volcanic subgroup
Richard Waitt	U.S. Geological Survey	Sedimentary subgroup
Peter D. Warwick	U.S. Geological Survey	Sedimentary subgroup
Richard Watson	U.S. Bureau of Land Management	General scientific review
Gerald A. Weisenfluh	Kentucky Geological Survey	Sedimentary subgroup (co-chair)
Carl Wentworth	U.S. Geological Survey	Sedimentary subgroup
Michael L. Williams	University of Massachusetts	Metamorphic subgroup
Ric Wilson	U.S. Geological Survey	Volcanic and plutonic subgroups
Robert P. Wintsch	University of Indiana	Metamorphic subgroup
Michael L. Zientek	U.S. Geological Survey	Plutonic and metamorphic subgroups

Rationale for standard science language

Standardized science language is needed to increase the usability and comparability of information contained in geologic map databases. A map user might conclude that terms occurring in map-unit explanations and in database fields have identical meanings from map to map and from region to region. This certainly is true for some specialized terms, and especially for more generalized terms. However, for some terms used in geologic maps, subtle to significant differences in geologic meaning can occur from map to map. This happens for various reasons:

1. The field description and interpretation of earth materials and geologic structures is as much an art as a science, and is predicated on the experience, training, intuition, skill, and persistence of the geologic-map maker. Moreover, each field area presents unique challenges to the geologic-mapping process (outcrop quality, climatic setting, accessibility, etc.). These realities open the door to differences in science language usage from map to map.
2. The meaning of some terms changes subtly to significantly from generation to generation as academic traditions change, and as new analytical techniques and geologic perspective influence and modify research results and teaching curriculums. New and different science language commonly emerges from these activities.
3. Some geologic terms once in vogue may completely disappear from the geologic lexicon as they are replaced with terms that are more accurate or precise or that better reflect current usage.
4. Some geologic terms take on meanings and applications specific to a particular geologic terrain or region; beyond that region, these terms may have a slightly different meaning, or may not even be used.
5. In a climate of open and competitive academic research, scientists constantly are experimenting with new, more creative, and more effective terminology to communicate information about earth materials that have complex combinations of composition, structure, fabric, and genesis.

For these reasons, the vocabulary (science language) of both historic and current geologic maps can vary—in some instances enough to create uncertainty on the part of the map user as to whether earth materials and geologic structures in one map are similar to or different from those in another. To minimize this problem, standardized science language that classifies and describes earth materials and their genesis is helpful, especially to facilitate information exchange.

Purpose and Intended Use for the SLTT Prototype Standard

The SLTT prototype standard provides a logical, consistent, hierarchical framework for naming and classifying earth materials, and for describing their physical characteristics and genesis—based on the way geologic maps are made by the field geologist or assembled by a science compiler. It is intended for use by persons and agencies submitting digital geologic-map data into public-domain databases that are managed by various State/Provincial and Federal agencies. Intended users include:

- geologists who collect original data in the field while making a geologic map,
- geologists who compile geologic-map data from legacy sources and must interpret and translate these data for representation in the compilation, and
- information-users who query public-domain geologic-map databases for information appropriate to their interests and applications.

It has been the SLTT's intention to break down common terms for earth materials into their fundamental science concepts. This is based on our belief that it is not so much what an object or concept is called, but what the name means in terms of the science concepts it represents. The SLTT documents provide specific defined names for earth-material objects and concepts, with the hope that they will be familiar and palatable to the average geologic-map maker and map user. However, we understand that each map producer and map user will have their own favorite names, and that humans are reluctant to abandon terms and meanings with which they are comfortable. With that recognition, we believe SLTT will have served its purpose if it provides a yardstick against which terms can be compared and translated—the true meaning of a "standard".

Related science-language efforts

SLTT deliberations benefited from previous and ongoing science-language efforts being conducted by other entities.

British Geological Survey

In 1999 the British Geological Survey (BGS) issued four reports that presented science language for earth materials from a geologic-mapping point of view:

- science language for igneous materials (Gillespie and Styles, 1999)
- science language for metamorphic materials (Robertson, 1999)
- science language for sedimentary materials (Hallsworth and Knox, 1999)
- science language for surficial and man-made materials (McMillan and Powell, 1999).

The SLTT adopted major elements of the BGS approach, but found that in order to accommodate North American geologic-mapping traditions and approaches we had to develop slightly modified terminology and taxonomic hierarchies.

International Union of Geological Sciences (IUGS)

SLTT activities benefitted from a series of IUGS subcommissions chartered to develop uniform classifications of earth materials:

- *Igneous materials:* A long-standing IUGS Subcommission on the classification of plutonic and volcanic igneous rocks (http://www.minpet.uni-freiburg.de/IUGS-CSP.html) has led to a widely accepted standard (IUGS, 1973; MacDonald, 1974; Streckeisen, 1974, 1976, 1978, 1979; Schmid, 1981; Heiken and Wohletz, 1985; Foley and others, 1987; Le Bas and others, 1986; Le Maitre and others, 1989; Le Bas and Streckeisen, 1991; Le Maitre and others, 2002).
- *Metamorphic materials:* An IUGS Subcommission on the classification of metamorphic rocks (http://www.bgs.ac.uk/SCMR/scmr_products.html) is underway, and is stimulating wide-ranging discussion of terminology for the naming, description, and genesis of metamorphic rocks.
- *Sedimentary materials:* An IUGS Subcommission on the classification of sedimentary materials (http://www.iugs.org/iugs/science/sci-cgsg.htm) is in the initial phases of its activities.

Science language for glacial sedimentary materials

The International Union for Quaternary Research [INQUA] in the 1970's sponsored a Commission on Genesis and Lithology of Glacial Quaternary Deposits

(Commission C-2). The results of Commission C-2 were published in Goldthwait and Matsch (1988; see Commission summaries in Goldthwait and others, 1988, p. vii-ix, and Dreimanis, 1988, p. 19-25). The SLTT used this document to develop science language for sedimentary materials of glacial origin.

Geological Survey of Canada science language

Concurrent with SLTT activities, the Geological Survey of Canada (GSC) is developing science language for use by GSC projects producing digital geologic-map databases. Through a series of projects, GSC has investigated approaches to developing geological map databases, including prototype data models and user interfaces. Bedrock and surficial geological maps have to date been addressed separately. As part of data modeling, based on variants of NADM, several approaches have been tested to enable interoperability among maps that use varied, usually undefined and sometimes inconsistent science language, particularly for the earth-material constituents of map units.

Two main approaches have been tried, both relying on map context and geological experience as guides to the authors' meaning. For surficial geological maps, the uncontrolled and variable terminology is reinterpreted within a controlled set of defined terms (a translation, in effect). For bedrock maps, earth material names are "reverse-engineered" into the properties (genetic process, composition, texture, etc.) implied by each name (single word or phrase), using sets of keywords for these properties (Davenport and others, 2002). In both approaches, a hierarchical organization of terms is applied wherever possible to allow for categorization at variable levels of precision in accordance with the information available, and to enable efficient querying of the databases.

For bedrock maps, Struik and others (2002) followed a different approach, recognizing that earth material names are multi-dimensional and can be organized in a variety of hierarchies depending on the choice of criteria (genetic process, composition, texture, etc.). The earth material names that Struik and others (2002) considered were uncontrolled terms gleaned from several published geological maps, but were neither exhaustive nor representative of the entire collection of published maps for Canada. This approach has been extended to collect earth material names in a master list as additional maps are brought into the database, and associate controlled keywords for earth material properties to each unique term (single word or phrase) through a data model that supports multiple ontologies. This enables map units to be searched or grouped by one or several of these keywords. User interfaces have been written to streamline the analysis of map unit descriptions, extraction of earth material types, and the assignment of keywords.

Federal Geographic Data Committee (FGDC) science language

Within the United States, an important science-language activity is occurring under auspices of the Federal Geographic Data Committee (FGDC) Geologic Data Subcommittee (http://ncgmp.usgs.gov/fgdc_gds/). The FGDC has developed a draft cartographic standard for polygon, line, and point symbols that depict geologic features on geologic maps and digital displays. Although primarily concerned with cartographic technical specifications, the FGDC cartographic standard contains science-language concepts that should be integrated with the science-language in these SLTT documents.

THE SLTT WORKING DOCUMENTS

Working documents versus a "standard"

As originally envisioned by the NADMSC and by the SLTT charter (see http://nadm-geo.org), our intent was to develop formal science-language standards for evaluation and use by the North American geologic-mapping community. Based on the charter and early discussions among SLTT members, it seemed logical to pursue the following strategy:

- develop formal science-language standards for the major classes of earth materials (metamorphic, plutonic, sedimentary, and volcanic). Do this by creating a set of SLTT subgroups, one for each earth material class,
- submit the standards for peer review and for simultaneous release as official publications of the U.S. Geological Survey and the Geological Survey of Canada,
- upon publication of the formal standard, obtain peer review and feedback from the North American geologic-mapping community,
- use this feedback to revise and refine the standard through a stewardship process maintained by the NADMSC and its SLTT, and
- on an as-needed basis, archive and distribute subsequent versions of the science-language standard.

This strategy proved unsupportable for the following reasons:

- Differences in philosophy among the various SLTT participants led to science-language approaches that differ from subgroup to subgroup, with the result that the SLTT documents do not have commonality of purpose, content, and scope,
- Participation from a broad cross-section of U.S. and Canadian agencies proved elusive, and the SLTT chair became concerned that the SLTT

documents would not be perceived as a truly North American science-language standard,
- SLTT subgroup leaders concluded that technical peer-review prior to USGS and GSC publication would lead to significant editorial revision and response by the SLTT subgroups—each of which already was overwhelmed by the weight of its SLTT responsibilities. Moreover, the SLTT documents would have been completely out of context for the average peer reviewer not already involved in the science-language process or its philosophical and operational complexities; hence, the agency peer-review process would have been lengthy and difficult to execute and would have been of uncertain benefit,
- The SLTT charter did not anticipate or identify science-language stewardship as a mandated function, nor did it include mechanisms for responding to community feedback or for preparing and releasing revised versions of the science-language documents,
- The NADM SLTT process, although sanctioned generically by various memoranda of understanding between the USGS, GSC, and AASG (but not the Canadian Provincial geological surveys), has no formal mechanism for communicating science-language issues and results to their respective agencies and downward to their geologic-mapping projects (for evaluation and testing). Until such mechanisms are defined and tested, it is premature to consider standardization, stewardship, and versioning, and
- In short, the SLTT process does not have the mandate or the personnel to execute a formal science-language process on behalf of the various North American federal, state, and provincial agencies that conduct geologic mapping.

For these reasons, the NADMSC accepted the SLTT chair's recommendation that formal publication of the science-language document be reconsidered. NADMSC agreed that the best approach was to post the various SLTT reports on the NADM website, and to present them as a work in progress (i.e., as "working documents"). The inclusion of the working documents as appendices to this report serves to fulfill a principal NADMSC objective—to publish and archive these documents as a permanent record of the SLTT's endeavor.

This strategy allows the SLTT to conclude its responsibilities, and to present the North American geologic-mapping community with a range of science-language approaches and issues for their evaluation and discussion—pursuant to any next steps in the science-language process that are determined necessary by the NADMSC or by any geological survey.

A philosophical issue

Early in the SLTT process, tensions developed between two very different science-language goals and strategies:

1. Classifying the terminology of geologic maps so that each term commonly used in map legends and map-marginal explanations can be found in science-language classification schema. This objective focuses on *legacy* geologic-map information and on science language that enables the compilation of such information, without having to determine how the author of the map used the geologic terminology. By this rationale, science-language deliberations should determine how to organize *existing* earth-material names, based on the premise that the names are the principal basis for conveying science content.
2. Creating science-language schema that allow the map author or map compiler to represent what actually is known about the earth materials portrayed on a geologic map. This objective focuses on the geologic-mapping process itself—that is, on the way geologists use terms to express what they see in outcrops and in hand specimens, how they make mapping decisions in the field, how they organize and present their map data to express confidence in their observations and interpretations, and how the scientific content of current and future geologic-map databases can be improved and clarified. By this rationale, science-language deliberations should provide the map maker or map compiler with (1) very specific names that can be used where field data warrant or where legacy map terminology is clear, or (2) higher-level general names that can be used where field data are ambiguous or where the use of legacy map terminology is not clear. This rationale is driven by the premise that the scientific content, not just the names, is what geologic-map users are looking for.

These two objectives are equally legitimate. However, they reflect different philosophies and lead to different science-language strategies. Tensions between them were not resolved during the course of SLTT deliberations and, as a consequence, significant differences in scope, content, purpose, and philosophy exist among the various SLTT reports. This did not invalidate the SLTT effort, but it does illustrate the complexity and challenges of developing a standard science-language. Moreover, it should be a valuable lesson for agencies that conduct geologic mapping and that intend to develop local, regional, and national geologic-map databases that have uniform science content.

The composite-genesis and sedimentary subgroups concluded that their principal objective was to examine the science concepts embedded in geologic-map terminology, and to develop classification schema organized around that conceptual content. This philosophical approach forced a re-examination of how traditional map terms are used, and in some instances led these subgroups either not to adopt as controlled terms some familiar earth-material names, or to position these names in classification hierarchies in a different place than where some workers might expect to find them. For future geologic-mapping activities and their resulting databases, this probably will not create any long-term problems—provided future geologic mappers understand and agree with SLTT approaches. For legacy geologic-map information, the approach adopted by the composite-genesis and sedimentary groups might require some decision making on the part of the information compiler: (1) for a legacy term whose original meaning was not clear, the map compiler might have to use a higher-level, more generalized SLTT term instead, or (2) where a legacy term is understood to have a different meaning than the SLTT rendering of the same term, the map compiler may have to use a different SLTT term for the same concept.

General classification

The classification adopted by the SLTT follows this high-level architecture for earth-material name (see also Appendix A):

- Earth Material
  - Igneous earth material
    - Volcanic rock
      - lithologic class based on composition
      - lithologic class based on texture
      - lithologic class based on emplacement characteristics
    - Hypabyssal rock (BGS classification, Gillespie and Styles, 1999)
    - Plutonic rock (BGS classification, Gillespie and Styles, 1999)
  - Sedimentary earth material (unconsolidated, consolidated)
    - Sedimentary material, unclassified
    - Terrigenous-clastic sedimentary material
    - Carbonate sedimentary material
    - Organic-rich sedimentary material
    - Non-clastic siliceous sedimentary material
    - Noncarbonate-salt sedimentary material
    - Phosphate-rich sedimentary material
    - Iron-rich sedimentary material
  - Composite-genesis earth material
    - Cataclastic rock
    - Impact-metamorphic material
    - Metamorphic rock (traditional sense) (including hydrothermally-altered rock)
      - granoblastic rock
      - foliated metamorphic rock

These high-level categories fundamentally are genetic: they reflect how earth material was formed (genetic process, crustal depth, etc.). This raises the irony that, while deeper levels of the earth-material classification hierarchy are based on what the mapping geologist can see in the outcrop (empirical factors such as composition, structure, and texture), upper-level categories are based on interpretations about how the material was formed. Once this choice is made, an earth material is classified in more detail based on textural or compositional criteria—criteria that actually can be satisfied on the basis of empirical observation.

The use of standardized science language in digital geologic-map databases is a new frontier that is likely to evolve with time and experience. With this in mind, we developed classifications of earth materials that we believe reflect not only how mapping geologists view them but also how such materials might be queried and analyzed in geologic-map databases. No single classification of earth materials will please all workers. However, the schemes we propose hopefully will be clearly understandable, internally consistent, and usable by both data-producer and data-user.

Detailed Classification

Volcanic SLTT

The volcanic SLTT document (see Appendix D) provides a concise look at the science language of unconsolidated and consolidated volcanogenic earth materials. The goal of the volcanic subgroup was:

"...to develop standardized nomenclature for use in digital geologic map databases, specifically to describe lithologies in volcanic rock units. Although this nomenclature takes the form of a hierarchy of terms, it is important to note that this is not the same as a formal rock-naming system....

We consider it critical to remember that the purpose of our hierarchical subdivision of terms is to describe the *lithologic characteristics* of *geologic map units*. [Our hierarchical subdivision] is to be used to logically retrieve or select those map units that contain a specified set of lithologic characteristics. Thus, it must be flexible enough to accommodate the extremely varied and unsystematic way in which map units are described and defined by various authors. This report groups lithologic features necessary to adequately characterize **volcanic materials** in the map units of a geologic map database into three fundamental classes based on **composition**, **texture**, and **emplacement characteristics**.

No one of these classes is primary, and any or all may be used to select the lithologies of map units. The subdivision of any one of the fundamental classes consists of a list of words, arranged in a hierarchy that can be used to select lithologies. The words that describe these subdivisions are not given formal definitions here, but brief descriptions are given in the appendices. Many of the words have multiple, sometimes conflicting definitions and have been used differently over the years by different map authors. We have attempted to make the hierarchy sufficiently comprehensive, especially at the higher levels, to allow adequate lithologic characterization and to accommodate the vast majority of lithologic descriptions on existing geologic map legends."

The volcanic SLTT subgroup focused on how to bring the variable and inconsistent usage of legacy geologic maps into a modern database. To accomplish this, they characterize volcanic materials using three fundamental classes: composition, texture, and emplacement characteristics. Their report provides informal characterizations of volcanogenic materials in terms of these three aspects, but does not provide formal material descriptions, deferring instead to other sources (such as Le Maitre and others, 2002). The report does not provide a comprehensive listing of petrologic descriptors, as the subgroup felt it was beyond their mandate.

Plutonic SLTT

Owing to conflicting agency science-project obligations, members of the plutonic SLTT subgroup were unable to conclude their deliberations and were unable to develop plutonic science-language standards for use by geologic-mapping projects in North America. In the interim, the NADMSC recommends that the British Geological Survey report on plutonic science language (Gillespie and Styles, 1999) be used for North American geologic-map databases.

Sedimentary SLTT

The sedimentary subgroup produced a comprehensive analysis of the attributes for sedimentary earth materials, both consolidated and unconsolidated (see Appendix C), that includes the following components:

- attempts to identify from a database point of view the essential science concepts that underlie sedimentary terminology,
- science language for the various lithologic classes of sedimentary earth material,
- science language for the physical properties of sedimentary earth materials, including outcrop characteristics, consolidation state, sedimentary structures, sedimentary texture and fabric, particle composition, and material strength,
- science language for upper-surface attributes of sedimentary earth materials, including depositional and erosional landform features and surface-modification features (e.g., surface smoothing, surface dissection, surface armoring, particle weathering, pedogenic modification, cryogenic modification, and microrelief),
- science language for the genesis of sedimentary earth materials, including particle origin, depositional process, depositional place, geomorphic configuration, ambient conditions, and tectonic setting and basin type, and
- science language for human-affected landscapes, including made ground and worked ground.

Composite-genesis SLTT

Science language for metamorphic rocks and for other earth materials that form through modification of pre-existing earth material owing to the effects of temperature, pressure, and deformation, is discussed in the SLTT report on composite-genesis materials (see Appendix B). The domain of this classification system 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 according to descriptive properties that are interpreted to reflect processes that made the rock composite.

The Composite-genesis subgroup members discussed whether or not to include within the composite-genesis domain earth material such as pedogenic soil that forms at the earth's surface through low temperature-pressure processes that modify pre-existing sediment and rock. No consensus was reached on this subject, hence pedogenic materials are not currently included in any of the SLTT science-language documents, except as a modifier to describe the upper surface of sedimentary earth materials.

Preliminary results of the SLTT process

The SLTT process was an experiment with mixed outcomes:

- We produced documents that can be evaluated for their contribution to the science content and increased uniformity of North American geologic-map databases.
- However, committee deliberations revealed significant differences in how various individuals, agencies, and scientific programs view geologic-map

databases and how they should be constructed to further their science missions.

The NADMSC believes the SLTT documents will be of significant value to the North American geologic-mapping community: hopefully, the effort will stimulate discussion about how the content of geologic-map databases is used, how it is accessed, and how it can be structured and represented through the use of standard science language. Such discussions could lead to future work that will build on SLTT accomplishments.

Finally, and because the SLTT process was conducted to support agency needs for standardized map databases, we offer the following recommendations to high-level science managers in agencies that execute geologic mapping:

1. understand and appreciate the fundamental importance and intellectual complexity of a geologic-map data-model standard and its scientific content,
2. require your agencies to develop such a standard, or to adapt and build on the SLTT standard,
3. encourage your scientific workforce to participate fully and legitimately in standards development, and to implement the standards once they are developed, and
4. mandate and empower a single entity within your agency to take the lead on standards development on behalf of all other producers and users of geologic-map information within your agency.

If these four requirements are not advocated and facilitated, then science-language standards will be neither robust nor comprehensive, and most likely they will not be viewed seriously by a workforce that may (or may not) be asked to adopt them.

CREDITS

The SLTT chair (Jon Matti) prepared the summary document (Appendix A) in coordination with the SLTT subgroup leaders (Table 2), each of whom contributed to the SLTT subgroup narratives in this report. Dave Soller assisted with preparation of this report by adapting it from the summary document.

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Table 2. SLTT Subgroup leaders who contributed to this report.

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APPENDICES

(NOTE: these Appendices are only available in the Web version of the document, at http://pubs.usgs.gov/of/2004/1451/.)

Appendix A. Philosophical and operational guidelines for developing a North American science-language standard for digital geologic-map databases.

Appendix B. Classification of metamorphic and other composite-genesis rocks, including hydrothermally altered, impact-metamorphic, mylonitic, and cataclastic rocks.

Appendix C. Sedimentary materials: Science language for their classification, description, and interpretation in digital geologic-map databases.

Appendix D. Volcanic materials: Science language for their naming and characterization in digital geologic-map databases.