APPENDIX A

PHILOSOPHICAL AND OPERATIONAL GUIDELINES FOR DEVELOPING A NORTH AMERICAN SCIENCE-LANGUAGE STANDARD FOR DIGITAL GEOLOGIC-MAP DATABASES

North American Geologic-Map Data Model Steering Committee

Science Language Technical Team (SLTT)

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[This report was formerly available at the North American Geologic Map Data Model Steering Committee website as http://nadm-geo.org/sltt/products/sltt_summary_12_18_04.doc.]

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1 EXECUTIVE SUMMARY

A single uniform language to classify and describe earth materials and their genesis is needed because producers and consumers of geoscience information use 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.

The Science Language Technical Team (SLTT) of the North American Data Model Steering Committee is a multi-constituency group of geologic-map producers and geologic-map users that—during the period April 2000 to November, 2004—developed a prototype science-language for the naming and describing of earth materials in digital geologic-map databases produced by public-sector entities in North America. The classification adopts the following high-level architecture for earth-material name:

- 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 are developing 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.

2 INTRODUCTION

2.1 Background

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 storing digital data, and for manipulating these data in a relational and (or) object-oriented 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 the standardized model at the front end (data-producer) and for extracting the data at the back end (data-user);
(4) Methodologies and techniques for exchanging data sets having different structures and formats.

To attain these objectives, public-sector geologic-mapping entities in the United States and Canada formed a partnership called the North American Data Model Steering Committee (NADMSC, http://nadm-geo.org). This informal group 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). Through the former, NADMSC is linked to the database and standards development activities of the National Geologic Map Database (http://ngmdb.usgs.gov/); through the latter, NADMSC is linked to database-development activities ongoing in Canada under the auspices of the Canadian Geoscience Knowledge Network.

This document and those that accompany it deal with task (2) above—standardized science language that allows geologic materials and geologic structures to be described, classified, and interpreted. To execute this task, NADMSC chartered a Science Language Technical Team (SLTT, http://nadm-geo.org/sltt) that first convened in early 2000. 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;
(5) Scientists from academic institutions were selected by SLTT subcommittee co-chairs.

The assembled group (Table 2.1.1) represents a cross section of public-sector geologic-map producers and map users in the United States and Canada.

NADMSC Science Language Technical Team (Jonathan C. Matti, Chair) Committee Members		
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
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
Jonathan C. Matti	U.S. Geological Survey	Sedimentary subgroup
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

Table 2.1.1. NADMSC Science Language Technical Team committee members (Jonathan C. Matti, Chair)

2.2 What is science language?

Science language is the *vocabulary* of digital geologic-map databases:

Vocabulary—"n. **1.** the stock of words used by or known to a particular people or group of persons....**2.** a list or collection of the words or phrases of a language, technical field, etc., usually arranged in alphabetical order and defined. **3.** the words of a language. **4.** any collection of signs or symbols constituting a means or system of nonverbal communication: *vocabulary of a computer*...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 2129).

As with other endeavors, geologic maps and their accompanying databases have a rich vocabulary of words, terms, and icons. These terms range from the erudite (e.g. monzodiorite, arenite, granitic gneiss, granoblastic) to the commonplace (landslide, sand, mudflow, fracture). This language is the way geologists communicate technical information about earth materials, and is the starting point for spatial analysis that integrates geologic-map information with other kinds of geospatial data sets.

2.3 Rationale

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 is even more true 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 vulnerable to 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 thinking;

(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.

In short, in a diverse world of words, standardized terminology is useful to facilitate information exchange.

2.4 Purpose

The SLTT purpose is to develop a science-language standard[1] for the description, classification, and interpretation of earth materials in geologic-map databases. The language should provide 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 (Section 3.6.2).

It is our hope that, in the SLTT documents, we have broken 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. If we can reach consensus on the concepts then, perhaps with a single mouse click, the defining attributes of each object or concept can be parsed into a geologic-map database for subsequent query and analysis—no matter what the object is called. 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".

2.5 Intended use

Science language developed by the SLTT is intended for use by persons and agencies that submit digital geologic-map data into public-domain databases managed by various State/Provincial and Federal agencies. We are not setting standards for use by academia or by the private sector, unless these entities contribute geologic-map products to public databases.

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;
- information-users who query public-domain geologic-map databases for information appropriate to their interests and applications.

2.6 Related science-language efforts

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

2.6.1 British Geological Survey

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

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[1]*standard*—"*n*. **1**. Something considered by an authority or by general consent as a basis of comparison. **3**. a rule or principle that is used as a basis for judgment: *they tried to establish standards for a new philosophical approach*.
—*adj*. **23.** serving as a basis of weight, measure, value, comparison, or judgment. **24**. of recognized excellence or established authority. **25.** usual, common, or customary:..." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 1857).

- 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.

2.6.2 International Union of Geological Sciences (IUGS)

SLTT activities benefitted from a series of IUGS sub-commissions 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.

2.6.3 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.

2.6.4 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 "reverseengineered" 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.

2.6.5 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.

2.7 Who prepared this report?

The SLTT chair (Matti) prepared this summary in coordination with the SLTT subgroup leaders (Table 2.7.1), each of whom contributed to the narratives in Section 5.

Robert L. Christiansen	U.S. Geological Survey	Volcanic subgroup
Andrée Bolduc	Geological Survey of Canada	Sedimentary subgroup
Ron DiLabio	Geological Survey of Canada	Sedimentary subgroup
J. Wright Horton, Jr.	U.S. Geological Survey	Metamorphic subgroup
Stephen D. Ludington	U.S. Geological Survey	Volcanic subgroup
Jonathan C. Matti	U.S. Geological Survey	Sedimentary subgroup
David M. Miller	U.S. Geological Survey	Sedimentary subgroup
Carolyn G. Olson	Natural Resources Conservation Service	Sedimentary subgroup
Stephen M. Richard	Arizona Geological Survey	Metamorphic subgroup
David R. Soller	U.S. Geological Survey	Sedimentary subgroup
Gerald A Weisenfluh	Kentucky Geological Survey	Sedimentary subgroup

Table 2.7.1. SLTT Subgroup leaders who contributed to this report.

3 SLTT ACTIVITIES

3.1 Mandate and housekeeping

The SLTT was created in 1999 as a technical working group of the North American Geologic-map Data Model Steering Committee (NADMSC), and is guided by a charter that identifies our goals and objectives (Appendix 1).

Early in its deliberations, SLTT had to figure out what exactly we were going to do, what the scope of our assignment was, how we would reconcile various geological traditions and perspectives represented by the SLTT group and their constituents, and how we would develop a consensus science language. To facilitate this discussion, the SLTT chair (Matti) periodically issued memoranda that stated guidelines, summarized deliberations, and ameliorated differences of approach. Some of these memos are archived in Appendices 2-6 of this report.

SLTT conducted its activities without dedicated salary and without a dedicated travel budget. As a result, face-to-face meetings generally were not possible, and SLTT members had to boot-leg time from their agency science projects—usually at the expense of project deliverables. The majority of SLTT interactions have been in the form of email discussions and conference calls. Both internal and external evaluation of science-language concepts was facilitated by a web-conference site (see http://nadm-geo.org/sltt/terms/index.html) that stimulated discussion of philosophical and operational issues.

3.2 Issues

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 principle 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 is not a deal-breaker, 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 volcanic subgroup concluded that their principal objective was to classify volcanic earth-material names into schema (picklists) that accommodate the diversity and inconsistency of usage in legacy geologic maps—where it commonly is not possible to know the exact meaning or intent of the original map maker. In general, the volcanic subgroup decided not to address these issues by exploring ways of reconfiguring or re-organizing the science language of volcanic earth materials, but instead focused on how to preserve the meaning of original map usage in the context of traditional classification approaches.

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 (but see footnote 2).

3.3 20-queries exercise

SLTT's first order of business tasked each committee member to submit twenty queries to a hypothetical geologic-map database. This exercise had two purposes;

(A) it served as a proxy for a requirements analysis that might be conducted among users of digital geologic-map data, to determine how such products are used and how the geologic data might be structured and organized from a content and language point of view;

(B) it was a means of getting each SLTT member to think about the science concepts that might be embraced by geologic-map databases, along with the issues and problems associated with naming, relating, and querying information about geologic materials and geologic structures.

Results of the 20-queries exercise (see http://nadm-geo.org/sltt/products/sltt_20_queries_master.pdf) revealed that database-users (at least those on the committee) were interested in a broad spectrum of geologic concepts and database targets ranging from (1) academic queries related to the lithology, genesis, geometry, and age of geologic materials and structures to (2) pragmatic queries targeting what information geologic-map units and geologic structures contain about natural resources, fluid transmissivity (ground water and hydrocarbons), geologic hazards (swelling ground, landslides, earthquake-induced ground-shaking), and land-use planning (landfill siting, ground-water recharge, commercial and residential development, infrastructure siting). SLTT's task was to develop science language to facilitate this broad range of potential database queries.

Results of the 20-queries exercise were passed along to the NADMSC Data Model Design Team (DMDT) for analysis and (especially) to ensure that science concepts emerging from the SLTT process were considered by DMDT as it developed architecture for a standard geologic-map data model.

3.4 Separation into subgroups

Early on, SLTT decided to split into subgroups organized around major classes of earth material:

- plutonic subgroup (R.L. Kistler and D.M. Morton, co-chairs)
- volcanic subgroup (S. Ludington and R. Christiansen, co-chairs)
- metamorphic subgroup (J.W. Horton and S.M. Richard, co-chairs)
- sedimentary subgroup (J.C. Matti and G.A. Weisenfluh, co-chairs)
- surficial-materials subgroup (R. DiLabio, D.M. Miller, C.G. Olson, D.R. Soller, and A.M. Bolduc, co-chairs).

Ultimately, SLTT recommended to NADMSC that the surficial and sedimentary subgroups merge into a single group, based on three factors:

(1) unconsolidated surficial materials are sedimentary in origin;
(2) the lithology, physical properties, genesis, and geomorphology of sedimentary and surficial materials are identical;
(3) scientific perspectives and geologic-mapping experience in the two subgroups complemented each other and provided insights beneficial to both groups.

NADMSC approved this recommendation, and the combined sedimentary and surficial subgroups have worked together to develop a single body of science language for unconsolidated and consolidated sedimentary materials.

The SLTT chair selected subgroup co-chairs based on the following criteria: geologic-mapping experience, expertise in their science field, and knowledge of their agency's role in producing or using geologic-map databases. Subgroup co-chairs reflect a range of American and Canadian constituencies and Federal and State perspectives.

3.5 Subgroup activities

3.5.1 Iterative science-language development

Using the 20-queries exercise and building upon the four BGS classification documents, the SLTT subgroups iteratively developed science-language schemes that were exchanged by email among subgroup members. This process continued from about September, 2000 through November, 2004.

3.5.2 Internal SLTT review

After each subgroup completed a consensus classification of earth materials, subgroup documents were submitted for SLTT-wide peer review. This review was intended to ensure uniformity of philosophical and operational approach throughout the SLTT science-language process.

3.5.3 NADMSC review

Following internal SLTT-wide peer review, SLTT science language documents were forwarded to the NADMSC for evaluation and review for consistency, for geopolitical sensitivity, and for compatibility with the data-model architecture being developed by the DMDT.

3.5.4 Community-wide distribution

Following NADMSC approval, the SLTT documents are being released on the NADM website for presentation to the North American geologic-mapping community.

4 PHILOSOPHICAL AND OPERATIONAL ISSUES

4.1 Philosophical approach

The question of "What's in a name?" has plagued taxonomic classifications in all scientific arenas.

Historically, people have coined names for objects or concepts in order to convey information about them. The names are shorthand expressions (representations or proxies) for information packets that commonly are quite complex. This is acceptable practice because the human brain is able to extract from a single name the many attributes and components that the name represents. Now, we are asking computer databases to do this job.

To come to grips with our task, SLTT members wrestled with the difference between "name" and "modifier" (see definitions in Section 4.3), and the implications these two concepts have for naming earth materials and for organizing the names into classification hierarchies. We considered the following two end-member choices:

- Should each "name" express *multiple attributes and concepts*, as names historically have? By this approach, names for earth materials would synthesize as much information as possible about lithologic and genetic attributes in order to make communication efficient (i.e., fewer words, with each word being compound and reflecting multiple attributes);
- Should each "name" express *few attributes and concepts*, in order to reflect only those attributes essential for the identification and naming of an object or concept? This approach might make communication more cumbersome in terms of word load (i.e., more words, with each word having a narrow meaning), but communication would be extremely accurate and precise.

The SLTT subgroups did not reach consensus on which of these approaches to follow.

Some committee members argued that our mandated task (Appendix 1) was to organize existing terminology into classification schema, without addressing how this terminology might be used more effectively in geologic-map databases. Other members argued that the SLTT classification schema should preserve traditional usage as much as possible, but organize classification schema around the fundamental science concepts or attributes represented by an earth-material name. This philosophical approach would require a re-examination of how traditional map terms are used, and might lead to schema that (1) do not adopt as controlled terms some familiar earth-material names, or (2) that place certain names in hierarchical positions that are not familiar to or comfortable with all geologists.

Each SLTT subgroup handled the "what's in a name" issue in its own way, but the resulting classification schema have some common themes:

- We all agreed that high-level terms, by their very nature, must be compound and complex because, at their high classification level, they need to embrace all the attributes and concepts represented by deeper-level terms in the classification;
- for progressively deeper-level geologic terms we tried to minimize their compound nature, but allowed each subgroup to develop classifications schemes that reflected their own vision for how names best describe their earth material;
- each hierarchical level in the proposed classifications is designed to contain names or terms that represent geologic concepts that are as narrowly defined as possible.

4.2 Legacy data *versus* future data

The North American geologic-map endowment has two components: (1) "legacy data" archived in paper maps and digital files as the result of many generations of geologic-mapping activities, and (2) new data that will be collected through the efforts of future geologic-mapping activities. Incorporation of these two kinds of data sets into digital geologic-map databases involves different kinds of strategies, each posing its own challenge to geologic-map science language.

North American legacy geologic maps are rich in geologic terminology. Typically, such data are contained either in map-marginal descriptions of map units or in pamphlets and reports that accompany the geologic map. Unfortunately, legacy maps rarely cite the classification systems used by the map maker to name and describe earth materials. Consequently, it is left to the map user to interpret the meaning and usage of such terminology. For high-level terms (e.g., sedimentary rock, terrigenous-clastic sediment, plutonic rock, metamorphic rock, volcanic rock) the meaning may be universally understood. However, for deeper-level terms (e.g., shale, mud, basalt, quartz latite, quartz monzonite, granodiorite, volcaniclastic, slate, lahar, greenstone, gneiss, layered gneiss) the meaning may not be clear because many terms have inconsistent usage depending on when and where the map maker learned his or her craft. As a result, the map user commonly must interpret the meaning of earth-material terms according to his or her own experience.

This problem is compounded by two factors:

(1) some terms (e.g., sandstone, granite, shale, gneiss) have acquired usages that border on the generic or commonplace, and lack strict definitions or meanings;

(2) some terms (e.g., alluvium, greenschist, till, turbidite, metasediment, loess, debris flow, lahar) have been used as though they were lithologic names, when in fact they are genetic terms; this practice has blurred the distinction between lithologic description and genetic interpretation.

As a group, the SLTT committee had to wrestle with these issues, and decide on whether our science-language approach (1) should attempt to accommodate historical usage that is diverse, inconsistent, and in some cases generic, or (2) should reflect the needs and requirements of future geologic-map makers for science language that is stable and consistent. Ideally, any such decision will reflect the policy of the database developer, which usually means the management policy of the geologic-mapping agency or entity. With respect to legacy information, two contrasting data-management choices apply:

(1) modern databases should archive and organize legacy terminology verbatim, without attempting to translate such terms into modern science language;

(2) modern databases should interpret and translate legacy terms in the context of modern science-language structures, preserving archival terminology where it is clearly understood in terms of a modern standard but using more generalized terminology where the specific original meaning cannot be reconstructed[2].

[2]NOTE: Legacy terminology absolutely must be preserved in modern geologic-map databases. The question is not whether such language is *preserved* (for example, in a "legacy_description" data field), but whether it is *integrated* into the dynamic structure of the database so that it can be easily and systematically queried for its science content.

The SLTT group is not mandated to make such a policy decision on behalf of its constituent agencies. However, we recognize that legacy geologic maps include a wide variety of earth-material terms, many of which have similar, if not identical, meanings. Our purpose was to review how such terms have been used historically, and to judge how useful they are for storage, manipulation, retrieval, and analysis in geologic-map databases. In most instances, we found that traditional earth-material nomenclature lends itself well to database applications. However, the composite-genesis and sedimentary SLTT groups found that some traditional terminology and classification schemes did not adapt themselves easily to database requirements. In such instances, those subgroups had to modify existing names slightly, abandon some terms, or propose new names.

The SLTT result is a hierarchical classification of earth materials that accommodates two objectives:

(1) it allows legacy map terminology to be brought into modern geologic-map databases, using archival terminology where appropriate or by using generalized terminology where the specific original meaning is not clearly determinable;

(2) it allows future geologic mappers to archive information about earth materials in a manner that is consistent, uniform, flexible, and forward-looking.

4.3 Definition of concepts

The SLTT documents use concepts and terms that have common generic meanings. However, in the case of science language for geologic-map databases, these terms need to be delineated without ambiguity. The following definitions guided our deliberations:

Characterize—"v.t. **1.** to mark or distinguish as a characteristic; be a characteristic of....**2.** to describe the character or individual quality of....**3.** to attribute character to...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 347).

Classify—"v.t. **1.** to arrange or organize by classes; order according to class. **2.** to assign a classification to (information, a document, etc)" (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 381). To classify is to assign an *instance* to a group defined on the basis of a set of properties shared by members of the group. To *classify* answers the question "what kind of X is instance Y?", where X represents the domain of the classification.

Controlled term—A term or name whose meaning and scope is restrained or restricted so that the term can be used or applied only according to the definition contained in a standard.

Define—" v.t. **1.** to state or set forth the meaning of....**2.** to explain or identify the nature or essential qualities of....**3.** to fix or lay down definitely; specify distinctly....**4.** to determine or fix the boundaries or extent of....**5.** to make clear the outline or form of...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 523).

Describe—"**1.** to tell or depict in written or spoken words; give an account of: *he described the accident very carefully*...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 538).

Description—"1. a statement, picture in words, or account that describes: descriptive representation...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 538). A description is a set of statements that characterize the nature of an object or thing such that it can be identified and named.

Earth material—A naturally occurring substance formed in or on the Earth by physical, chemical, or biogenic processes that produce solid particles or crystals of mineral and (or) rock.

Instance—"n. **1.** a case or occurrence of anything...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 988).

Geologic-map unit—An intellectual construct that a geologist delineates on a map as a way to communicate a geologic concept to the map user. Each geologic-map unit corresponds to a three-dimensional volume of earth material that consists of one or more discrete lithotopes whose character and (or) frequency of occurrence makes each map unit distinct and unique from other such units (ideally). The map maker defines the scope, scale, boundaries, names, and reference sections for geologic-map units according to rules developed and adjudicated by the North American Commission on Stratigraphic Nomenclature (NACSN, 1983). According to the NACSN, geologic-map units can be lithostratigraphic units, lithodemic units, allostratigraphic units, and pedostratigraphic units.

Lithotope—A body of sediment or rock that can be "a stratigraphic unit, a part of a stratigraphic section, a particular kind of sediment or rock, [or] a body of uniform sediments formed by the persistence of the depositional environment" *Glossary of Geology* (Jackson, 1997, p. 373).

Modifier—A term or word that qualifies or amplifies a controlled term or name. By the rules that SLTTS_1.0 followed, the name of an object reflects the defining attributes by which the object is recognized; by contrast, a modifier extends the name by adding supplemental information, usually about a different concept that is not used as a defining attribute. For example, if a sedimentary earth material is defined strictly by textural criteria (e.g., grain-size ratios), then any words that add information about composition or structure, etc., add value beyond the information necessary to recognize the material. . The distinction between "modifier" and "name" is discussed further in Section 4.4.4.

Name—"n. **1.** a word or a combination of words by which a person, place, or thing, a body or class, or any object of thought is designated, called, or known...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 1276). By this definition, a name is a shorthand proxy for the description that defines the nature of something. The naming process needs to reflect the rules of the game: that is, names should correspond to the essential attributes by which the object is defined. The distinction between "name" and "modifier" is discussed further in Section 4.4.4.

Necessary—"**1.** being essential, indispensable, or requisite....**4.** *Logic*....**c.** (of a condition) such that it must exist if a given event is to occur or a given thing is to exist...." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 1284).

Standard—"*n*. **1**. Something considered by an authority or by general consent as a basis of comparison. **3**. a rule or principle that is used as a basis for judgment: *they tried to establish standards for a new philosophical approach*. —*adj*. **23.** serving as a basis of weight, measure, value, comparison, or judgment. **24**. of recognized excellence or established authority. **25.** usual, common, or customary:..." (Webster's Encyclopedic Unabridged Dictionary of the English Language, 2001, p. 1857).

4.4 Guidelines followed by SLTT

In developing science language for sedimentary materials, we adopted the following rules:

4.4.1 Science language compatible with geologic-mapping strategies

The goals and methods of geologic mapping require science-language structures that are different from those of other endeavors. This is because geologic maps are made using rules, procedures, and interpolations whose objectives differ from those of other geoscience activities.

The very nature of the geologic-mapping process requires that the scope, scale, and consistency of geologic observation varies throughout the map footprint. This is because the nature and quality of each observation varies from place to place, depending on its purpose, the time available to make it, and the quality of the geologic outcrop. Many observations upon which the map is based are detailed and comprehensive; others are generalized and cursory. The latter typically are not the fault of the geologic-map maker, but rather are intrinsic to the geologic-mapping process itself: every potential observation point within the map footprint cannot be examined with the same level of definitive care and quality, and the information content within a geologic-map unit must be extrapolated between observation points—some of which may be quite far apart.

Consider the type of observation a mapping geologist might make in determining whether a particular outcrop should be included within a particular map unit or excluded from it:

- Binocular observation of a distant outcrop series to determine the ratio between 'sandstone' and 'conglomerate' ("Looks to me like 'sandstone' dominates over 'conglomerate');
- Casual observation of grain-size ratios in an outcrop in order to confirm that lithologic trends in a series of outcrops still apply ("Looks like the same old 'sandstone' beds. Don't need to examine these very carefully");
- Detailed hand-lens determination of grain-size ratios in a series of sedimentary beds in order to characterize a given outcrop in detail ("These 'sandstone' beds look a little different from the previous ones; I better spend some time and compare them to those in the preceding outcrops, just to be sure they belong in the same map unit");
- Follow-up petrographic analysis to determine details of texture, fabric, and grain mineralogy ("Even though I described these beds in the field as 'sandstone' based on hand-lens observation, I see on the basis of microscope observation that the mud-size fraction is greater than I originally believed. These beds more properly should be termed 'muddy sandstone', and they are more akin to the mudstones of Formation Y than they are to the sandstones of Formation X").

The preceding examples suggest that a hierarchical observational approach characterizes the geologic-mapping process—ranging from generalized observations that are cursory in scope to detailed observations that are definitive in scope. Each observational style has its own confidence level. Moreover, science-language terms for each observational level have slightly different meanings depending on the scale of observation. In each of the preceding examples, does the term "sandstone" have the same meaning? Are different types of information communicated through the use of "sandstone" in each circumstance?

We answer "no" to the first question and "yes" to the second, and we conclude that the science language of earth materials must be structured to be parallel with or consistent with the hierarchical nature of observations made during the geologic-mapping process. This is a different process than takes place in the controlled environment of a petrology laboratory, where specific kinds of questions are pursued systematically and answered using a specific kind of precise language.

This is not to say that the observational quality of geologic-map information is inferior. However, developers and users of science language for geologic maps need to be aware that (1) not all observations have the same level of refinement and (2) information projected (extrapolated) outward away from observation points without benefit of intervening data—the essence of geologic-map making—is vulnerable. These limitations compel the science language of geologic-map data sets to be constructed in a way that is compatible with geologic-mapping strategies.

4.4.2 Descriptive classification basis

To produce a classification system for earth materials 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. The properties traditionally used for field classification of earth materials include particle mineralogy and composition, particle size, particle shape, fabric (the arrangement of particle in an aggregate to form the material), and structures in the material (bedding, layering, etc.). Although bodies of earth material may be recognized based on other physical properties (e.g., magnetic susceptibility, density), these generally are not used as field criteria.

The approach to a lithologic classification developed in the SLTT documents fundamentally is descriptive—that is, classification of an earth material is based on observable features of the material, and its assignment to a lithologic class implies that certain descriptive criteria are met. These criteria must be defined in the database in order to document the classification system. The descriptions that define the lithologic classes also serve to provide default values for rock properties that are assigned to a lithologic class, but not described in greater detail. Thus, the name for a sedimentary material (e.g., sandstone, calcareous dolostone, slightly gravelly sand) is a proxy for a default description parsed into the database simply through application of a name to the material (e.g., sandstone, monzogranite, pelitic schist).

4.4.3 Hierarchical structure

The science language should be progressive—that is, it should be based on what the geologist can observe and describe sequentially during the course of making a geologic map, first with the un-aided eye, then with hand lens, and then with more detailed analysis (e.g., thin sections). Each of these observation types yields a package of information that differs in scope, content, and rigor from that in the others. If this is true, then the SLTT process ideally should develop lithologic names that are compatible with these various observation types.

The progressive nature of the observation process (from reconnaissance to detailed) requires a hierarchical language structure—that is, language that begins at a generalized level and develops into progressively more specific categories that communicate more refined information about an earth material. To the extent possible, this hierarchical structure should follow the rules of parent-child lineages—that is, each child can occur only once in the hierarchy, and can have only one parent. If this rule is not followed, multiple parentage will complicate the organization of geologic concepts and it will be more difficult to retrieve information from the database.

Developing a logical hierarchical structure proved to be vexing. As with Linnean zoological taxonomy, the purpose of organizing earth-material names into parent-child lineages is to identify logical relationships among individual rock types and groups of rock types; taxonomic names presumably should reflect these relationships. In the case of digital geologic-map databases, the premise is that lumping and splitting real-world objects into inter-related categories will help in analyzing the objects, and will facilitate searching the geologic-map data set for items as narrowly or broadly defined as our interests require. We assume this premise is a valuable one, and that a hierarchical classification approach is not just a clerical device but has functional utility.

4.4.4 "Names" *versus* "modifiers"

Classification schema must distinguish clearly between *defined earth-material names* versus *modifiers that add information to each name*. Distinctions between names and modifiers should be incorporated into the architecture of the data fields and relational tables that support digital geologic-map databases, rather than into the rock names themselves.

4.4.5 Clarity and ease of use

Data-producer and the data-user both must understand clearly the basis for the SLTT classification schema, and must be able to use them easily and comfortably.

4.4.6 Robust yet flexible

SLTT deliberations led to considerable tension between "top-down" requirements for database uniformity on the one hand, and "bottom-up" requirements for individual scientific expression on the other. We saw the need for a balanced approach that accommodated some unifying structure (robustness) yet maintained some degree of individual control over the science content of a geologic-map database (flexibility):

(1) To be *robust*, language definitions must be clear and unambiguous, and parent-child relations among categories must be logical and based on common sense;

(2) To be *flexible*, the classification structure should not paint the data-producer into a corner at high levels of the classification: the schema must allow the field geologist and map compiler to move fairly deep into the classification hierarchies before feeling constrained by narrowly-defined terms whose meaning might be more stringent than the data-producer intends.

(3) To be even *more flexible*, the classification structure should allow the mapping geologist to use the SLTT science-language standards to build a "local favorites list" using concepts and terms defined in the standard. Thus, even though terms like "black shale" or "mangerite" or "arkosic sandstone" may not be defined in the standard, a local favorites list could contain these terms mapped into the SLTT science-language structure in the following fashion (Table 4.4.6.1):

Rules and procedures for building a "local favorites list" defined using SLTTS_1.0 science concepts and science language				
Local term	**Local meaning**	**SLTT concept 1**	**SLTT concept 2**	**SLTT concept 3**
black shale	Fissile claystone containing abundant organic matter	*grain size* (specify clay:silt:sand ratio)	*depositional fabric* (specify fissile fabric)	*composition* (specify amount and type of organic content)
mangerite	A charnockitic plutonic rock equivalent to an orthopyroxene-bearing monzonite	*modal mineralogy* (specify pyroxene modal percent)	*plutonic family* (specify monzonite)	*genesis* (specify plutonic igneous)
arkosic sandstone	A terrigenous-clastic rock having < 0.01% gravel-size grains and containing a significant amount of feldspar grains	*grain size* (specify mud:sand:gravel ratio)	*depositional fabric* (fabric attributes not part of the default definition)	*composition* (specify amount of feldspar content)

Table 4.4.6.1

In order for the flexibility of (3) to be accommodated, four mutually supportive concepts need to be agreed to and implemented:

- Data-entry software tools for the map maker should support the functionality of creating a local favorites list;
- To be compatible with SLTT terminology, lithology terms in a "local favorites list" should be formally defined using science concepts and language laid out in the SLTT standard, and using data fields equivalent to those defined in the NADM data-model standard (North American Data Model Steering Committee, 2004).
- The map maker should "contractually" agree to define his or her terms using the science concepts and science language provided by the standard;
- software tools that query the database should allow map users to specify or indicate clearly what they are searching for, and be able to execute database queries using their own definitions of earth materials and their attributes.

4.4.7 Compliance with North American traditions

Earth-material names and parent-child relations among them must make sense according to common North American practice.

4.5 Does genesis play a role in earth-material classification?

High-level categories in the SLTT earth-material classification—e.g., sedimentary, volcanic, composite-genesis, metamorphic, impact metamorphic, hydrothermally altered, mylonite-series, and cataclastic—fundamentally are genetic: they reflect how earth material was formed (genetic process, deformation style, crustal depth, etc.). Obviously, the origin and geologic history of earth materials are important to most geologic-map users, and should be recorded in appropriate tables and data fields in the geologic-map database. Except for these high-level categories, SLTT did not use genesis as a factor in taxonomic classification because it is so interpretive. In any event, many map users are interested in the physical characteristics of earth materials, rather than their genesis. Hence, SLTT generally avoids the use of genetic factors in its classification schema, especially at deeper levels where classification categories are based on what the mapping geologist can see in the outcrop (empirical factors such as composition, structure, and texture).

4.6 A final philosophical caveat

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 are developing 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.

5 WHAT HAS SLTT ACCOMPLISHED?

5.1 Working documents *versus* a "standard"

As originally envisioned by the NADMSC and by the SLTT charter (Appendix 1), 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);
- 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 science-language teams;
- 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 over-whelmed 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, including mechanisms for responding to community feedback and for versioning 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 beta testing). Until such mechanisms are defined and tested, it is premature to consider standardization, stewardship, and versioning;
- 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 re-considered. 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”). 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.

5.1.1 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 by the SLTT report on composite-genesis materials (North American Geologic Map Science Language Technical Team, 2004a). 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.

Subgroup members discussed whether or not to include within the composite-genesis domain earth material like 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 currently do not have a home in any of the SLTT science-language documents, except as a modifier to describe the upper surface of sedimentary earth materials.

5.1.2 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.

5.1.3 Sedimentary SLTT

The sedimentary subgroup produced a comprehensive analysis of the attributes for sedimentary earth materials (North American Geologic Map Science Language Technical Team, 2004b) 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;
- science language for human-affected landscapes, including made ground and worked ground.

5.1.4 Volcanic SLTT

The volcanic SLTT document (North American Geologic Map Science Language Technical Team, 2004c), provides a concise look at the science language of unconsolidated and consolidated volcanogenic earth materials. The goal of the volcanic team 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*. The volcanic 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 that this was beyond their mandate.

5.2 Have we learned anything from 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 deep differences in how various individuals, agencies, and scientific programs view geologic-map databases and how they should be constructed to further their science missions.

We believe the SLTT documents will be of significant value to the North American geologic-mapping community: hopefully, they will stimulate discussion about how the information 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 hopefully will lead to future work that will build on SLTT accomplishments.

Based on our experience, 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 and adapt the SLTT standard;
(3) encourage the your scientific workforce to participate fully and legitimately in standard’s development, and to implement the standards once they are developed;
(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.

6 SUMMARY OF SCIENCE-LANGUAGE CLASSIFICATIONS

In parallel with the NADMSC Data Model Design Team, SLTT defines the highest level in the classification hierarchy as "earth material":

Earth Material—A naturally occurring substance formed in or on the Earth by physical, chemical, or biogenic processes that produce solid particles or crystals of mineral and (or) rock[3].

SLTT organizes earth materials into the following high-level hierarchy:

- 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)
  - Composite-genesis earth material
    - Cataclastic rock
    - Impact-metamorphic material
    - Metamorphic rock (traditional sense) (including hydrothermally-altered rock)
      - granoblastic rock
      - foliated metamorphic rock
  - 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

6.1 Igneous earth material

The science language of igneous materials was addressed by two SLTT subgroups, one dealing with *volcanic igneous materials* and the other dealing with *plutonic igneous materials*. In one sense this subdivision is arbitrary, as the processes, compositions, and textures of the two igneous families overlap. However, the accumulation of many volcanic materials at the Earth's surface yields geologic products having unique geomorphic, compositional, and textural attributes; accordingly, SLTT developed science language for volcanic materials separately from plutonic materials.

6.1.1 Plutonic earth material

SLTT science language for plutonic earth materials adopts the BGS classification scheme for plutonic rocks (Gillespie and Styles, 1999) that is based on material names

[3]This is similar to the DMDT definition of *earth material*: "the substance of the solid Earth (rocks, minerals, organic material, glass, void space), defined based on intrinsic properties independent of their disposition within the Earth" (North American Data Model Steering Committee, 2004d).

recommended by the IUGS (IUGS, 1973; Streckeisen, 1974, 1976, 1978, 1979; Le Bas and others, 1986; Le Maitre and others, 1989; Le Bas and Streckeisen, 1991). SLTT did not produce a report on plutonic materials.

6.1.2 Volcanic earth material

SLTT science language for volcanic earth materials is structured around four concepts:

Material name based on *modal composition*

- 1.0 Felsic (high-silica) volcanic material
  - 1.1 rhyolite
  - 1.2 rhyodacite
  - 1.3 dacite
  - 1.4 trachydacite
  - 1.5 trachyte
- 2.0 Mafic (low-silica) volcanic material
  - 2.1 andesite
  - 2.2 basaltic andesite
  - 2.3 basalt
  - 2.4 trachyandesite
  - 2.5 trachybasalt
- 3.0 Ultramafic volcanic material
  - 3.1 picrobasalt
  - 3.2 picrite
  - 3.3 komatiite
- 4.0 High-alkali volcanic material
  - 4.1 alkali rhyolite
  - 4.2 alkali trachyte
  - 4.3 phonolite
  - 4.4 tephriphonolite
  - 4.5 phonotephrite
  - 4.6 tephrite
  - 4.7 basanite
  - 4.8 basalt
  - 4.9 foidite
- 5.0 Volcanic carbonatite
- 6.0 Lamprophyre

Deeper-level volcanic names based on composition derive from recommendations by the IUGS (IUGS, 1973; Streckeisen, 1974, 1976, 1978, 1979; Le Bas and others, 1986; Le Maitre and others, 1989; Le Bas and Streckeisen, 1991).

Material name based on *texture*

- 1.0 Unconsolidated volcanic material
  - 1.1 ash
  - 1.2 lapilli-ash
  - 1.3 lapilli
  - 1.4 block-ash
  - 1.4 blocks
  - 1.4 bombs
  - 1.4 scoria
  - 1.5 pumice
- 2.0 Consolidated volcanic material
  - 2.1 fragmental volcanic rock

- 2.1.1 tuff
- 2.1.2 lapilli tuff
- 2.1.3 lapillistone
- 2.1.4 tuff breccia
- 2.1.5 pyroclastic breccia
- 2.1.6 agglomerate

- 2.2 lava rock
  - 2.2.1 vitric lava
    - 2.2.1.1 obsidian
    - 2.2.1.2 vitrophyre
    - 2.2.1.3 pitchstone
    - 2.2.1.4 perlite

Material name based on *genesis*

- 1.0 Intrusive volcanic rock
  - 1.1 volcanic dike
  - 1.2 volcanic sill
  - 1.3 volcanic laccolith
  - 1.4 volcanic stock
  - 1.5 volcanic plug
  - 1.6 intrusive volcanic breccia

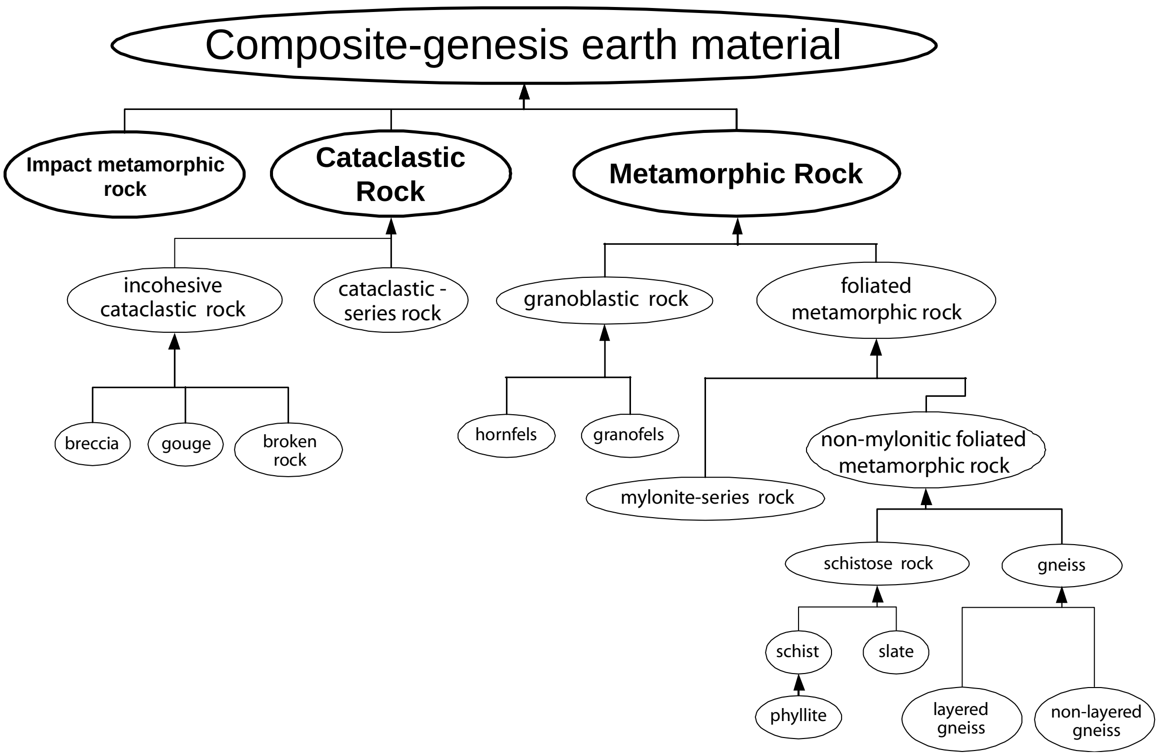
- 2.0 Extrusive volcanic rock
  - 2.1 lava flow
    - 2.1.1 pillow lava
    - 2.1.2 pahoehoe
    - 2.1.3 aa
    - 2.1.4 block lava
    - 2.1.5 massive lava
  - 2.2 lava dome
  - 2.3 stratocone
  - 2.4 shield volcano

- 3.0 Volcaniclastic material
  - 3.1 pyroclastic material
    - 3.1.1 pyroclastic flow
    - 3.1.2 pyroclastic surge
    - 3.1.3 pyroclastic fall
      - 3.1.3.1 agglutinate (spatter)
      - 3.1.3.2 ejecta blanket
      - 3.1.3.3 cinder cone
      - 3.1.3.4 tuff cone
      - 3.1.3.5 tuff ring

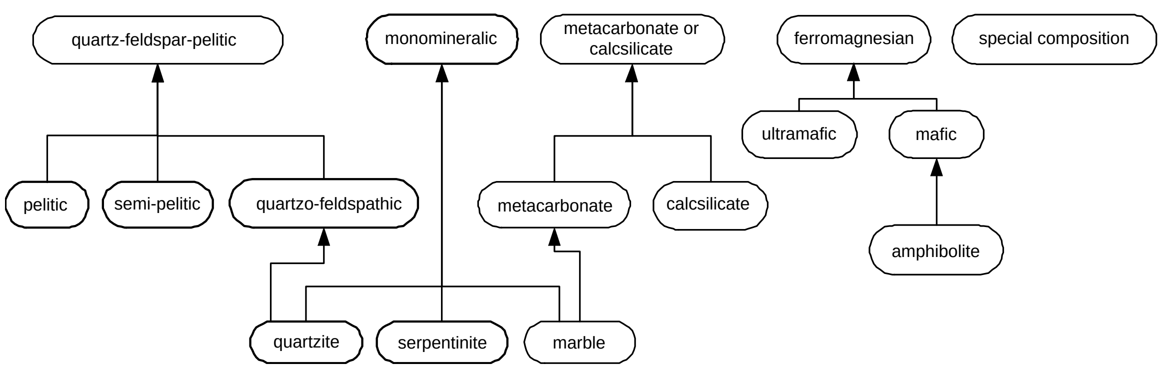
6.2 Composite-genesis rocks and rock particles

As defined in the SLTT classification, composite-genesis earth material is any earth material having observable features that document mineralogical, chemical, or structural change of a preexisting earth material essentially in the solid state. The category includes metamorphic rocks (*sensu strictu*), hydrothermally altered rocks, cataclastic rocks, and impact-metamorphic rocks. Weathered rock and pedogenic soil also could be considered composite-genesis materials, but SLTT has not included these materials in the development of the classification. Where possible, the British Geological Survey classification of metamorphic rocks (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.

Composite-genesis rocks are classified along two orthogonal dimensions, fabric and composition. Because both of these dimensions are hierarchical (Text-figures 1 and 2), the class hierarchy for composite-genesis rocks is a directed acyclic graph rather than a tree. Classes that have both composition and fabric criteria are 'children' of both a 'composition' parent and a 'fabric' lithology parent. Actual class names for rocks have a *fabric* component (such as schist) and a *compositional* component (such as marble or quartzofeldspathic).



Text-figure 1—Simplified hierarchy of fabric-based composite-genesis rock names



Text-figure 2—Simplified hierarchy of composition-based composite-genesis rock name terms

6.2.1 Metamorphic rock (traditional sense)

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). The basic level of classification is the definition of fabric-based types described as hornfels, granofels, schist, layered gneiss, non-layered gneiss, slate, and mylonite-series rock (Table 6.2.1). In this classification, hydrothermally altered rocks are treated as metamorphic rocks; the full metamorphic classification is applied to these rocks without treating them as a distinct, separate category.

Fabric-based Metamorphic-rock Class	Definition and scoping notes
Hornfels	A non-foliated aphanitic metamorphic rock having granoblastic fabric. The term does not necessarily denote a contact metamorphic origin, although that is most commonly the case
Granofels	A phaneritic metamorphic rock that has little or no foliation or lineation, implying that that less than 10% of the particles in the rock are fabric elements that have an inequant shape and an aspect ratio ≥ 1.5:1
Schist	a phaneritic metamorphic rock that has well developed continuous schistosity. "Well developed" schistosity is defined here 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 (Jackson, 1997). Continuous is defined 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. Phyllite is a fine-grained subclass of schist having an average grain size between 0.25 mm and 0.1 mm and a silvery sheen.
Layered gneiss	a foliated, phaneritic rock that lacks well developed, continuous schistosity and has laterally continuous compositional layering > 5 mm thick
Non-layered gneiss	a foliated, phaneritic rock that lacks both 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)
Slate	an aphanitic rock that has well developed schistosity (Brodie and others, 2002). The definition of schistosity used in this classification 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 for precision.
Mylonite-series 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 have observable features that document continuous, crystal-plastic deformation. Mylonite-series rock is subdivided according to matrix percentages into protomylonite, mylonite, and ultramylonite (Sibson, 1977)

Table 6.2.1—Fabric-based metamorphic-rock classes

Composition-based rock classes include amphibolite, marble, and common monomineralic rocks such as quartzite and serpentinite, which are defined individually by modal mineral composition. Other monomineralic metamorphic rocks consisting predominantly (>75%) of a single mineral are classified as monomineralic-granofels, monomineralic-hornfels, monomineralic-schist, etc., depending on the fabric.

Composition qualifiers defined on the basis of modal mineralogy (ferromagnesian, calcsilicate, carbonate, pelitic, semipelitic, quartzofeldspathic; see Table 6.2.2) are combined with a fabric term as in "pelitic schist." Traditional non-systematic rock terms such as amphibolite that are based on modal mineralogy are also treated as composition qualifier terms. This classification leans towards a minimum of special rock names for unusual composition rocks, and such rocks would be assigned a 'special composition' qualifier. The uncontrolled rock-name field in the database is available to assign any special rock name the geologist may prefer.

Composition qualifiers	Definition
amphibolite	Rock 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
argillic	Rock is apparently clay-rich. Use for aphanitic rocks
calcareous	Rock reacts to form bubbles when hydrochloric acid is applied. Use for aphanitic rocks (e.g. hornfels)
calcsilicate	Rock consists of ≥ 50% calcsilicate or carbonate minerals and carbonate minerals ≤ calcsilicate minerals in mineral mode
ferromagnesian	Rock consists of >40% dark ferromagnesian minerals. Standard term defined by Bates and Jackson (1987) to mean "containing iron and magnesium"
impure marble	Rock consists of >50% calcsilicate or carbonate minerals and relative proportion of calcsilicate and carbonate minerals is unknown or not specified
mafic	Rock consists of ≥ 40% and <90% ferromagnesian minerals
marble	Rock consists of > 75% carbonate minerals
metacarbonate	Rock consists of >50% calcsilicate or carbonate minerals and carbonate minerals > calcsilicate minerals in mineral mode
monomineralic	Rock 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…)
pelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥ 70%, and aluminous mineral + mica content is ≥ 40%
quartzite	Rock consists of ≥ 75% quartz
quartzofeldspathic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥70%, and quartz + feldspar (sensu Robertson, 1999) >60%
semipelitic	Rock for which the sum of modal quartz+feldspar+ mica + aluminous mineral is ≥70%, and quartz+ feldspar < 60%
silicic	Rock is apparently silica-rich. Use for aphanitic rocks. Jackson (1997) includes denotation of igneous origin. For SLTT classification, should be considered to mean "appears to consist largely of quartz and feldspar", generally is aphanitic with hardness >= 6.
special composition	Rock 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
ultramafic	Rock consists of >90% ferromagnesian minerals

Table 6.2.2—Selected composition-based classes (qualifiers) for metamorphic rocks

The SLTT classification of metamorphic rocks does not apply the 'meta' prefix to a protolith name (as in metasiltstone), because it cannot be simply integrated into a classification based on fabric and composition, and because interpretations of protolith can be highly subjective. Rock name terms in the form 'meta-(*some rock name*)' can be placed by the user in an uncontrolled rock name field and can also appear in a user interface by having underlying software that maps the name assignment to the implied dual classification. Where the protolith can be determined, the classification includes two distinct parts—a protolith classification using the criteria applicable to the protolith lithology, and a composite-genesis classification based on the fabric and composition criteria outlined here. The data model design should include a mechanism that allows the ‘dominant’ aspect of a rock that has multiple classifications to be specified.

6.2.2 Cataclastic rock

SLTT classifies a rock as cataclastic if >10% of the volume consists of fragments bounded by fractures. 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) Cataclastic rock having evidence of primary cohesion is subdivided according to matrix percentages into *protocataclasite*, *cataclasite*, and *ultracataclasite* (Sibson, 1977). Cataclastic rock that lacks primary cohesion is subdivided into fault breccia (visible fragments >30% of rock) and gouge (visible fragments <30%).

6.2.3 Impact-metamorphic rock

Impact-metamorphic rocks have observable features, such as microscopic planar deformation features, that are unequivocally the result of shock metamorphism (Stöffler and Grieve, 2001), high-pressure minerals, or field evidence such as shatter cones and crater structure. Adapting Stöffler and Grieve’s (2001) IUGS recommendations with slight modifications, impact-metamorphic rock is classified as shocked rock, impact melt rock, or impact breccia.

6.3 Sedimentary earth material

The SLTT Sedimentary Subgroup developed science language for the lithologic classification (material name), physical characteristics, and origin and depositional history of sedimentary materials.

At the top hierarchical level, sedimentary earth materials are classified into eight categories based on sediment composition (Table 5.3.1). At a high level, unconsolidated sediment is distinguished from consolidated rock, and separate (but parallel) naming schemes are developed for each consolidation state.

Sedimentary material (unconsolidated, consolidated)	**Definition**
Sedimentary material, unclassified	Not enough information is known about a sedimentary material to classify it as anything other than sedimentary rock or sediment, unclassified
Terrigenous-clastic sedimentary material	A rock or sediment composed principally of broken fragments that are derived from the land or continent. To be considered as terrigenous-clastic, a rock (sediment) must have ≥ 50% of its constituents derived from the land or continent
Carbonate sedimentary material	Sediment or sedimentary rock ≥50% of whose primary and (or) re-crystallized constituents are composed of carbonate minerals (calcite, aragonite, dolomite). By definition, such materials are *intra-basinal* in origin—that is, they formed by processes operating within the depositional regime, and were not transported into that regime from other sediment sources
Organic-rich sedimentary material	Sedimentary materials having sufficiently high organic content that they can not be identified as another kind of sedimentary rock (e.g., terrigenous-clastic or carbonate). Pragmatically, SLTT places this threshold at ≥50% organic content by weight to be consistent with the established definition for coal without conflicting with definitions of other compositionally-based categories
Non-clastic siliceous sedimentary material	Sedimentary materials dominated by non-clastic silica are those composed of ≥50% silica of biogenic or chemical origin (Hallsworth and Knox, 1999, p. 21)
Noncarbonate-salt sedimentary material	Sedimentary materials dominated by non-carbonate salts are those whose primary constituents consist of chloride, sulphate, or borate minerals. Such materials also are known as *evaporite* materials because they form through evaporative precipitation of mineral salts from brines—either directly from the water column or from pore fluids during diagenesis
Phosphate-rich sedimentary material	Phosphatic sedimentary materials are those in which phosphate minerals or phosphatic components comprise >50% of the sedimentary framework as determined by hand-lens or petrographic analysis (Hallsworth and Knox, 1999). This corresponds with a rock (sediment) typically containing ≥ 15% P_2O_5 (by weight)
Iron-rich sedimentary material	Iron-rich sedimentary materials are those in which iron-bearing minerals comprise ≥ 50% of the sedimentary framework as determined by hand-lens or petrographic analysis (Hallsworth and Knox, 1999). This corresponds with a rock (sediment) typically containing ≥ 15% iron (by weight)

Table 5.3.1.

Within each compositional category, lower-level, more detailed material names are based on textural or compositional criteria (or both), depending on the parental category.

The distinction between “unconsolidated” and “consolidated” (sediment *versus* rock) occupied considerable SLTT discussion and attention. We concluded that SLTT can suggest guidelines for distinguishing unconsolidated from consolidated materials. However, ultimately it will be the subjective decision of the data producer as to whether a specific sedimentary material is “consolidated” or “unconsolidated” according to his or her judgment. Table 5.3.2 provides guidelines that can facilitate this determination.

	Consolidation state	**Field criterion**	**Relative density** (D_r)[4]
Unconsolidated	Very slightly consolidated	Easily indented with fingers	0.00—0.20
	Slightly consolidated	Somewhat less easily indented with fingers. Easily shoveled	0.20—0.40
	Moderately consolidated	Shoveled with difficulty	0.40—0.70
Consolidated	Well consolidated	Requires pick to loosen for shoveling	0.70—0.90
	Lithified	Requires blasting or heavy equipment to loosen	0.90—1.00
	Indurated	Rings to the blow of a hammer	1.00

Table 5.3.2

SLTT developed science language for a variety of attributes that characterize the outcrop appearance of sedimentary materials (Table 5.3.3):

Outcrop characteristics		
Science concept		**Data-field content**
Lithotope abundance		indicates the relative abundance of each lithotope in an outcrop
Map-unit geomorphology		describes how a map unit crops out (prominent, subdued)
Outcrop profile		describes how individual lithotopes crop out (ledge-forming, slope-forming, etc.)
Outcrop weathering		describes how sedimentary materials weather (cavernous, friable, etc.)
Material color	Color (fresh)	describes the color of fresh geologic materials
	Color (weathered)	describes the color of weathered geologic materials
	Color (dry)	describes the color of dry geologic materials
	Color (wet)	describes the color of wet geologic materials
Consolidation state		describes how firm and knitted together a sedimentary material is, and how hard it is once it has been lithified

Table 5.3.3

[4]As translated by Bowles (1984, p. 151-152), relative density is an engineering parameter that relates void space determined in the laboratory to a ratio involving index values of minimum and maximum void space for specified materials under specified conditions. Void space in turn is related to *in situ* dry unit weight. Also see the *Glossary of Geology* definition of relative density (Jackson, 1997, p. 540).

SLTT classifies sedimentary structures into primary and secondary structures, with the following major categories (Table 5.3.4):

PRIMARY SEDIMENTARY STRUCTURE
Inorganic sedimentary structure
Syngenetic structure
Depositional structure
Erosional structure
Penecontemporaneous structure
Bed-surface structure
Within-bed structure
Multi-bed structure
Biogenic sedimentary structure
SECONDARY SEDIMENTARY STRUCTURE
Secondary deformation structure
Sedimentary hardground
Dissolution structures
Epigenetic growth structure
UNCLASSIFIED SEDIMENTARY STRUCTURE
Bed-surface structure
Within-bed structure
Multi-bed structure

Table 5.3.4

SLTT developed science language for a variety of attributes that characterize the fabric and texture of sedimentary materials (Table 5.3.5):

Sedimentary fabric and texture elements		
Science concept		**Data-field content**
Preservation of depositional fabric		Yes or no (character field)
Grain-support *versus* matrix support		indicates whether fabric is clast-supported or matrix-supported
Particle size	Matrix grain size (range)	indicates range of matrix grain size
	Matrix grain size (average)	indicates mean of matrix grain size
	Particle grain size (range)	indicates range of particle grain size
	Particle grain size (average)	indicates mean of particle grain size
Particle sorting		indicates sorting in terms of Inclusive Graphic Standard Deviation (Folk, 1968)
Particle shape and rounding		indicates the shape of grains and clasts (rounded, subangular, tabular, spherical, etc.)
Coated particles		indicates the fabric type created by particle coating (ooidal, pisoidal, oncoidal)
Particle orientation		indicates the geometric orientation of elongate or disk-shaped particles
Particle packing		indicates the spacing or density patterns of particles as expressed by nature of grain contacts

Table 5.3.5.

SLTT classified sedimentary genesis according to a scheme that integrates three attributes: Table 5.3.6 lists the science concepts that SLTT used to guide the development of sedimentary-genesis terms. These concepts suggest that genetic information about sedimentary materials in geologic-map databases should be scalable, hierarchical, and multi-faceted.

Science Concept	Meaning
Particle origin	How a particle of sediment originally was produced
Depositional process	How a sediment volume was transported and deposited
Depositional place	Where a sediment was deposited
Geomorphic (physiographic) configuration	How process and place have interacted to yield a geomorphic configuration recognizable on the Earth's surface
Ambient conditions	Information about climatic conditions, depositional slope, distance from source area, oxygen levels at depositional site, etc.
Tectonic setting and basin type	Plate-tectonic setting of the depocenter within which sedimentary materials accumulate

Table 5.3.6

Ultimately, it is the interaction between *depositional process* and *depositional environment* that yields a *depositional product*. This interaction can be viewed as a two-dimensional matrix in which process is arrayed against place (Table 5.3.7):

			PHYSIOGRAPHIC SETTING (Selected high-level environments only)					
			Alluvial setting	Deltaic setting	Lacustrine setting	Playa setting	Shorezone setting	Subaqueous-fan setting
DEPOSITIONAL PROCESS (High-level processes only)	**Nonbiogenic process**	Chemogenic Process						
		Fluid-Flow						
		Gravitational Potential						
		Glacial flow						
	Biogenic process	Sediment-binding						
		Sediment-trapping						
		Framework-building						

Table 5.3.7—Two-dimensional matrix arraying *depositional process* (left) against *physiographic setting* (right) to yield cells in which a *depositional product* may (or may not) occur. Representative depositional products are listed in Table 5.3.8.

In Table 5.3.7, the intersection of a genetic process with a sedimentary environment yields a grid cell that represents a potential depositional product. Table 5.3.8 lists representative examples of such products:

algal-mat deposit	bog deposit	bar deposit	beach deposit	braided-channel deposit	channel deposit	chute-channel deposit	crevasse-channel deposit
crevasse-splay deposit	debris-flow deposit	distributary-mouth bar deposit	dune deposit	fan deposit (subaerial)	fan deposit (subaqueous)	fan-delta deposit	flood-plain deposit
glacial-till deposit	inlet-channel fan deposit	lagoon deposit	levee deposit (subaerial)	levee deposit (subaqueous)	marsh deposit	meandering-channel deposit	mud-flat deposit
overbank-fines deposit	pelagic-ooze deposit	pond deposit	reef, framework-built	reef, sediment-trapping	sabkha deposit	sand-flat deposit	sand-flat deposit
sheet-flow deposit	sheet-sand deposit	shelf deposit	slide deposit	slope deposit	slump deposit	supratidal-flat deposit	swamp deposit
tidal-channel deposit	tidal-flat deposit	tidal-inlet deposit	tidal-ridge deposit	turbidite deposit	washover-fan deposit		

Table 5.3.8. Examples of depositional products.

All three genetic attributes (depositional process, depositional environment, depositional product) can be classified hierarchically to yield a complete description of how a sedimentary material was formed.

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8 APPENDIX 1 (SLTT CHARTER)

PROPOSED NORTH AMERICAN GEOLOGIC-MAP DATA MODEL
SCIENCE-LANGUAGE TECHNICAL TEAM CHARTER
11/1/99

Executive Statement.—See the Data Model Steering Committee (DMSC) charter for an executive statement on technical teams.

MANDATE AND CHARGE

Mandate.—The Science Language Technical Team (SLTT) is mandated to develop standardized nomenclature for digital geologic-map databases—including (but not limited to) the following areas:

- nomenclature for the description of geologic map units (lithology, stratigraphy, geomorphology, pedology, petrology, genesis, etc.)
- nomenclature for the description of linear geologic features (contacts, faults, fold axial traces, mapped marker units, geomorphic features, etc.),
- nomenclature for the description of point geologic features (structural points, etc.);
- nomenclature for descriptive and interpretive information about spatial and geologic relations among geologic map units, linear features, and point features (e.g., sequencing relations, stratigraphic relations, and geometric relations, etc.).

The standardized terminology will support a proposed standard geologic-map data model for North America.

Charge.—To achieve its mandate, the Science Language Technical Team is charged with the following tasks:

(1) To determine the scope and comprehensiveness appropriate to a continent-wide terminology for geologic map databases. Terminology scope should reflect several realities, including (1) the intended use of the geologic-map terminology, (2) the geologic scale to which the terminology will be applied, (3) the prerogatives of historic usage by various geologic-mapping constituencies, and (4) the degree to which geologic terminology is amenable to a single hierarchical classification structure. These factors (and others developed by the SLTT) should determine the degree and level of standardization appropriate for continent-wide geoscience language.

(2) To develop one or more strawman classifications for geologic-map science language that will be made available for widespread peer review.

(3) To prepare and publish documents describing the basis for the science-language terminology, and presenting the classification scheme(s) and their technical and non-technical definitions.

Authority.—The SLTT derives its authority and legitimacy from the DMSC, which provides guidance and requirements on behalf of the constituencies it represents.

Accountability.—The SLTT is accountable to the DMSC. Through a representative mutually acceptable to the SLTT and DMSC, the SLTT periodically apprises the Steering Committee of progress toward science language terminology and about issues and problems that need consideration by the DMSC.

TECHNICAL-TEAM OPERATIONS

Execution of work.—The SLTT will convene an initial meeting to evaluate goals and to discuss issues, problems, and terminology strategies. The Technical Team should have as many face-to-face meetings as required to allocate responsibilities and to resolve issues and problems not easily resolvable via e-mail.

Lateral Coordination.—The SLTT will regularly communicate strategies and proposed terminologies laterally to other Technical Teams—especially the Data-Model Design Technical Team—in order to ensure that data-model architecture and software tools consistently reflect the evolving science language and concepts.

Technical Review.—Science-language documents prepared by the SLTT will be presented to the DMSC for initial review and evaluation for compliance with the overall goals of the North American geologic-map data model. Following DMSC review and SLTT response, the science-language documents will be widely distributed for technical peer review by the geosciences community (probably through a web-based venue).

TECHNICAL-TEAM MEMBERSHIP

Work Group Size.—The size of the SLTT should be commensurate with its mandate: If geologic and political realities require that the scope and content of data-model science language be generalized and narrow, then the size of the Technical Team should be small; however, if the scope and content of data model science language is to be comprehensive and detailed, then the size of the Technical Team should be large enough to ensure scientific comprehensiveness and consensus of the larger geologic community.

Scientific Breadth.—SLTT membership should span the range of surficial and bedrock geologic disciplines, including expertise in sedimentary, igneous, metamorphic, structural, stratigraphic, and geomorphic/pedogenic arenas. Experts on specific scientific disciplines can be added for short durations to address specific geologic issues that arise during SLTT deliberations.

Geographic Breadth.—SLTT membership should include a broad range of geographic representation so as to reflect provincial geologic usages.

Constituency Breadth.—SLTT membership should represent the constituencies that will contribute to geologic map databases—initially including the U.S. Geological Survey (USGS), the Association of American State Geologists (AASG), the Geological Survey of Canada (GSC), and the Canadian Provincial Surveys. Inclusion of industry and academic participants will depend on the narrowness or breadth of the science-language standards.

Appointment procedure.—SLTT members shall be appointed by the DMSC based on the recommendations of each constituency and considering the criteria defined in Scientific, Geographic, and Constituency Breadth:

- AASG recommendations will come from the AASG Digital Geologic Mapping Committee;
- GSC recommendations will come from that agency as appropriate to its internal selection procedures;
- Recommendations from the Canadian Provincial Surveys will come from those agencies consistent with their interest and appropriate to their internal selection procedures;

- Recommendations from the USGS will come from that agency as appropriate to its internal selection procedures.

Lifespan of Technical Team.—Continued existence of the SLTT as a standing committee responding to data-model science–language needs shall be at the discretion of the DMSC. The SLTT will remain intact during the review period, and shall respond to Steering Committee review and to peer review until such time as version 1.0 of the science-language classification is adopted for use in the draft standard data model.

MILESTONES

Within a year of convening its first session, the SLTT shall carry out its charge to produce one or more science-language strawman classifications. The SLTT receives guidance on milestones from the DMSC, evaluates their feasibility, and reaches targets in conjunction with DMSC.

9 APPENDIX 2

Memorandum from SLTT Chair (Matti) to SLTT committee members (4/03/2000)

Participants on the Science Language Technical Team For a Proposed North American Geologic-Map Data Model 04/03/2000

Science Language Technical Team colleagues:

By now, each of you hopefully is aware that you have been selected as a participant on a technical team (Science Language Technical Team, SLTT) tasked with coming to groups with how (or whether) a common set of geoscience terms can be developed for digital geologic-map data bases produced in North America. The SLTT is one of several parallel teams commissioned on behalf of a proposed North American Geologic-Map Data Model.

<u>Background</u>

A standardized data-base model for the input, storage, manipulation, retrieval, and analysis of digital geologic-map information is being developed 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 data model currently being evaluated was developed as a cooperative venture by the USGS, the GSC, and the AASG.

This model attained visibility through a series of workshops and through presentations at national GSA meetings. It developed as a likely candidate for a North American data-model standard, and over a period of time was revised and refined under the aegis of the AASG, the USGS, and the GSC. The data model can be found on the World Wide Web at http://geology.usgs.gov/dm/model/Model43a.pdf (version 4.3, Johnson and others, 1999). Continued development of a data-model standard is proceeding under the auspices of a multi-constituency North American Data Model Steering Committee (NADMSC, http://geology.usgs.gov/dm/steering/), which has commissioned the technical teams that are developing various aspects of the data model.

<u>How did you come to be a participant in this process</u>?

Scientists from the American state geological surveys were identified by the Association of American State Geologists. Participants from the USGS were nominated through a process that was coordinated through the three Regional Geologists and through the Geologic Division Program Coordinators. The two Canadian participants represent the Provincial surveys and the Geological Survey of Canada; hopefully, additional Canadian participants will be identified in the near future. I am in the process of recruiting a few representatives from the geologic-map using community within the U.S. Departments of Interior and Agriculture, one of whom has been identified. All of you are viewed as ideal for responding to the task before us.

<u>Where is the SLTT process now, and what is next</u>?

It has taken a while to establish the SLTT membership because it has not been easy to coordinate among multiple constituencies. But, we are about there, so I thought I would bring you up to speed, and address some mechanical issues.

(1) I want to start business on April the 17th.

(2) We have a year from that date to execute our responsibilities.

(3) I imagine a month of your time will be required throughout the 12-month cycle, but time invested will depend on interest level and commitment to the SLTT process.

(4) As a Team, we will work together to develop interim milestones.

(5) We will regularly keep the Data Model Steering Committee appraised of our progress.

(6) Our initial dialogue will be electronic, in the form of email and a web-conference site devoted to science-language issues (http://geology.usgs.gov/dm/terms/).

(7) Please access the web-conference site and register. The site was constructed and is maintained by Peter Schweitzer of the USGS, who assures me that it will work as advertised (all who register at the site are supposed to be notified by email when a new contribution is made, but if anything can go wrong, it must go wrong!).

(8) My role is that of a facilitator. My job is to stimulate *your* creativity and *your* analytical approach to our task. If I am not doing that, I am failing and you must so inform me.

(9) Attached to this mail are several .pdf files, one being an archival copy of this email. My hunch is that .pdf exchange will be a common tool for the SLTT's business, so if you do not have a .pdf reader or if somehow my files are not readable by you, we need to find a fix. Please advise.

(10) The attached files include the SLTT charter, a roster of SLTT participants, and a guidelines document that the Data Model Steering Committee has reviewed, revised, and endorsed. The guidelines set the philosophy and tone of how the SLTT should go about its business. We will not be scrutinized by the DMSC, but we do have a specific mission that body expects us to achieve.

(11) I encourage you to reach out to colleagues in your organization to discuss science-language issues. We represent our colleagues and speak for them—not in place of them.

(12) Travel and travel costs: Yes, there will be a face-to-face meeting among us. As a Team, and in conjunction with the DMSC, we will have to work out the mechanics of a face-to-face, and how (or if) funds can be identified to defray (not subsidize) travel costs. I think a face-to-face is essential, for it will unite us in our task and because inter-personal exchange of ideas is always better than the impersonal electronic forum. However, travel has its costs (time and money), and such costs cannot be treated in cavalier fashion. We will discuss this as we go along.

(13) Finally, if you have searched your gut and truly do not want to participate in the SLTT process, or have second thoughts owing to the press of other obligations, please inform me as soon as possible. I will wish you well and find a replacement for you. It is essential that we all feel good about this process, and truly want to be a part of it.

I will be on the road for most of this week, and not able to check my email for much of that time. Please use this period before 17 April to get yourself into the swing of things regarding geologic-map standards. I will be back in contact next week with more mechanical issues.

In the meantime, here is our first task:

In order to set the tone for our task and see how each of us views the information content of a geologic map, please come up with 20 data-base queries that you personally would want to launch at a digital geologic-map data base. We can exchange these query-lists by email, and post them at the web-conference site. Use the following syntax:

(1) show me all metasedimentary rocks;

(2) show me Paleozoic and Late Proterozoic metasedimentary rocks intruded by Cretaceous 2-mica monzogranite;

(3) show me all low-angle faults, irrespective of their extensional or contractional origin;

(4) show me all rock units affected by two generations of folding;

(5) show me all slope-failure deposits;

(6) show me all slope-failure deposits of slump-block and earth-flow origin;

(7) show me all surficial deposits with well-developed Bt soil horizons.

I will come through with my 20, but this quick sample represents just a smattering of topics and issues that I would need to retrieve from a typical geologic-map data base in southern California. Good luck, and have fun.

Personally, I am looking forward to working with all of you. Collectively, we represent a considerable body of common sense, scientific breadth, and geologic-map experience (either on the data-production side or the data-use side). With such a mix, I am confident that we will do justice to the notion of common standards for geologic-map terminology—or, if such standards can not be developed and adopted, then at least a good set of minds will have reached that conclusion.

Adios from Tucson, Jonathan

10 APPENDIX 3

Memorandum from SLTT Chair (Matti) to SLTT committee members (4/03/2000)

SCIENCE-LANGUAGE TECHNICAL TEAM
Guidance from the North American data-model Steering Committee

04/03/2000

MANDATE

The Science Language Technical Team (SLTT) is mandated to develop standardized nomenclature for digital geologic-map data bases, including (but not limited to) the following areas:

(1) nomenclature for the description and characterization of geologic-map units (lithology, stratigraphy, geomorphology, pedology, petrology, genesis, etc.)

(2) nomenclature for the description and characterization of linear geologic features (contacts, faults, fold axial traces, mapped marker units, geomorphic features, etc.),

(3) nomenclature for the description and characterization of point geologic features (structural points, etc.);

(4) nomenclature for descriptive and interpretive information about spatial and geologic relations among geologic map units, linear features, and point features (e.g., sequencing relations, stratigraphic relations, and geometric relations, etc.).

GUIDING PRINCIPLES

(1) The SLTT's focus is digital geologic-map data bases—NOT geologic maps. Geologic maps as cartographic products should be viewed by the SLTT as derivative output FROM the data bases, not as mainline products supported BY the data bases;

(2) The SLTT's focus is the geoscience content of geologic-map data bases—not data-base design. SLTT recommendations and decisions regarding geoscience concepts and their attendant vocabulary and inter-relations will be passed upward to the Steering Committee and laterally to the Data-model Design Technical Team for evaluation and incorporation into data-model modification and tool development;

(3) Geoscience classification and nomenclature scheme(s) should be scale-independent;

(4) Classification and nomenclature scheme(s) should allow the data-base author to describe and interpret geologic elements as richly or poorly as the data allow—even within a single data base. To support this functionality, nomenclatural items should be related hierarchically in a way that allows geologic materials and geologic structures to be described and interpreted in progressively more detail and richness while still allowing them to be grouped into progressively broader categories;

(5) Classification and nomenclatural scheme(s) should be robust enough to provide stability and consistency of usage, but flexible enough to accommodate differences owing to regional or institutional mapping traditions or mission requirements;

(6) Classification and nomenclatural scheme(s) should allow the data bases to be queried for standardized geoscience concepts and geoscience attributes—ranging

from the mundane to the sophisticated. Data-base queries can be only as successful as the architecture and language of the geologic data base that is queried;

(7) Classification and nomenclatural scheme(s) should accommodate all audiences and data-base users—from the educated lay audience through the end-user in local through Federal agencies, culminating in the technical geoscience user in academic and institutional audiences;

(8) Classification and nomenclatural scheme(s) should integrate seamlessly with a broad range of interdisciplinary data bases—including (but not limited to) engineering, geophysical, geochemical, hydrologic, environmental, and geographic data bases and interactive applications.

11 APPENDIX 4

Memorandum from SLTT Chair (Matti) to SLTT committee members (12/01/2000)

Science Language Technical Team
Action Plan
1 December, 2000

SLTT colleagues:

About 15 of us got together the morning of 13 November [at Geological Society of America Annul Meeting, Reno, Nevada, 2000] to discuss general issues and to develop an action plan for our science-language activities. This document summarizes the discussions, and provides the guidance for our activities over the next few months.

Participants

Lucy Edwards (USGS)
Bruce Johnson (USGS)
Ron Kistler (USGS)
Alison Klingbyle (GSC)
Diane Lane (USGS)
Steve Ludington (USGS)
Jim MacDonald (Ohio Geological Survey)
Jon Matti (USGS)
David Miller (USGS)
Steve Richard (Arizona Geological Survey)
Peter Schweitzer (USGS)
Loudon Stanford (Idaho Geological Survey)
Andy Rorick (U.S. Forest Service)
Richard Watson (U.S. Bureau of Land Management)
Jerry Weisenfluh (Kentucky Geological Survey)

(1) What we need to do

- develop lists of **control-words** for the description and naming of geologic materials and geologic structures. Control-words are rigidly defined words whose definitions cannot be violated (sandstone has exactly one definition; monzogranite has exactly one definition; thick-bedded has only one definition);
- provide formal definition of each control-word (sources: AGI dictionary of geoscience, IUGS plutonic-rock classification, widely-cited geoscience textbooks, etc.)
- develop hierarchical classification of control-words (parent-child relationships using software to be announced) (e.g., Visio2000pro)
- provide all documentation by 30 April, 2001, including:
  (1) definitions of control-terms
  (2) diagrams of parent-child relations
  (3) Minimal boiler-plate that describes our results and places them in the context of the proposed North American geologic-map data model
- Consider developing a thesaurus approach to control-terms and their non-controlled equivalents (synonyms, related terms, proxies for control-terms)

(2) Specific components of 1.0 strawman

- For the following categories, develop control-terms for the deepest level possible in each hierarchy:

  (1) **rock name** (e.g., limestone, monzogranite, blueschist, colluvium)
  (2) **lithologic attribute** (e.g., coarse-grained, fissil-weathering, thin-bedded, unconsolidated, texturally massive, porphyritic, porphyroclastic, mullion)
  (3) **rock genesis** (e.g., marine, nonmarine, alluvial, plutonic, volcanic, fluvial, colluvial, dynamothermal, high-strain)
  (4) **genetic structures** (e.g., flow foliation, eutaxitic fabric, cumulate layering, graded bedding, sole structures, slaty cleavage, earth flow,)

- If possible, develop as part of each hierarchy generic field terms that allow for general-purpose classification of materials and structures (e.g., “granitic”, “basaltic”, “conglomeratic”, “marble”, “mudrock”, “cross-bedded”, “gneissic” “mylonitic”, “silty”) so that reconnaissance observations can be recorded meaningfully in the data model

- Identify internationally-recognized geologic-time classifications that can be used by the data model. The SLTT does not have to recommend or advocate any one scheme: we merely have to collect them together as schemes that can be used by the data producer. The data model design team will develop a metadata technique for associating an age term with its time-scale scheme. Time scales that come to mind include:

  (A) Harland and others (1989)
  (B) IUGS timescale (Remane, 2000)
  (C) time scales compiled in Berggren and others (1995)

(3) Target Audience: Science language should be technical—that is, it should be developed by and speak to the trained geologist. Although we all are concerned about how the professional and non-professional non-geoscience audience will access and understand our database content, this concern should be addressed by a technical team tasked with designing the data-model user interface.

(4) Basis and scale of terminology: Map-unit categories (i.e., formation, member, tongue, lentil, bed) are conceived and extended through a process that integrates hierarchical observations beginning at the ***hand-sample and outcrop level*** but extending to the ***hillside and regional level*** and augmented by the ***thin-section and chemical-analysis*** level. Thus, hierarchical terminology schemes leading to map-unit description should reflect:

- regional-scale observation
- hillside-scale observation
- outcrop-scale observation
- hand-sample-scale observation
- thin-section-scale observation
- chemical analysis-scale observation

(5) Existing strawman-classifications for consideration include (but are not limited to):

- Rock classification schemes of British Geological Survey (BGS)

- Version 6.0 classification scheme of SLTT member Bruce Johnson (Matti will distribute again; Johnson will provide parent-child diagrams)
- Volcanic and plutonic classification schemes of SLTT member Steve Ludington (Matti will distribute again)
- SCAMP version 2.0 rock-classification schemes (Matti will distribute again)
- Any other hierarchical classification schemes that subgroup members can identify

(6) In addition to nomenclature for sedimentary, igneous, metamorphic, and surficial materials, we need to develop language for the following materials:

- tectonic rock units (e.g., broken formations, mélanges, tectonic breccia, bolide-impact rocks)
- rock-types of hydrothermal or alteration origin
- rock-types of mixed origin
- rock-types of unknown origin

(7) The following rules MUST be adhered to:

- hierarchies must follow independent non-intersecting pathways (or so I understand [correctly?] from the data model design people)
- A control-term cannot be arrived at by more than one pathway. For example, the mineral “calcite” cannot be arrived at via a sedimentary pathway leading to calcite or a metamorphic pathway leading to calcite or an igneous pathway leading to calcite. Instead, the mineral calcite must be approached via a single pathway in a mineralogy hierarchy that incorporates children of calcite (e.g., calcite, *sedimentary*; calcite, *metamorphic*; calcite, *vein*)

(8) To assist data-model design team, we need to distinguish between the following terms:

- “rock”
- “rock unit”
- “map unit”

(9) To assist data-model design team in developing a map-unit characterization field

- develop language that allows each map unit to be characterized concisely and distinguished clearly from other map units
- develop control terms applicable to lower, upper, and lateral **boundaries of map units** (e.g., conformable, unconformable, sharp, discrete, transitional, gradational, mixed, migmatitic, intrusive, extrusive, interfingering) and for distinguishing properties (geologic, geomorphic, pedogenic, paleontologic. This may not be possible within the scope of our initial lithologic assignment, but we need to have it on our radar screen as we do our job, and make some progress in this direction.

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12 APPENDIX 5

Memorandum from SLTT Chair (Matti) to SLTT Sedimentary and Surficial subgroup members (2/15/2001)

Sedimentary and Surficial Subgroup Colleagues: 02/15/2001

Now that the surficial and sedimentary SLTT teams both have launched their deliberations, we need to address an issue of concern to both teams.

Several members of the sedimentary group have indicated concern about possible overlap between “unconsolidated” sediment and unconsolidated surficial materials. This concern originates from the British Geological Survey’s (BGS) classification of sedimentary materials into “lithified” and “unlithified” materials:

"The primary classification of sediments and sedimentary rocks is based on their compositional attributes present at the time of deposition. This allows sediments to be classified by the same compositional boundaries as sedimentary rocks."

The following points address this issue, and seek to clarify the unique assignments of the surficial-materials team and the sedimentary team. As you see fit, please comment on any of the points

(1) I do not think the BGS blurs the boundaries between their “unlithified sediment” and “unconsolidated surficial materials”;

(2) The BGS scheme simply provides names for unlithified sediment that are parallel with the names for lithified sedimentary rock;

(3) The surficial team is charged with developing a classification of surficial materials like “alluvium”, “colluvium”, “landslides”, and so forth. I suspect that the group will come up with classification categories such as “alluvial deposits”, “colluvial deposits”, “landslide deposits”, etc., all representative of surficial materials that are relatively “unlithified”;

(4) These surficial materials will have certain physical properties (such as grain size, particle shape, bedding thickness, grain composition, grain-matrix ratios, color, etc.) that will overlap with the physical properties of sedimentary materials, both lithified and unlithified. This overlap will be especially obvious between surficial materials that are water-laid and unlithified sediment that is water-laid: the two are one and the same, are they not? And that is the source of the apparent overlap;

(5) Should both the surficial team and the sedimentary team independently create classification schemes for (a) unlithified sand bodies that form bars on the Platte braided-river plain or (b) unlithified sand bodies in coastal chenier plains or (c) unlithified oolitic shoals in the Bahamas or (d) unlithified mudrock and channelized sand bodies in the Mississippi River delta?

(6) My answer to question (5) is “no”. I expect that the surficial team will view those specific examples as surficial materials that could be classified and named and mapped as (a) alluvium, braid-plain type or (b) paralic deposits, chenier-plain type or (c) marine surficial deposits, carbonate, oolitic-shoal type or (d) alluvial deposits, deltaic (to name some hypothetical possibilities);

(7) I believe that the physical properties of unlithified deposits and the *naming of specific sediment types they contain*, are the purview of the sedimentary team. This is the position the BGS takes, I believe;

(8) Thus, for points (5) and (6): (a) alluvium, braid-plain type, may consist of medium-bedded, texturally massive to flat-laminated, moderately sorted, medium- to coarse-

grained quartzofeldspathic lithic sand, while (b) paralic deposits may consist of crudely bedded flat-laminated to trough-laminated, well-sorted, fine- to medium-grained quartz arenite sand while (c) marine surficial deposits, carbonate, oolitic-shoal type may consist of.......etc.;

(9) I think the tasks of the two teams will be clarified if we adopt the following:

- the surficial team is classifying deposit types that can be used as map units, and that also may occur within map units, but are not specific lithologies or petrographic sediment names
- the sedimentary team is classifying rock types that occur as specific lithologies in outcrops and in map units
- the sedimentary team will develop much of the classification and description nomenclature for specific rock types, but they must do so in partnership with the surficial team so that cross-pollination occurs

(10) The distinction between “consolidated” and “unconsolidated” or between “lithified” and “unlithified” is going to be a vexing issue, irrespective of the issues raised in the preceding nine points. I will not venture into this now.

Please ruminate over the ideas in this note. If we are not on the same page on this one, we could get into trouble. I am just thinking out loud, so give it your own treatment.

Adios, Jonathan

13 APPENDIX 6

Memorandum from SLTT Chair (Matti) to SLTT committee members (3/14/2001)

SLTT colleagues: 03/14/2001

Recent discussion within some of the subgroups indicates the need to restate and clarify the purpose of our SLTT goals and the nature of our classification activities. Please read this memo carefully and at your earliest convenience. If any of you has major reservations, concerns, or disagreements about these objectives, please raise them to all of us now.

By separate mailing, I am sending a copy of this memo to the North American Data Model Steering Committee, whose members also are asked to comment and evaluate the statements.

(1) Databases versus geologic-maps: *Our purpose is to develop classification structures for digital geologic-map databases*, not for digital versions of geologic maps. The production of a geologic-map plot is incidental to the database, and is not the primary focus of the language that the SLTT is developing.

The difference in tone here is important: the hierarchical structure, number of rock classes, and other aspects of our language schema should be tailored to storing and searching science concepts in a digital database, not tailored to the requirements of database fields in a particular data model or tailored to the text in a geologic-map legend.

(2) Language for new data *versus* language for compilation: While the compilation of pre-existing geologic mapping obviously is part of a geologist's activities, the SLTT's primary driver is to develop schema that *facilitate the classification and communication of new field information*. We must look into the future toward novel ways of organizing new data, not into the past to find ways of facilitating the compilation of old data. The former will benefit the latter in obvious ways.

Map compilation (the collation, evaluation, interpretation, and translation of geologic-map information contained in products produced by other workers) is a necessary and legitimate goal. However, the creation of science language that supports geologic-map compilation is not the SLTT purpose.

(3) Do we need to accommodate pre-existing science language?: Compilation of pre-existing geologic-map information requires the geologist to deal with a wide array of lithologic names and descriptors that have come down through the generations. Should the SLTT classification schema create a place for these terms, or define equivalencies for them?

No. *Our task is to create a single uniform, coherent classification that logically, objectively, and thoughtfully establishes rock names and descriptors that classify geologic materials accurately and comprehensively according to modern usage*. We are not obliged to create a list of synonyms or equivalencies. We are not necessarily required to make a place for previous usage, no matter how entrenched that usage might be.

For the compilation of pre-existing map information, it is (and always should be) the responsibility of the map compiler to interpret what a published geologic map contains, and to place this information in the context of modern rock classifications. This is why geologists (who have the training and expertise to make geologic judgments) should be map compilers. The SLTT classification schema will be *the* modern standard for geologic-map database attributes. *It will be the responsibility of future map compilers to interpret the nomenclature of pre-existing geologic-map information for its position in the SLTT schema, not the responsibility of the SLTT to accommodate all previous language.* Pre-existing language should be treated either in feature-level metadata or dataset metadata: this will create a paper trail for original usage, but will not burden the SLTT schema with the diverse nomenclature of the past.

(4) Language for data producer *versus* end user: *The lithologic classification schema we are developing are NOT for the end user, but for the geologist who is collecting attribute data and populating a database with the attributes*. The production of derivative databases and map plots that serve end users is not the SLTT concern.

Does this mean that the SLTT is not mindful of end-users? Nope. Each of the four subgroups is working hard to develop science language that will form a foundation for users of all kinds—from technical to non-technical. But the SLTT focus needs to be geologist-directed in order for the multiple-user base to be served.

We all are interested in and concerned about how end users access and use geologic-map information. However, I strongly believe that the proper focus of end-user facilitation should be the design of an appropriate user-interface. It will be the job of (a) the SLTT, (b) the data-model design team, and (c) a user-interface team (currently not designated) to design an appropriate tool-set to take the concepts and language designed by the SLTT and make them user-friendly.

(5) Hand-sample language *versus* map-unit language: *The SLTT mandate is to provide classification schema for individual rock types that occur in geologic-map units, together with language that describes the physical appearance, composition, and genesis of these rock types*. The science language must focus on hand-sample and outcrop-scale attributes, but should include rock names and fabric relations that derive from thin-section observations as well as language for sequencing and stratigraphic relations at the map-unit scale.

(6) How comprehensive or finite should our classification schema be? *Our science language should reflect the realities of geology, not the requirements of end users*. However, the geologic universe is complex, so should the classification schema be complex and opaque? Nope. And that is the challenge: to represent rock names and rock structures within families that bring order to the complexity.

In a note to the metamorphic subgroup, Bruce Johnson correctly pointed out that " if the classification is hierarchical, and the first and second levels of the hierarchy are limited to a small number of classes, then it becomes possible to render the map by ignoring lower levels". Bruce's concern here is that the plethora of detail that we could create in our classification schema should not bar the database user from perceiving the major high-level relationships among geologic elements. I agree completely. However, if logically structured, then the number of classes or branches or levels of the hierarchy will not matter.

In my opinion, the user interface will be THE critical device for sorting through the database from higher (general) levels to lower (detailed) levels to accommodate user needs.

(7) Do we need flow charts and glossaries?: To the extent that we must define control terms and root names, etc., then to that extent we are defining a glossary of terms. One strength of the British Geological Survey Rock Classification schemes is the

decision-making pathways (flowcharts) that the schemes establish for the use of data producer and data-compiler (and ultimately, from an interface point of view, the data user). A decision-support mechanism is a natural fallout of control terms: the terms must have definitions, and a decision process must be executed in order for a control term to be used or not used by the geologist and end-user. A flow chart is a logical device for displaying the decision-support process.

Let me end by sharing what I am discovering while working with the sedimentary subgroup. In my opinion, we need hierarchical classification schema that allow the geologist to go as deep into the data-attribution process as possible—without getting painted into a corner. The BGS sedimentary classification scheme doesn't have a lot of wiggle room in it. For example, feldspar-rich sedimentary rocks are termed "feldspathic arenites" as defined by Pettijohn. End of statement. End of choices. I personally would be more comfortable if an intermediate level existed that gave the geologist (and the end user) more generic terms like "feldspar-rich" or "lithic-rich", *before* requiring the geologist (and the end user) to commit to the name "feldspathic arenite". This would allow me to classify a rock in the field as a "feldspar-rich sandstone" based on hand-lens observation, and I could stick with this name if I never obtained modal data that would allow me to document the rock as a feldspathic arenite (*sensu* Pettijohn). My audience can get a lot out of the term "feldspar-rich sandstone", even though I haven't tagged the rock as a "feldspathic arenite" *sensu strictu*.

In other words, common sense needs to drive our process—and I ask that you work with each other to find this common sense. A purely academic approach to rock classification and description is not going to do us any good. Even though I minimized the role of the end-user as a target for our deliberations, none-the-less both the field geologist and the land-use manager need a classification that allows each to (a) classify a rock in as much detail as desirable and (b) search the forest before searching out individual trees.

In other words, we do not have an easy job.

Adios, Jonathan