Leveraging International Earth Science Standards to Enhance Mineral Exploration Success in British Columbia

Seeking the Efficiencies of Order

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Adherence to standards by disparate groups compiling information for a common good has been a controversial subject for centuries. However, in the computer age, it has assumed greater importance, and it is easier to demonstrate the high cost of ignoring available standards. The computer age also makes it easier for us to work with multiple standards alongside each other, if agreement cannot be reached on which standard to adopt. This proposal makes the case for introducing the use of international earth science standards to minerals exploration in British Columbia.
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1. Introduction

Adherence to standards by disparate groups compiling information for a common good has been a controversial subject for centuries. However, in the computer age, it has assumed greater importance, and it is easier to demonstrate the high cost of ignoring available standards. The computer age also makes it easier for us to work with multiple standards alongside each other, if agreement cannot be reached on which standard to adopt.

This report, and its associated web pages\(^1\), introduces the use of international earth science standards\(^2\) to minerals exploration in British Columbia.

The report provides a mapping to the internationally-recognised GeoSciML Earth Material Taxonomy\(^3\) of three non-standard rock nomenclature taxonomies broadly used by the BC Geological Survey. In so doing, it sets the stage for:

(i) The development of computer-based mediators enabling real-time, on-screen interoperation of the databases during exploration research, and for
(ii) The compilation of future data sets according to the international terminological standards\(^4\).

Embedding these standards into BC Survey databases will materially improve the science of minerals exploration in British Columbia, and can be expected to have impact at mineral claim, provincial, regional, national and international scales, as elegantly depicted in the US government’s web portal promoting a similar approach to standardisation shown in Figure 1 below.

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\(^1\) See: \url{http://similar2.com/RockClassifications/}

\(^2\) See Appendix E for a presentation on current international support for earth science standards.

\(^3\) See Appendix A for descriptions of the meanings of the words “term”, “taxonomy”, “ontology” and “language”.

\(^4\) See Appendix B for a presentation on the importance of terminology to exploration geochemistry and geophysics.
2. Problem Statement: Terminology in Minerals Exploration is not Standardised

Minerals exploration is a multi-disciplinary science requiring, to be cost-effective, the integration of geology, geochemistry, geophysics, remote sensing, and a number of other disciplines.

As geologists have become more dependent on computers for managing and integrating the very large volumes of data collected in each of these disciplines, they have become aware of the costly inefficiencies caused by the proliferation of non-standard terms within their exploration databases, and within institutional databases critical to their work – for example, geological maps published by, and mineral occurrence databases maintained by, geological surveys.

These problems were manageable, to some degree, when integration of disparate data sets was mediated through a human being (such as a geologist or a GIS technician). “Interoperation” between the data sets was made possible by the human being working out, usually at considerable cost, the relationships between the different terms used by each data set to be co-interpreted, and by then taking appropriate “transformational” action (transforming one data set’s vocabulary to match the other’s).

This “human mediation” between data sets has become more and more inefficient as data sets have grown in size and complexity – to the extent that it is now broadly recognised that computers should be used to carry out this mediating function. Brodaric (2010) has presented how this is being addressed by the Canadian Groundwater Information Network (GIN)\(^5\). Figure 2 overleaf illustrates the three-layered architecture of GIN, drawing data at the lowest level synchronously from online data sources in different jurisdictions. Figure 3 overleaf shows the location of the computer mediator in such an architecture.

The key element to mediating between disparate data sets is to first gain a full understanding of each term used in each data set so that mappings between the terms may be drawn. A problem with this approach, however, is that in dealing with N disparate data sets, there are \((N \times N)/2\) terminological mappings to attend to.

An alternative “standards-driven” approach is to compile a single standard set of terms for each category of terms used by the databases in each discipline, and to use that set of terms when integrating data sets of disparate origins – an approach which results in only N-1 terminological mappings having to be undertaken. This approach also depends on the standard sets of terms being adequate for most user applications. Exploration geologists may need terms not required by groundwater geologists.

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Figure 2: The three-layered architecture of the GSC’s Groundwater Information Network.

Figure 3: The location of mediators and ontologies in the architecture of interoperable internet mapping systems.
If the standard set of terms developed for these mediation purposes is sufficiently broad and well-defined, it lends itself to adoption during future data gathering exercises, greatly facilitating the interoperation of the resulting new data sets with other data sets adhering to the same standard, and consequently greatly enhancing the quality of work which can be carried out with the data.

As discussed below, a number of institutional data sets very important to minerals exploration in British Columbia are not currently interoperable without costly and error-prone human mediation because of their incorporation of non-standardised vocabularies.

In a nutshell, then, a problem facing minerals exploration in BC, and elsewhere is: “Given that the practice of minerals exploration requires the integration of disparate data sets, and given that, for this integration to be successful, the data sets have to reference the same vocabularies, how do we achieve this integration when different vocabularies were used, and are still being used, to compile the data sets?”

In other words: “How do we make our different databases interoperable?”

3. The GeoSciML and ERML Vocabulary Standards

GeoSciML is a model for the exchange of geoscience information which has been developed by the international geosciences community, in particular Geological Survey Organisations.

EarthResourceML (ERML) is a data-exchange model that describes Earth Resources independent of associated human activities, permitting descriptions using internationally recognised minerals deposit classifications, mineral systems and processes. EarthResourceML was developed by the Australian Chief Government Geologists Committee (CCGC) but is now under the governance of the Commission for Geoscience Information (CGI), a commission of the International Union of Geological Sciences (IUGS).

Both models are summarised below, and described in greater detail in Appendices C and D respectively.

3.1. GeoSciML

GeoSciML\(^6\) or Geoscience Markup Language is a GML\(^7\) Application Schema (Figure 4) that can be used to transfer information about geology, with an emphasis on the “interpreted geology” that is conventionally portrayed on geologic maps. Its feature-type catalogue includes Geologic Unit, Mapped Feature, Earth Material, Geologic Structure, and specializations of these, as well as Borehole and other observational artifacts.

It was created by, and is governed by, the Commission for the Management and Application of Geoscience Information (CGI\(^8\)) to support interoperability of information served from Geologic Surveys and other data custodians. It is being used in the OneGeology Project (see Appendix E).

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\(^7\) [http://www.opengeospatial.org/standards/gml](http://www.opengeospatial.org/standards/gml)

\(^8\) [http://www.cgi-iugs.org/](http://www.cgi-iugs.org/)
The GeoSciML organisation includes a Concept Working Group\(^9\) which is currently working on Version 3 of the following terminology standards, the “Simple Lithology” standard of which is dealt with in this report:

<table>
<thead>
<tr>
<th>Alteration Type</th>
<th>Genetic Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition Category</td>
<td>Geologic Unit Morphology</td>
</tr>
<tr>
<td>Compound Material Constituent Part Role</td>
<td>Geologic Unit Part Role</td>
</tr>
<tr>
<td>Consolidation Degree</td>
<td>Geologic Unit Type</td>
</tr>
<tr>
<td>Contact Character</td>
<td>Lineation Type</td>
</tr>
<tr>
<td>Contact Type</td>
<td>Mapped Feature Observation Method</td>
</tr>
<tr>
<td>Convention Code</td>
<td>Metamorphic Facies</td>
</tr>
<tr>
<td>Description Purpose</td>
<td>Metamorphic Grade</td>
</tr>
<tr>
<td>Determination Method_orientation</td>
<td>Particle Aspect Ratio</td>
</tr>
<tr>
<td>Event Environment</td>
<td>Particle Shape</td>
</tr>
<tr>
<td>Event Process</td>
<td>Particle Type</td>
</tr>
<tr>
<td>Fault Movement Sense</td>
<td>Proportion Term</td>
</tr>
</tbody>
</table>

---


Earth Science Standards for Minerals Exploration in British Columbia

<table>
<thead>
<tr>
<th>Fault Movement Type</th>
<th>Simple Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Type</td>
<td>Stratigraphic Rank</td>
</tr>
<tr>
<td>Feature Observation Method</td>
<td>Value Qualifier</td>
</tr>
<tr>
<td>Foliation Type</td>
<td>Vocabulary Relation</td>
</tr>
</tbody>
</table>

Table 1: Listing of terminology standards developed for GeoSciML.

GeoSciML is described in further detail in Appendix C.

3.2. EarthResourceML

The Australian Chief Government Geologists Committee (CGGC) has developed the EarthResourceML Data Exchange Model\(^1\) (and\(^2\)). This has been developed collaboratively under the leadership of the Australian Government Geoscience Information Policy Advisory Committee as an extension of the geoscience exchange standard (GeoSciML). This data model with standard vocabularies is designed to deliver mineral data in a consistent format to appropriate web portals, such as the AuScope Discovery Portal (http://portal.auscope.org/gmap.html), and facilitate transfer of the most recent data between government, industry and other organisations. The model describes Earth Resources independent of associated human activities, permitting description using mineral deposit models encompassing internationally recognised deposit classifications, mineral systems and processes. It also provides the ability to describe commodity resources formally or informally utilising international reporting standards including basic JORC requirements (the 2004 Australasian code for reporting exploration results, mineral resources and ore reserves).

EarthResourceML is currently the only standard under evaluation by INSPIRE for adoption as its “Mineral Deposits” description standard\(^3\) and is appropriate for adoption in Canada as well.

EarthResourceML (ERML) and INSPIRE are described in further detail in Appendices D and E respectively.

3.3. Exploring the GeoSciML “Simple Lithology” Terminology Standard

Although no single document has yet been written to describe this standard, the history of its development may be traced by visiting the web pages of the group which developed it:

https://www.seegrid.csiro.au/wiki/CGIModel/LithologyCategories and


The standard constitutes a taxonomy of “earth materials”, which is best understood by being “explored”.

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\(^1\) https://www.seegrid.csiro.au/wiki/CGIModel/EarthResourceML


The following are five ways to explore the taxonomy, each with its own advantages and disadvantages:

(a) Online on a simple web page which allows clicking through the taxonomy, and displays definitions of each term, together with its key attribute values, which is available here:

(b) Offline, by reading the Excel spreadsheet within which its primary development took place, which includes provenance information about many of the terms used. The spreadsheet is available here:

(c) Online at the BRGM Vocabulary Service, available at this URL:
http://srvgeosciml.brgm.fr/eXist2010/brgm/client.html

(d) Online within ACE (Aristotelian Class Explorer), a taxonomy exploration tool, available here:
http://www.similar2.com:8080/ACE-Editor/?ontology=http://similar2.com/ontologies/earthmaterials201001d.owl

(e) Offline, using the TLE taxonomy development application (www.georeferenceonline.com/tle/) to explore a download of the taxonomy from
http://similar2.com/RockClassifications/data/RocksGeoSciML.zip


There are at least five areas in which GeoSciML nomenclature standards can immediately be used to benefit minerals exploration in British Columbia:

(1) Geological mapping of BC
(2) Description of mineral occurrences in BC
(3) Documentation of physical rock properties in BC (to aid interpretation of geophysical surveys)
(4) Descriptions of models of mineral deposits that occur in BC
(5) Statutory (and non-statutory) reporting of mineral exploration work carried out in BC

Each of these will be addressed in the following sections.

4.1. Geological Maps

For reasons discussed in Section 2 above, it would be to the advantage of all explorers in BC if descriptions of the rock units on all geological maps of BC were available using the GeoSciML "Simple Lithology" standard.

The “foundation reference” geological map of British Columbia (the BC Geology Map) was under revision when the work presented in this report was undertaken, and was available for download. It was

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14 Online access to these reference URLs, and many of the other online references cited in this report, is available on this web page: http://similar2.com/RockClassifications/Default.htm
15 http://www.empr.gov.bc.ca/MINING/GEOSCIENCE/BEROCKMAPPING/Pages/BCGeoMap.aspx
16 Online access to this reference, and many of the other online references cited in this report, is available on this web page, organised according to the sections of this report: http://similar2.com/RockClassifications/Default.htm
called “Draft BCGeologyMap2010 with QUEST Area Update (version 0.1)” and was used as the source of the bedrock mapping vocabulary discussed in this report. It is described as follows:

“This 2010 draft release represents a pilot project to integrate the QUEST compilation into the 2005 edition of the BC Digital Geology Map (Geoscience Map 2005-3). The new digital files are from Geoscience Map 2010-1, Bedrock Geology of the QUEST map area, central British Columbia (also Geoscience BC Report 2010-5, Geological Survey of Canada Open File 6476). The BCGeologyMap: QUEST Area Update is the interpretive result of previous bedrock geology, new mapping, surficial geology, and geophysical and geochemical results. The draft of the BCGeologyMap is the starting point to streamline integration of past and future geological mapping results into the provincial database. A future release will include enhanced metadata, cleanup of line work due to projections issues, the integration process methodology, and update on MapPlace.”

Documentation of this map is scattered across a number of publications and web pages.

Of most immediate relevance to this study is the documentation of the map legend, and, in particular, aspects of the legend dealing with the type of bedrock found within the polygons on the map.

In this regard, the BC Geology Map would appear to use the same lithology legend as that used by, and distributed with, Geoscience Map 2005-2 (the GIS version of the meant-for-print pdf Geoscience Map 2005-3 mentioned above).

This lithology legend must be understood at three levels:

1. Understanding which layer of polygons is being described;
2. Understanding the attributes (fields) described for each polygon in the layer;
3. Understanding the values used for each attribute described

The BC Geology Map polygon layer containing lithological information is named “BC Geology”, and the “explanation of attribute fields” presented in Table 2 below is provided in the documentation of this layer.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>Polygon area in square metres.</td>
</tr>
<tr>
<td>PERIMETER</td>
<td>Polygon perimeter in metres.</td>
</tr>
<tr>
<td>KEYCODE</td>
<td>Original geological tag; derived from the Mineral Potential geological compilations; also includes new tags assigned during this compilation in updated areas.</td>
</tr>
<tr>
<td>TECUNIT</td>
<td>Tectonic assemblage code; derived from GSC Map 1712A and Journeay &amp; Williams (1995) with slight modifications. Codes used are listed in BC_Tecunit.xls.</td>
</tr>
<tr>
<td>STRAT_UNIT</td>
<td>Recommended stratigraphic tag. This is in standard geological unit label format, comprising various elements including the age, stratigraphic name (Group and/or Formation) and lithology. Age and stratigraphic codes are listed in BC_Stratcode_Components.xls; lithological codes are listed in BC_Lithology.xls.</td>
</tr>
</tbody>
</table>

17 A new, 2013, release of the BC Geology Map is now available from: http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2013/Pages/2013-4.aspx
18 No documentation could be found suggesting that the legend has been changed, although the context is been set for imminent modification of the legend with the words describing this map as “… the starting point to streamline integration of past and future geological mapping results into the provincial database.”
Table 2: Listing of attribute fields associated with BC_Geology layer polygons in the BC Geology Map. ROCK_TYPE and ROCK_CLASS fields, of immediate relevance to this study, are entered in bold.
The attribute fields of relevance to this study, as shown in Table 2, are “Rock_Type” and “Rock_Class”, as well as “Original_D”, a description of the rock unit on which the map compiler(s) would have decided to base the Rock Type entry for each polygon. These are discussed in Section 4.1.1 below.

4.1.1. “Rock Types” Currently used in the Geological Map of British Columbia

Some degree of confusion often surrounds the naming of categories used in classification systems, particularly regarding the use of words such as “class”, “type”, “family”, “sub-class”, etcetera.²⁰

The BC Geology Map rock classification system recognises only two levels, a “Rock Class” on the upper level, and “Rock Types” on a level below Rock Classes.

The complete (very short) list of “Rock Class” values used in the BC Geology Map is presented in Table 3 below.

### Table 3: "Rock Classes" recognised by the BC Geological Map.

<table>
<thead>
<tr>
<th>Rock Class</th>
<th>Rock_Type</th>
<th>Original_D(escription)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusive rocks</td>
<td>tonalite intrusive rocks</td>
<td>Tonalite: rectangular plagioclase phenocrysts, unfoliated.</td>
</tr>
<tr>
<td>Volcanic rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metamorphic rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedimentary rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultramafic rocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Examples of relationships between “Rock Classes” and their subordinate “Rock Types” are shown in Table 4 below, which includes polygon unit descriptions which have been matched with these classes and types.

A complete list of all “Rock Type” values used in the BC Geology Map is presented in Table 5 in the next section (Section 4.1.2) with their closest GeoSciML term.

²⁰ Our preference is to use the same word, be it “class” or “type” or any other appropriate word, for all levels of a classification hierarchy, unless it is a very mature classification with very broad acceptance of particular words for particular levels in the classification (such as “species” in a biological classification).

²¹ A case can be made for a third level if single-word rock names such as “Trondhjemite” and “Blueschist” which appear in the Original_D attribute field are recognised as a classification level below the rock categories represented in the “Rock Type” attribute field.

²² Note that “intrusive rocks”, “metamorphic rocks” and “volcanic rocks” do not have close equivalents in single GeoSciML terms – presenting a significant problem to workers wishing to map to the current GeoSciML standard.
<table>
<thead>
<tr>
<th></th>
<th>metamorphic rocks</th>
<th>calcsilicate metamorphic rocks</th>
<th>Original Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>blueschist</td>
<td>Bluesth facies: glaucophane schist, metabasalt, dolostone, listwanite, metachert, limestone</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>metamorphic rocks</td>
<td>calc-silicate metamorphic rocks</td>
<td>Amphibolite, calc-silicate and minor marble</td>
</tr>
<tr>
<td>8</td>
<td>metamorphic rocks</td>
<td>calc-silicate metamorphic rocks</td>
<td>Calcisilicate gneiss</td>
</tr>
<tr>
<td>9</td>
<td>calc-silicate metamorphic rocks</td>
<td>Calc-silicate gneiss, amphibolite, carbonatite, marble;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>calc-silicate metamorphic rocks</td>
<td>Marble, calc-silicate rock, possible metamorphic equivalent of Pts and PMGm.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>calc-silicate metamorphic rocks</td>
<td>Skarn</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>calc-silicate metamorphic rocks</td>
<td>Varially schistose epidote-actinolite-quartz and garnet-epidote skarn; lesser amounts of chloritic schist and sericite-quartz shist (Sicamous Formation includes units EBL and EBK of the Eagle Bay assemblage)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>eclogite/mantle tectonite</td>
<td>Cassiar-Quartzrock Creek Ultramafite: serpentinite, harzburgite tectonite, pyroxenite, gabbro.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>eclogite/mantle tectonite</td>
<td>Ultramafites of upper mantle origin: tectonized harzburgite, dunite, wehrlite (included with unit CPu where undivided).</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>eclogite/mantle tectonite</td>
<td>Zus Mountain-Blue River Ultramafite: dunite, harzburgite tectonite, serpentinite, pyroxenite.</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>greenstone, greenschist metamorphic rocks</td>
<td>Actinolite-chlorite schist and gneiss (metabasite), locally chlorite more abundant, lesser epidote.</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>greenstone, greenschist metamorphic rocks</td>
<td>amphibolite; minor siliceous mylonite</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4: Example relationships between “Rock Class”, “Rock Type” and “Original Description” field values in the BC Geological Map.**

Examination of the values in all three of the columns in Table 4, “Rock Class”, “Rock Type” and “Description” makes clear that none of them is very appropriate for efficient, direct production of an accurate, useful lithological map of British Columbia, for the following reasons:

(a) “Rock Class”, with only 5 possible values, is too general for most purposes;
(b) “Rock Type” includes combinations of different rock types (example in Table 5: “limestone, slate, siltstone, argillite”) which indicate that the compiler was thinking rather of rock units (See Section 4.1.1.1 below) than of rock types;
(c) “Rock Type” includes a number of errors (examples in Table 5: Both quartzite and marble are classified as sedimentary and not as metamorphic rocks);
(d) “Descriptions” are classified under only one “Rock Type” (presumably under the dominant type, although this relationship is corrupt in many cases because “Rock Type” itself may include more than one lithology), when the polygons they are describing may have more than one very different kind of rock (Example: Row 6 in Table 4, classified as “blueschist”, whose description also mentions “metabasalt and limestone”).

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4.1.1.1. Managing Rock Units

It is clear to the reader that the *BC Geology Map* “Description” field is, in reality, describing a rock unit, or, in GeoSciML terminology, a number of earth materials that occur within a particular polygon (mapped area) which may not have the status of a geological unit.

In GeoSciML, such polygons which contain more than one kind of earth material can be managed modeled either as a “GeologicalUnit”, or, more simply, as a “CompoundMaterial”. A GeologicalUnit may be made up of a single earth material (eg: granite, or sand), or, in the case of more than one earth material, of a “CompoundMaterial”. A “CompoundMaterial” can have each of the earth materials out of which it is constituted specified, together with their proportions. [For clarity, it is worth stating that a “Geological Unit” may have a “CompoundMaterial” as a constituent, but, by the rules of the GeoSciML model, a “CompoundMaterial” may not be composed of a “GeologicalUnit”.]

While further treatment of this subject is beyond the scope of this study, it is important to note that the ultimate objective of serving the *BC Geology Map* according to the WFS standard would be to serve “GeologicalUnit” and/or “CompositeMaterial” descriptions of mapped polygons using the GeoSciML EarthMaterial terminology standards which are the focus of this study.

Only once the “EarthMaterials” within the mapped polygons of the *BC Geology Map* are (a) described with “controlled vocabularies” and (b) served via WFS (c) according to GeoSciML standards, will they be truly interoperable, and therefore most useful to their users.

### 4.1.2. BC Geological Map Rock Types mapped to GeoSciML Earth Materials Vocabulary

Table 5 below lists all the “Rock_Types” used in the BC Geology Map alongside their closest equivalent in the GeoSciML “Earth Material” concept list (but see also Footnote 22 on page 13).

<table>
<thead>
<tr>
<th>BC Geology Map “Rock Types”</th>
<th>Code</th>
<th>GeoSciML “Earth Material” Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>intrusive rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diabase, basaltic intrusive rocks</td>
<td>db</td>
<td>Doleritic rock</td>
</tr>
<tr>
<td>diorite intrusive rocks</td>
<td>dr</td>
<td>Diorite</td>
</tr>
<tr>
<td>feldspar porphyritic intrusive rocks</td>
<td>fp</td>
<td>Porphyry</td>
</tr>
<tr>
<td>gabbroic to dioritic intrusive rocks</td>
<td>gb</td>
<td>Gabbro</td>
</tr>
<tr>
<td>granite, alkali feldspar granite intrusive rocks</td>
<td>g</td>
<td>Granite</td>
</tr>
<tr>
<td>granodioritic intrusive rocks</td>
<td>gd</td>
<td>Granodiorite</td>
</tr>
<tr>
<td>high level quartzphyric, felsitic intrusive rocks</td>
<td>qp</td>
<td>Acidic igneous rock</td>
</tr>
<tr>
<td>intrusive rocks, undivided</td>
<td>g</td>
<td>Intrusive rock</td>
</tr>
<tr>
<td>migmatitic metamorphic rocks</td>
<td>mi</td>
<td>Migmatite</td>
</tr>
<tr>
<td>monzodioritic to gabbroic intrusive rocks</td>
<td>dg</td>
<td>Monzodioritic rock</td>
</tr>
<tr>
<td>pegmatitic intrusive rocks</td>
<td>pe</td>
<td>Pegmatite</td>
</tr>
<tr>
<td>quartz dioritic intrusive rocks</td>
<td>qd</td>
<td>Quartz Diorite</td>
</tr>
<tr>
<td>quartz monzonitic to monzogranitic intrusive rocks</td>
<td>qm</td>
<td>Quartz monzonite</td>
</tr>
<tr>
<td>syenitic to monzonitic intrusive rocks</td>
<td>sy</td>
<td>Syenitic rock</td>
</tr>
</tbody>
</table>

www.georeferenceonline.com
<table>
<thead>
<tr>
<th>Rock Class</th>
<th>EarthMaterial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonalite intrusive rocks</td>
<td>Tonalite</td>
</tr>
<tr>
<td>metamorphic rocks</td>
<td>Glaucophane lawsonite epidote metamorphic rock</td>
</tr>
<tr>
<td>blueschist metamorphic rocks</td>
<td>Metamorphic rock</td>
</tr>
<tr>
<td>calcisilicate metamorphic rocks</td>
<td>Eclogite</td>
</tr>
<tr>
<td>eclogite/mantle tectonite</td>
<td>Chlorite actinolite epidote metamorphic rock</td>
</tr>
<tr>
<td>greenstone, greenschist metamorphic rocks</td>
<td>Fault-related material</td>
</tr>
<tr>
<td>imbricate zone</td>
<td>Amphibolite</td>
</tr>
<tr>
<td>lower amphibolite/kyanite grade metamorphic rocks</td>
<td>Metamorphic rock</td>
</tr>
<tr>
<td>metamorphic rocks, undivided</td>
<td>Metamorphic rock</td>
</tr>
<tr>
<td>metasediments</td>
<td>Metamorphic rock</td>
</tr>
<tr>
<td>mid amphibolite/andalusite grade metamorphic rocks</td>
<td>Amphibolite</td>
</tr>
<tr>
<td>mylonitic metamorphic rocks</td>
<td>Mylonitic rock</td>
</tr>
<tr>
<td>orthogneiss metamorphic rocks</td>
<td>Orthogneiss</td>
</tr>
<tr>
<td>paragneiss metamorphic rocks</td>
<td>Paragneiss</td>
</tr>
<tr>
<td>serpentinite ultramafic rocks</td>
<td>Serpentinite</td>
</tr>
<tr>
<td>sedimentary rocks</td>
<td>Sedimentary rock</td>
</tr>
<tr>
<td>argillite, greywacke, wacke, conglomerate turbidites</td>
<td>Wacke</td>
</tr>
<tr>
<td>chert, siliceous argillite, siliciclastic rocks</td>
<td>Chemical sedimentary material</td>
</tr>
<tr>
<td>coarse clastic sedimentary rocks</td>
<td>Clastic sedimentary rock</td>
</tr>
<tr>
<td>conglomerate, coarse clastic sedimentary rocks</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>dolomitic carbonate rocks</td>
<td>Carbonate sedimentary rock</td>
</tr>
<tr>
<td>evaporite</td>
<td>Evaporite</td>
</tr>
<tr>
<td>limestone bioherm/reef</td>
<td>Limestone</td>
</tr>
<tr>
<td>limestone, marble, calcareous sedimentary rocks</td>
<td>Impure limestone</td>
</tr>
<tr>
<td>limestone, slate, siltstone, argillite</td>
<td>Impure limestone</td>
</tr>
<tr>
<td>marine sedimentary and volcanic rocks</td>
<td>Rock</td>
</tr>
<tr>
<td>mudstone, silstone, shale fine clastic sedimentary rocks</td>
<td>Mudstone</td>
</tr>
<tr>
<td>mudstone/laminitie fine clastic sedimentary rocks</td>
<td>Mudstone</td>
</tr>
<tr>
<td>quartzite, quartz arenite sedimentary rocks</td>
<td>Quartzite</td>
</tr>
<tr>
<td>undivided sedimentary rocks</td>
<td>Sedimentary rock</td>
</tr>
<tr>
<td>ultramafic rocks</td>
<td>Rocks</td>
</tr>
<tr>
<td>volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>alkaline volcanic rocks</td>
<td>Andesite</td>
</tr>
<tr>
<td>andesitic volcanic rocks</td>
<td>Basalt</td>
</tr>
<tr>
<td>basaltic volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>bimodal volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>calc-alkaline volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>coarse volcaniclastic and pyroclastic volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>dacitic volcanic rocks</td>
<td>Dacite</td>
</tr>
<tr>
<td>rhyolite, felsic volcanic rocks</td>
<td>Rhyolite</td>
</tr>
<tr>
<td>trachytic volcanic rocks</td>
<td>Trachyte</td>
</tr>
<tr>
<td>undivided volcanic rocks</td>
<td>Fine grained igneous rock</td>
</tr>
<tr>
<td>volcaniclastic rocks</td>
<td>Pyroclastic rock</td>
</tr>
</tbody>
</table>

Table 5: Mapping of BC Geology Map "Rock_Type" terms and "Rock_Codes" to their closest GeoSciML "EarthMaterial" equivalents.

An attribute field named “GEOSCIMLRT” has been added to the BC Geology Map (discussed in Section 4.1 above) to carry these values, which can be accessed via the WFS service described in Section 4.1.4 below,
using WFS-compatible GIS systems such as MapInfo and ArcMap. Section 4.1.4 also discusses the production of legends for the GEOSCIMLRT attribute.


Geological surveys and similar institutions that wish to contribute to the OneGeology initiative\(^{23}\) at Level 1 aim to provide an OGC Web Mapping Service (WMS\(^{24}\)) from a web server within their organisation, or hosted by a neighbouring organisation, of some basic geological maps. Such a service, serving the BC Geology Map “ROCK CODE” attribute, has been provided as part of this project, and may be accessed using this URL\(^ {25}\) in a WMS-compatible application (such as MapInfo or ArcMap or Gaia\(^ {26}\)):

http://www.similar2.com:8060/cgi-bin/BCGS_Bedrock_Geology/wms?

WMS maps, such as that shown in Figure 6 below, will able to appear in any computer user’s WMS-compatible application, being in a raster or “image” form, where it will be combinable with other spatial datasets depending on the application the user is using. If the data that is the source behind the WMS is of digital vector data form with attributes associated with those vectors (e.g. information attached to a particular polygon or boundary) then the WMS will allow the display of such attributes for each polygon, as shown in Figure 5. If the data source behind the WMS is of a simple scanned raster type e.g. scanned from a paper map and served as a raster image, then such attributes or further information do not exist for separate polygons.

Figure 5: BC Geology Map polygons delivered by WMS to Gaia desktop application, colour-coded by “Rock Code”.

\(^{23}\) Or achieve goals similar to those of the OneGeology initiative, as discussed in Section 2 above.

\(^{24}\) [http://www.opengeospatial.org/standards/wms](http://www.opengeospatial.org/standards/wms)

\(^{25}\) Note: Pointing a browser at this URL will not yield the map, as this URL is designed to return information to a WMS-compatible application about the map which can be provided from the server.

Generation and provision of legends is a complex subject for complex data sets such as maps of lithology types. The WMS service does not make it possible\footnote{Without specific code being written for this purpose and embedded in a particular WMS application for legend manipulation. By contrast, WFS allows, by default, the consuming application to generate and customise legends, as shown in Figure X below.} for the user/viewer of a layer to control the layer’s legend (but the WFS service does – see Section 4.1.4 below). The legend has to be generated by the service provider, and made available to the user at a different URL. The legend for the BC Geology Map “ROCK CODE” is shown in Figure 6 and is available at this URL:

\url{http://similar2.com:8060/cgi-bin/BCGS_Bedrock_Geology/wms?SERVICE=WMS&Request=getLegendGraphic&sld_version=1.1.0&version=1.3.0&format=image/png&layer=BC_bedrocks_2010_with_GeoSciML_region_ROCKTYPE&}

The meanings of the rock codes shown in Figure 7 may be found in Table 5 above.

![Figure 6: "Rock Code" legend for WMS rendition of the BC Geology Map polygons shown in Figure 5 (decoded in Table 5).](image)

As this rendition of the BC Geology Map has been produced simply to illustrate WMS features, no attention has been given to the relationship between rock codes and the colours used to represent them. This matter is addressed in greater detail in Section 4.1.4 below.

### 4.1.4. GeoSciML-compliant WFS delivery of the Geological Map of BC

The OGC Web Feature Service (WFS\footnote{http://www.opengeospatial.org/standards/wfs}) has the advantage of serving to applications which use it, such as MapInfo and ArcMap, actual vectors and the attributes which describe them. This enables those applications to carry out complex GIS operations on the served data, including the creation of user-customised legends, which are not possible on the raster data served by WMS.
Figure 8 shows MapInfo displaying the legend for the GeoSciML rock type (attribute “GEOSCIMLRT”) of the BC Geology Map which was delivered to the application by WFS, the connection properties for which are also shown in Figure 7.

The URL from which this service is served is:

http://similar2.com:8060/cgi-bin/BCGS_Bedrock_Geology/wfs?

Figure 7: Legend for the GeoSciML rock type (attribute=”GEOSCIMLRT”) of the BC Geology Map which was delivered to the application by WFS.

As with the WMS legend presented in Section 4.1.3 above, attention has not at this time been given to the relationship between the GeoSciML terms used to qualify the map polygons and the colours or symbology used to represent them on the map.

However this is a subject (“attribute portrayal”) receiving considerable attention within the international community, as, once agreement has been reached on standard terms to be used for mapped attributes (such as rock type), seamless integration of maps also requires agreement on portrayal.

At least two colour mappings to GeoSciML rock type terms are currently available, one documented by the OneGeology-Europe project (Appendix F and Table 6 below), and one in use by the GeoSciML Working Group (Appendix G).
### 4.1.5. Standards-Based Access to Historical Geological Maps

To deliver historical maps in the manner advocated in this document, mappings would need to be established between terms used in historical maps and the standard terminology, and these maps could then be made available on the internet interoperable with the standard terminology by using mediators (Figure 3). This would be prohibitively expensive to undertake for all historical maps, but highly cost-beneficial for selected, regularly-used maps.

### 4.1.6. Standardising Future Geological Maps

If the international standard terminology is judged beneficial by the community of BC geological map users, directives could be given that all future maps should be produced with a legend referring to the international standard terminology, possibly with a second legend referencing highly-specialised terms which are not available in the international standard.

### 4.2. MINFILE

MINFILE is the British Columbia government’s mineral inventory system. It contains geological, location and economic information on over 12,900 metallic, industrial mineral and coal mines, deposits and occurrences in the province.

A key parameter characterising mineral occurrences recorded in MINFILE is their host lithology/lithologies. Ensuring that standard terminologies are used in MINFILE would make it fully interoperable with other data sets available in, or mapped onto, these standard terminologies. For reasons discussed in Section 2 above, this would be to the advantage of all explorers in BC.

---

<table>
<thead>
<tr>
<th>GeoSciML/CGI-OneGeology-Europe Term</th>
<th>R</th>
<th>G</th>
<th>B</th>
<th>C</th>
<th>M</th>
<th>Y</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metamorphic Rock</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m1. Anchimetamorphic rock ??</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m1.2 Spilitic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m2 Sedimentary protolith</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m2.1 Quartzite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... Foliated metamorphic rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m3.10 Gneiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m2.5 Paragneiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.4 Mylonitic rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.3 Phyllite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.1 Slate</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m3.1 Serpentinite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m3.2 Porphyrod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... Glaucophane lawsonite epidote metamorphic rock = (Blueschist)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.2.6 Greenschist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.2 Schist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.2.7 Mica schist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.5 Skarn/Hornfels/Granofels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.6 Granulite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.7 Marble</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.8 Amphibolite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m5.9 Eclogite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m6 Migmaitite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m8 Impact Metamorphic rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Example Colour Mappings to GeoSciML Metamorphic Rock Terms (see Appendix F).
4.2.1. Rock Names Currently used in MINFILE
MINFILE permits the use of a great many “root” rock names, together with a large number of qualifiers, combinations of which lead to a bewildering number of different “attribute values” in the “Host Rock” attribute. MINFILE does not provide for a “classification of rocks”, whereby it recognises some rocks as “kinds” of other rocks.

The MINFILE manual describes the procedure for coding of “Host Rock” as follows:

At least one Rock Type/Lithology must be entered for each occurrence. A total of ten different rock types and up to three modifiers for each rock type may be identified for each occurrence. Appendix III is a listing of current rock names and modifiers. This table will be updated periodically as required. The rock types that host the significant mineralization should be listed in their order of importance and should correspond with the Dominant Hostrock category. Other lithologies identified should correspond with the FORMAL and INFORMAL hostrocks.

All rock types plus modifiers identified should be written out in full in the lithology field on the coding card. Care should be taken not to duplicate rock types by using synonyms (e.g., diabase dike and diorite dike). The Rock Type(s)/Lithologies must be included in the Capsule Geology description.

Example:

<table>
<thead>
<tr>
<th>MODIFIER SEARCH CODE(S)</th>
<th>ROCK TYPE SEARCH CODE</th>
<th>ROCK TYPE/LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALKL</td>
<td>BSLT</td>
<td>Alkali Basalt</td>
</tr>
<tr>
<td>QRTZ FLDP</td>
<td>PRPR</td>
<td>Quartz Feldspar Porphyry</td>
</tr>
</tbody>
</table>

The complete list of terms acceptable in the “Host Rock” attribute field in MINFILE can be viewed at this URL:

http://www.empr.gov.bc.ca/Mining/Geoscience/MINFILE/ProductsDownloads/MINFILEDocumentation/CodingManual/Appendices/Pages/III.aspx

4.2.2. MINFILE Rock Names mapped to GeoSciML Earth Materials Vocabulary
Because there are so many rock names used in MINFILE, it is not practical to include a complete mapping of MINFILE rock names to the GeoSciML vocabulary in the text of this report.

The mapping has, however, been completed, and is available for review online, as illustrated in Figure 8 below, at this URL:


In Figure 8, blue is used for lithology names in GeoSciML but not in MINFILE, green for names present in both systems, and red for lithology names present in MINFILE but not in GeoSciML.

Online access to this reference URL, and many of the other online references cited in this report is available on this web page, organised according to the sections of this report: http://similar2.com/RockClassifications/Default.htm

www.georeferenceonline.com
4.3. Physical Rock Properties Database (RPDS)
The Mira Physical Rock Properties Database will be introduced with a number of important extracts from “Rock Property Database System”, Parsons, E. and McGaughey, (2007)\textsuperscript{30}.

“Rock properties represent an important quantitative link between geology and geophysics because geophysical data is responsive only to physical rock properties. Physical property values can be correlated with geological description to characterize the rock property environment of specific ore deposits. Proper characterization of the physical property environment of ore deposits leads directly to significant exploration benefits through improved geophysical survey design, forward modelling, inversion, and interpretation.”

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“The vision of an extensive, authoritative compilation of rock property data that could underpin many avenues of quantitative interpretation is appealing. It has proven to be difficult to achieve in practice due to a number of significant challenges.”

“Data classification is a requirement for any database system in order to facilitate data organization and queries. The most significant classification challenge in RPDS was the geological rock type classification.”

As part of this study, we reviewed the very well-documented rock classification system\(^{31}\) adopted by the compilers of the RPDS and provide below a mapping between their classification and the GeoSciML classification.

### 4.3.1. RPDS Rock Names mapped to GeoSciML Earth Materials Vocabulary

Although not nearly as numerous as the rock names in MINFILE, the RPDS names are also too numerous to list, with their mappings to GeoSciML rock names, in this text. Consequently this mapping has also been provided on a web page, at the following URL:

http://similar2.com/RockClassifications/RockClassificationMain.aspx?ID=8

Figure 9 below shows part of the RPDS rock classification system alongside the GeoSciML classification system within the TLE taxonomy editor, all three of which are available for download from this URL:

http://similar2.com/RockClassifications/Default.htm

---

\(^{31}\) http://similar2.com/RockClassifications/data/RPDSLithologyClassification.pdf

www.georeferenceonline.com
4.4. Mineral Deposit Model Descriptions
The BC Geological Survey has compiled one of the world’s most comprehensive collections of “Mineral Deposit Profiles”. However, no appropriate standard existed at the time of compilation for rock nomenclature. Aligning these Deposit Profiles with the GeoSciML lithology-naming standard would make them much more useful to explorers in BC and globally.

4.5. ARIS: Exploration Results Reporting
The reporting of exploration results arising from mandatory exploration expenditure on valid mineral claims is mandatory in British Columbia, and some standards exist to govern the quality of that reporting. Unlike the case in certain other jurisdictions (Australia, for example), no rules govern the terminology to be used in this reporting. Encouraging, if not legislating, reporters to use standard terminology would greatly enhance the value of the reported data to future users of that data.

5. Conclusions
It is clear from the material presented in this report that the rock-type terminology used in three data bases very important to minerals exploration in British Columbia are so different as to prevent them from being interoperable in all but the most rudimentary – pre-computer era – way.

At the same time, the report makes clear that interoperation of data from these databases is fundamental to effective minerals exploration

Further, it can be concluded, from evidence presented in this report, that a large number of important international institutions have concluded that standardisation of terminology used to record earth sciences data for many societal purposes, including minerals exploration, is essential.

Finally, it is clear that the software tools exist to develop and publicise terminology standards, as well as to integrate these standards into existing government databases in a way that will make them more useful to the ultimate users of the data, in particular, mineral exploration companies.

6. Recommendations
The following recommendations are made as a result of the above conclusions:

(1) That arrangements be made within the Geological Survey of British Columbia to align the production of all future geological maps with the GeoSciML/EarthResourceML standards;
(2) That GeoSciML standards be introduced to MINFILE when next it is upgraded or re-engineered;
(3) That the custodians of the RPDS re-align their rock classification system to that of GeoSciML

Integrating standards into operations that have run for a long time without them can be a difficult, time-consuming and costly endeavour.
This will undoubtedly be the case in regard to introducing GeoSciML and EarthResourceML standards to British Columbia.

(4) It is therefore recommended that a committee of interested parties be constituted to consider the implications of the conclusions and recommendations of this study. That committee would most appropriately be led by the Geological Survey of British Columbia.

(5) Finally, as a means of integrating itself with the global standardisation initiative, it is recommended that the Geological Survey of British Columbia subscribe to the OneGeology organisation, and publish the geological map of British Columbia on the OneGeology portal.

7. Acknowledgements

The author is grateful to Peter Kowalczyk for championing the importance of standard terminology to minerals exploration, and Geoscience BC is thanked for sponsoring the production of this report.

C. P. Smyth
President
Georeference Online Ltd

(With minor updates in May and September 2013)
Appendix A  
Terms/Taxonomies/Ontologies/Languages

Terms are words and compound words that are used to denote meaning in specific contexts (eg: mafic rock; granite; sulphide mineral; pyrite).

Taxonomies are classifications usually arranged in a hierarchical structure. Typically they are organized by supertype-subtype relationships, also called generalization-specialization relationships, or less formally, parent-child relationships. In such an inheritance relationship, the subtype by definition has the same properties, behaviors, and constraints as the supertype plus one or more additional properties, behaviors, or constraints. For example: car is a subtype of vehicle, so any car is also a vehicle, but not every vehicle is a car. Therefore a type needs to satisfy more constraints to be a car than to be a vehicle. Rock and mineral taxonomies from which standard geological terms are drawn need to be clearly defined. They need to make clear to agents\textsuperscript{32} that use them that a granite is not a mafic rock, but that pyrite is a sulphide mineral (assuming\textsuperscript{33} the compound terms “mafic rock” and “sulphide mineral” appear in the taxonomies).

Ontologies\textsuperscript{34} are formal representations of knowledge as a set of concepts (eg: lithologies and minerals) within a domain (eg: geology), and the relationships between those concepts. They can be used to reason about the entities within that domain, and may be used to describe the domain. Ontologies are a critical element of interoperable computer systems.

Languages are means used by humans, and by computers, to record and communicate information. Societies speaking different languages may each use a term for naming ostensibly the same thing or concept which communicates subtly different information about that thing in each language. These differences usually emerge when compiling multi-lingual thesauri, or when mapping between terms in different language databases compiled on the same subject (eg: French and English databases on the geology of eastern Canada). Ontologies are helpful in resolving these differences, which may require the recognition and coining of a new term in one of the languages. Mapping between a set of standard and non-standard terms used to describe the same “thing” (such as a rock unit) can present problems similar to the problems which arise when mapping between terms in different languages, such as French and English. Consequently the solutions to these problems are also related. Figure 10 below illustrates the close relationship between terminological/ontological mapping (“medium sand” to “sand”), and English/French language mapping (to allow synchronous internet presentation of data from Ontario and Quebec databases in the same internet application in either English or French).

\textsuperscript{32} By agents here we mean humans or computers. A computer queried for “mafic rocks” needs to be able to return entries recorded as “basalt”, but not entries recorded as “granite”. Reference to the rock taxonomy (by appropriate software) makes this possible, provided that only standard terms have been used in the query target.

\textsuperscript{33} The need for general classification (compound) terms such as “mafic rock” in rock taxonomies appropriate for field-mapping-dependent disciplines such as minerals exploration was well-documented by the GSC in a paper published by Struik et al (2003): “A preliminary scheme for multihierarchical rock classification for use with thematic computer-based query systems”. The GeoSciML standard applies the principles proposed in this paper because it is focused on being of practical use to field geologists working with maps. View the paper at: \url{http://dsp-psd.pwgsc.gc.ca/collection_2007/nrcan-rncan/M44-2002-E18E.pdf}

\textsuperscript{34} In computer science and information science. In philosophy, ontology is the study of being, existence and reality.
Figure 10: Diagram illustrating the close relationship between terminological and cross-language mapping in interoperable computer systems.
Appendix B  Terminology in Minerals Exploration

Two examples are presented below of the key role lithological terms play in the interpretation of (a) geochemical data, and (b) geophysics data.

Lithology Terms in the Interpretation of Geochemistry
In most mineral exploration studies involving large collections of regional geochemical data, it is important for anomaly-recognition purposes to separate out sample populations by the rock type predominating around the sample site. Two examples in which this was done are Smyth (2003)\textsuperscript{35}, \textsuperscript{36} and Smyth (2004)\textsuperscript{37}.

Figures 11 and 12 present Box and Whisker plots illustrating the different levels of barium in stream sediments collected over different lithologies in British Columbia and in the Yukon. There are significant differences in the barium levels associated with different rock units, and this is the same for many other elements important to exploration. Abbreviated lithological descriptions of the rock units used to partition the samples are shown along the horizontal axis of each plot. These descriptions were derived from the 1:250,000 geological map rock unit descriptions for each jurisdiction. The rock names used in each unit description are derived from non-standard rock-type term lists (and they are combined in non-standard ways – this latter standardisation being more difficult to achieve than standardisation of the rock-type terms used within the descriptions).

CONCLUSION: Geochemical levels in streams, important to exploration, vary significantly as a function of underlying lithologies. For interoperability between different geochemical data sets, which is necessary for effective minerals exploration, custodians and generators of geochemical data should facilitate qualification of these data by related rock-types named according to international standards. In practice, this need translates to the need for geological maps with legends that are named according to international terminological standards.

\textsuperscript{36} www.rockstorichesbc.com
\textsuperscript{37} www.yukonmineraltargets.com
Figure 11: Ba (INAA) levels in streams (-80#) in British Columbia as a function of underlying map unit lithology.

Figure 12: Ba (INAA) levels in streams (-80#) in the Yukon as a function of underlying map unit lithology.
Lithology Terms in the Interpretation of Geophysics
The following extracts from Geoscience BC Project Report 2006-015 make clear the importance of lithology terms to the organisation and use of physical rock properties data in minerals exploration:

“Physical rock property data, systematically recorded and comparable using standard formats, is integral to successful interpretation of subsurface geology from geophysics.”

“RPDS is an Oracle-based relational data management system, which brings together geological and geophysical information and facilitates interpretation of rock properties and corresponding geological description across geographic areas. This permits statistical and spatial characterization of the rock property environment for various ore deposit types in different geological settings. The significance of the Rock Property Database System (RPDS) is that it provides a single repository for rock property data, as opposed to many disparate sources, thus allowing large-scale aggregation of data and in-depth analysis of rock property relationships.”

Figure 13 shows the web interface to the RPDS, in which it is clear that lithology is searchable/filterable by a three-level hierarchy of “Master Lithologies”. Of interest is the inset showing an enlargement of two of the records returned by this filter – both with lithologies “Tonalite”, even though tonalite is not a kind of granite.

CONCLUSION: The utility of the Mira/BC Rock Property Database System would be considerably enhanced by classifying the rock properties it seeks to organise using international standards for rock nomenclature, as applied through a taxonomy-aware user interface (see Footnotes 5 and 6 above).

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39 http://www.mira.geoscience.com/rpds
40 Tonalite, like granite, is a granitoid.
Lithological Classification (problematic) of Rock Properties Database

Figure 13: Mira/BC Rock Property Database System web interface illustrating utilisation of lithological grouping of data.
GeoSciML and Why we need It

Introduction

It is becoming increasingly important to be able to query and exchange digital geoscientific information between data providers and users. Technological opportunities arising from the development of geospatial information standards are making such interoperability a viable proposition. In order to investigate these opportunities a meeting of international geoscience data providers, mainly geological surveys, was held in Edinburgh in 2003. Following from this meeting a working group under the auspices of the IUGS Commission for the Management and Application of Geoscience Information (CGI) was set up.

The Interoperability Working Group (IWG) was tasked with developing a conceptual geoscience data model, mapping this to a common interchange format, and demonstrating the use of this interchange format through the development of a testbed. Active participants in the working group are drawn from BGS (United Kingdom), BRGM (France), CSIRO (Australia), GA (Australia), GSC (Canada), GSV (Australia), APAT (Italy), JGS (Japan), SGU (Sweden) and USGS (USA).

Conceptual data model

In order for there to be interchange of information there has to be agreement, on the nature and structure of the information to be interchanged. The simplest way of achieving this would be if all geoscience data providers shared a common database structure. However, because we all already have our own database implementations, and the information gathered and held by different providers is not exactly the same, this option is not possible. The solution is to agree a common conceptual data model, to which data held in our existing databases can be mapped. Such a data model needs to identify the objects being described (eg ‘faults’), their properties (eg ‘displacement’) and the relations between objects (eg ‘faults are a type of Geologic Structure’). Such a model can be described graphically using Universal Modeling Language (UML), an ISO standard.

Developing such a conceptual data model is a major piece of work and in the current phase of development the scope has been restricted to those geoscience objects which form the main components of a geological map (geological units, faults, contacts, and their defining concepts) as well as boreholes.

What exactly is GeoSciML?

Having agreed a conceptual data model it needs to be mapped on to an interchange format. The GeoSciML application is a standards-based data format that provides a framework for application-neutral encoding of geoscience thematic data and related spatial data. GeoSciML is
based on Geography Markup Language (GML – ISO DIS 19136) for representation of features and geometry, and the Open Geospatial Consortium (OGC) Observations and Measurements standard for observational data. Geoscience-specific aspects of the schema are based on a conceptual model for geoscience concepts and include geologic unit, geologic structure, and Earth material from the North America Data Model (NADMC1, 2004), and borehole information from the eXploration and Mining Markup Language (XMML). Development of controlled vocabulary resources for specifying content to realize semantic data interoperability is underway.

Intended uses are for data portals publishing data for customers in GeoSciML, for interchanging data between organizations that use different database implementations and software/systems environments, and in particular for use in geoscience web services. Thus, GeoSciML allows applications to utilize globally distributed geoscience data and information.

GeoSciML is not a database structure. GeoSciML defines a format for data interchange. Agencies can provide a GeoSciML interface onto their existing data base systems, with no restructuring of internal databases required (see figure below).

Scope of GeoSciML

The scope of GeoSciML is mostly interpreted information shown on geological maps but it also includes observational data from boreholes and field observations using the OGC Observations & Measurements (O & M) specification.
GeoSciML model does not provide definitions of everything that is in geoscience because some other groups may have governance of them.

It is out of scope for the IWG to design and govern them but in scope for IWG to use them. Other initiatives are handling these issues and the IWG are coordinating with them.

GroundwaterML is an example of a derived implementation of GeoSciML. It is also the first official collaboration between GeoSciML and an external exchange model group.

MineralOccurrences is an example of an inherited implementation of GeoSciML. It is being developed by the Australian Government Geologists Information Committee (GGIC) as a model to deliver mineral occurrences information as WMS/WFS. Australian State, territory and federal organizations presently govern the model.

**Where can I learn more about GeoSciML?**

The developments of GeoSciML can be followed on the GeoSciML collaboration portal. The portal is at https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/WebHome. Discussions of future developments, proposed changes, documentation of current efforts and presentations are freely available. Users can subscribe to be informed of changes daily.

**GeoSciML Testbed2**

Six International and 2 state surveys, stretching from Australia to Europe to North America, participated in a proof-of-concept demonstration of GeoSciML at the International Association of Mathematical Geologists (IAMG) meeting in Liège, Belgium in September 2006.

The demonstration showed that it was possible to access information in real time from globally distributed data sources. Geological map polygons and attribute information, and borehole data, were displayed, queried and re-portrayed using web applications hosted by the Geological Survey of Canada and the BRGM. GeoSciML data could also be downloaded. PowerPoint presentations on GeoSciML from the IAMG 06 meeting are available at https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/GeoSciMLPresentations.

**GeoSciML Testbed3**

The next GeoSciML Testbed3 was presented at the 33rd International Geological Congress (IGC 33) in Oslo August 2008. This is also the official release of GeoSciML version 2.1.0 with full documentation.
Appendix D  Earth Resources Markup Language (ERML)

Despite its maturity (its development began in the early 2000s), importance, and growing adoption by large organisations, ERML has not been comprehensively described in a single scientific or technical “white paper”.

Its most up-to-date description, at a level appropriate to this report, was provided in a Powerpoint presentation at the 34th IUGS meeting in Brisbase in August of this year:

EarthResourceML v.2.0 – an upgrade of the CGI-IUGS earth resource data model due to INSPIRE Data specification

By
Jouni VUOLLO¹
and
Bruce SIMONS², John LAXTON³, Daniel CASSARD⁴ and Adele SEYMON⁵

¹Geological Survey of Finland, Finland
²CSIRO Land & Water, Melbourne, Australia
³British Geological Survey, UK
⁴BRGM, France
⁵AMIRA International, Melbourne, Australia

The pages that follow present, as an introduction to ERML, most of the slides from that presentation, together with additional notes appropriate to the context of this report.

Much additional technical documentation is available from the ERML home page:

The IUGS-CGI Earth Resource Interoperability Working Group has worked together with the INSPIRE Thematic working group to modify the ERML standard to meet EU requirements, and ERML now forms the basis of the INSPIRE Mineral Resources data specification.

INSPIRE is a 5-year multi-million Euro EU directive set up to create a pan-European Union (EU), spatial data infrastructure. It includes 34 themes (GIS layers), of which one is mineral resources.
ERML began its life as the **Exploration and Mining Markup Language**, “XMML”, in 2000, as described on the XMML project introduction web page:

“The XMML project was initiated by CSIRO and Fractal Graphics in 2000. The requirement was to develop a data transfer encoding to facilitate the exchange between applications on the desktop, between networked computers, organisations, and possibly over time (archiving). It was decided to use an XML-based encoding on the grounds that this was likely to become the dominant basis for information exchange in web-based environments, which were becoming ubiquitous.

The project was announced at an AMF symposium in May 2000, and attracted support from several mining companies, geological surveys and mining industry consultants. The WA State Government provided substantial funding through the Minerals and Energy Research Institute of WA (MERIWA) and work began in late 2000.

Project results were restricted to project sponsors and collaborators until the end of June 2003. From that time the XMML schemas and documentation were made publicly available.”

By 2004 it had evolved to being called the “GGIC41 Mineral Occurrence Model” because most development work was being undertaken in Australia, and it was progressed under that name until, at Australia’s request, governance moved, in August, 2010, to the IUGS’s Council for Geoscience Information (CGI), the custodians of GeoSciML.

---

41 (Australian) Government Geoscience Information Committee.
A little more on the critical Australian contribution:

The first Mineral Occurrence Task Group was established in 2006, resulting in a first data model in 2007 which was deployed and tested on the AuScope portal.

A second model – now EarthResourceML version 1.1, was released in 2009 as a production service.

Currently five Australian state geological surveys are delivering mineral resource data through the “AuScope portal” according to the ERML standard.
Movement, at the end of 2010, of ERML governance to IUGS/CGI and its interoperability working group marks the emergence of ERML as a global standard.

Many European projects*, including INSPIRE (see next slide), have adopted ERML as a data delivery standard. And next speaker, Daniel Cassard will speak about ProMine project and its services – pan-European data!

ERML version 2 is now available as a release candidate. The official version with vocabularies is anticipated for release within 12 months.

Hope was expressed at the Brisbane IUGS congress that North American countries will soon adopt the ERML standard.

(* OneGeologyEurope and ProMine are examples.)
Since its decision to adopt ERML as its standard for mineral resource data, INSPIRE* has had considerable (positive) influence on the refinement of the ERML model.

[* In Europe a major recent development has been the adoption of the INSPIRE42 Directive of May 2007, establishing an infrastructure for spatial information in Europe to support EU environmental policies, and policies or activities which may have an impact on the environment, including geology and mining as specific subjects of attention.

INSPIRE is based on the infrastructures for spatial information established and operated by the 27 Member States of the European Union. The Directive addresses 34 spatial data themes43 (including geology and mining) needed for environmental applications, with key components specified by technical implementation laws and regulations (which include specification of standardised terminologies). This makes INSPIRE a unique example of a legislated regional approach – likely a long-term outcome in North America as well.

To ensure that the spatial data infrastructures of EU Member States are compatible and usable in a trans-country-boundary context, the Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). These IRs are adopted as Commission Decisions or Regulations, and are binding on all jurisdictions.

INSPIRE is adopting GeoSciML as its delivery standard.]

42 http://inspire.jrc.ec.europa.eu/
The above two screenshots illustrate the quality and volume of INSPIRE documentation.
“INSPIRE-driven” refinements to ERML arose from consideration of the following INSPIRE-related references and projects, and the needs they articulated:

(a) Two EU legal documents – The Raw Materials Initiative (RMI) and the Mining Waste Directive
(b) The EarthResourceML standard itself, and described by INSPIRE (i.e.: incorporating INSPIRE’s specific requirements)
(c) Other related projects, such as “EuroGeoSource” and “ProMine”
CGI-IUGS - EarthResourceML v 2.0 - key points

1. The model describes Earth Resources independent of associated human activities (i.e. mining)
2. Caters for description of Earth Resource using mineral deposit models that describe the actual deposit type, mineral systems that describe the processes associated with deposit formation; an supergene processes;
3. Utilises GeoSciML Mapped Feature to describe spatial representation and Earth Material to describe host and associated materials;
4. The model describes a mine as made up of a number of Mining Activities, each of which produce some commodity;
5. The model provides the ability to describe commodity resources formally or in formally.
6. New INSPIRE features – exploration activity and mining waste

A pictorial view of the relationships between ERML and other standards, organizations and projects.
ERML is an extension of GeoSciML, as shown in this graphic of ERML V1 (with a “Geology View”, but without a “Human Activity View”), from Bruce Simons’ 2010 Powerpoint on ERML. Contrast it with ERML V2 below, which includes mining features and their attributes.
New INSPIRE elements are marked with squares and a dotted oval.
Miscellaneous comments about ERML “Code Lists” (i.e.: Controlled Vocabularies) above, and names of the lists below (from which can be surmised the subject areas they cover).
Appendix E International Support for Terminology Standards

Mindful of the problems discussed in Section 2 of this report (Problem Statement), a number of international institutions have been developing standard terminologies for the earth sciences, as well as the computer infrastructure to leverage on these standards by those who wish to work with them. GeoSciML, OneGeology and INSPIRE are three of these institutions whose work is relevant to minerals exploration in British Columbia.

GeoSciML

GeoSciML\textsuperscript{44} or Geoscience Markup Language\textsuperscript{45} is a GML Application Schema that can be used to transfer information about geology, with an emphasis on the "interpreted geology" that is conventionally portrayed on geologic maps. Its feature-type catalogue includes Geologic Unit, Mapped Feature, Earth Material, Geologic Structure, and specializations of these, as well as Borehole and other observational artifacts. It was created by, and is governed by, the Commission for the Management and Application of Geoscience Information (CGI\textsuperscript{46}) to support interoperability of information served from Geologic Surveys and other data custodians. It is being used in the OneGeology Project (see section below).

The GeoSciML organisation includes a Concept Working Group\textsuperscript{47} which is currently working on Version 3 of the following terminology standards:

<table>
<thead>
<tr>
<th>Alteration Type</th>
<th>Genetic Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition Category</td>
<td>Geologic Unit Morphology</td>
</tr>
<tr>
<td>Compound Material Constituent Part Role</td>
<td>Geologic Unit Part Role</td>
</tr>
<tr>
<td>Consolidation Degree</td>
<td>Geologic Unit Type</td>
</tr>
<tr>
<td>Contact Character</td>
<td>Lineation Type</td>
</tr>
<tr>
<td>Contact Type</td>
<td>Mapped Feature Observation Method</td>
</tr>
<tr>
<td>Convention Code</td>
<td>Metamorphic Facies</td>
</tr>
<tr>
<td>Description Purpose</td>
<td>Metamorphic Grade</td>
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<tr>
<td>Determination Method_orientation</td>
<td>Particle Aspect Ratio</td>
</tr>
<tr>
<td>Event Environment</td>
<td>Particle Shape</td>
</tr>
<tr>
<td>Event Process</td>
<td>Particle Type</td>
</tr>
<tr>
<td>Fault Movement Sense</td>
<td>Proportion Term</td>
</tr>
<tr>
<td>Fault Movement Type</td>
<td>Simple Lithology</td>
</tr>
<tr>
<td>Fault Type</td>
<td>Stratigraphic Rank</td>
</tr>
<tr>
<td>Feature Observation Method</td>
<td>Value Qualifier</td>
</tr>
<tr>
<td>Foliation Type</td>
<td>Vocabulary Relation</td>
</tr>
</tbody>
</table>

\textsuperscript{44} https://www.seegrid.csiro.au/wiki/CGIModel/GeoSciML
\textsuperscript{45} http://www.opengeospatial.org/standards/gml
\textsuperscript{46} http://www.cgi-iugs.org/
\textsuperscript{47} https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG
Table 7: Listing of terminology standards developed for GeoSciML.

Figure 14: A simplified view of the GeoSciML architecture (Raymond (2008)\textsuperscript{48}).

OneGeology

OneGeology\textsuperscript{49} is an international collaborative project in the field of geology supported by 113 countries, UNESCO and major global geoscience bodies. It aims to enable online access to dynamic digital geological map of the world for everyone. The project uses the GeoSciML markup language and initially targets a scale of approximately 1:1 million. Downstream uses of OneGeology are identifying areas suitable for mining, oil and gas exploration, areas at risk from landslides or earthquakes, to help understanding of formations which store groundwater for drinking or irrigation, and to help locate porous rocks suitable for burying emissions of greenhouse gases. The project portal was launched on August 6, 2008 at the 33rd International Geological Congress (IGC) in Oslo, Norway.

\textsuperscript{48} Illustration taken from presentation by O. Raymond to the GeoSciML Workshop at the 33\textsuperscript{rd} IGC in Oslo, Norway in 2008; \url{http://www.cgi-iugs.org/tech_collaboration/docs/Ollie_Raymond_GeoSciML_v2_rc3.ppt}
\textsuperscript{49} \url{http://onegeology.com/}
Figure 15 below illustrates the geological map of Canada being displayed in the OneGeology portal on the same map as the geology of South Africa and Namibia. The same kind of internationally-integrated display of BC geology will be possible with the WMS product described in of this report.

Figure 15: Display of the geological map of Canada by the OneGeology web portal also showing the geology of Namibia and South Africa. Map data is supplied to the British-based portal synchronously from servers in Canada and South Africa.

INSPIRE
In Europe a major recent development has been the adoption of the INSPIRE\(^50\) Directive of May 2007, establishing an infrastructure for spatial information in Europe to support EU environmental policies, and policies or activities which may have an impact on the environment, including geology and mining as specific subjects of attention.

INSPIRE is based on the infrastructures for spatial information established and operated by the 27 Member States of the European Union. The Directive addresses 34 spatial data themes\(^51\) (including geology and mining) needed for environmental applications, with key components specified by technical

\(^{50}\) http://inspire.jrc.ec.europa.eu/

implementation laws and regulations (which include specification of standardised terminologies). This makes INSPIRE a unique example of a legislated regional approach – likely a long-term outcome in North America as well.

To ensure that the spatial data infrastructures of EU Member States are compatible and usable in a trans-country-boundary context, the Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). These IRs are adopted as Commission Decisions or Regulations, and are binding on all jurisdictions.

INSPIRE is adopting GeoSciML as its delivery standard.

**EarthResourceML**
The Australian Chief Government Geologists Committee (CGGC) has developed the EarthResourceML Data Exchange Model52 (and53). This has been developed collaboratively under the leadership of the Australian Government Geoscience Information Policy Advisory Committee as an extension of the geoscience exchange standard (GeoSciML). This data model with standard vocabularies is designed to deliver mineral data in a consistent format to appropriate web portals, such as the AuScope Discovery Portal (http://portal.auscope.org/gmap.html), and facilitate transfer of the most recent data between government, industry and other organisations. The model describes Earth Resources independent of associated human activities, permitting description using mineral deposit models encompassing internationally recognised deposit classifications, mineral systems and processes. It also provides the ability to describe commodity resources formally or informally utilising international reporting standards including basic JORC requirements (the 2004 Australasian code for reporting exploration results, mineral resources and ore reserves).

EarthResourceML is currently the only standard under evaluation by INSPIRE for adoption as its “Mineral Deposits” description standard54 and is appropriate for adoption in Canada as well.

Appendix F *OneGeology-Europe Colour Legend for GeoSciML Rock Types*

**Reference:** “Portrayal Rules for OneGeology-Europe”, Kristine Asch, Marco Klicker and Chris Schubert

http://onegeology-europe.brgm.fr/how_to201002/

See next page for Phaneritic Igneous Rocks, etc
### GeoSciML/CGI-OneGeology-Europe Term

<table>
<thead>
<tr>
<th>Term</th>
<th>R</th>
<th>G</th>
<th>B</th>
<th>C</th>
<th>M</th>
<th>Y</th>
<th>K</th>
</tr>
</thead>
</table>

#### Phaneritic igneous rock
- **Doleritic rock**
  - p1.1 Granite
    - p1.1.1 Charnockite
    - p1.2 Granodiorite
    - p1.3 Tonalite
- **Pegmatite**
- **Aplitic**
  - p1.1 Granite
  - p1.2 Granodiorite
  - p1.3 Tonalite
- **Granitoid**
  - p2 Syenitic rock
    - p2.1 Quartz syenite
    - p2.2 Syenite
    - p2.3 Foid-bearing syenite
    - p2.4 Quartz monzonite
    - p2.5 Monzonite
- **Doleritic**
- **Aplite**
  - p3 Dioritic rock
    - p3.1 Quartz diorite
    - p3.2 Diorite
    - p3.3 Monzodiorite
- **Gabbroid**
  - p4 Gabbroic rock
    - p4.1 Monzogabbro
    - p4.2 Gabbro
    - p4.3 Gabbronorite
    - p4.4 Norite
- **Anorthositic rock**
  - p5 Anorthositic rock
    - p5.1 Anorthosite
    - p5.2 Pyroxenite
- **Foid syenitoid**
  - p5.1 Foid syenite
- **Foid dioritoid**
  - p5.2 Foid diorite
- **Foid gabbroid**
  - p5.3 Foid gabbro
  - p5.4 Foid gabbronorite
  - p5.5 Foid norite
- **Foidolite**
  - p5.6 Foidolite
- **Ultramafic phaneritic rock**
  - p10.1 Peridotite
  - p10.2 Pyroxenite

#### Metamorphic Rock
- **Anchimetamorphic rock**
  - m1.1 Anchimetamorphic rock
  - m1.2 Sillite
- **Sedimentary protolith**
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  - m2.2 Siltite
  - m2.3 Shale
  - m2.4 Mudstone
- **Foliated metamorphic rock**
  - m3.1 Slate
  - m3.2 Schist
  - m3.3 Gneiss
  - m3.4 Mylonite
  - m3.5 Paragneiss
- **Serpentinite**
  - m4.1 Serpentinite
- **Porphyroblast**
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  - m5.4 Diabase
  - m5.5 Norite
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  - m5.7 Amphibolite
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