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

Seeking the Efficiencies of Order

Clinton Smyth

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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.

Figure 1: Graphic from the US Government Geospatial Platform portal emphasising the importance of integrating mapping data of different jurisdictional scales (from: www.geoplatform.gov).

[1] See: 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 x 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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[5] "Leveraging Geospatial Standards for Interoperability in the Canadian Groundwater Information Network". http://www.geoplace.com/Media/MediaManager/BoyanBrodaric.pdf

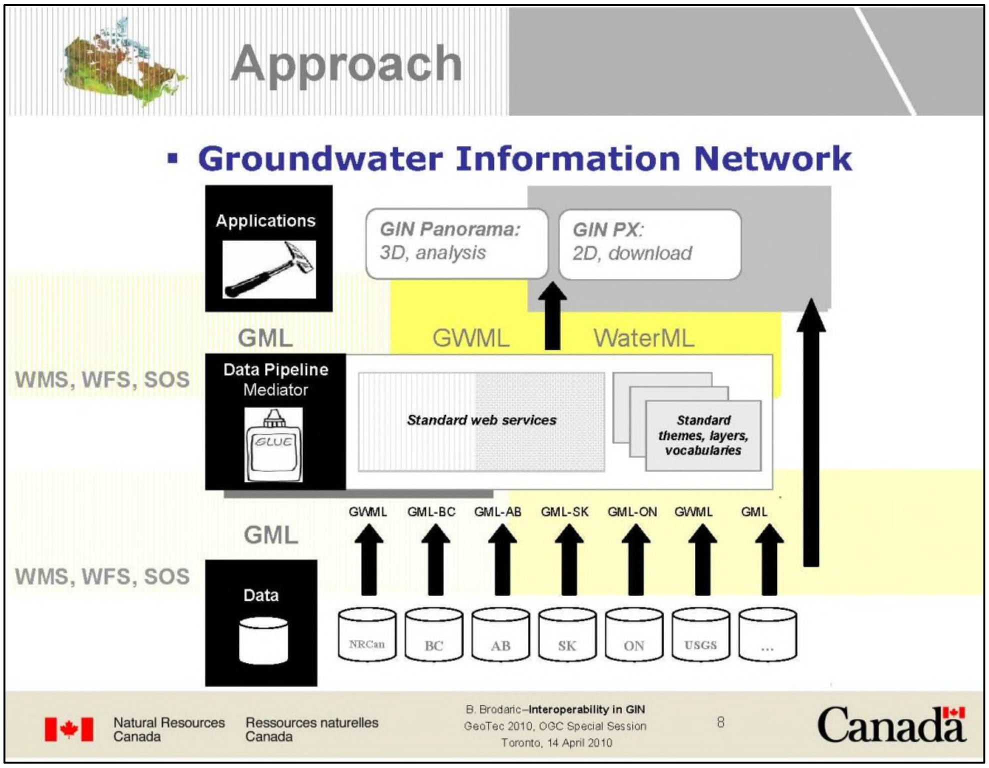


Figure 2: The three-layered architecture of the GSC's Groundwater Information Network.

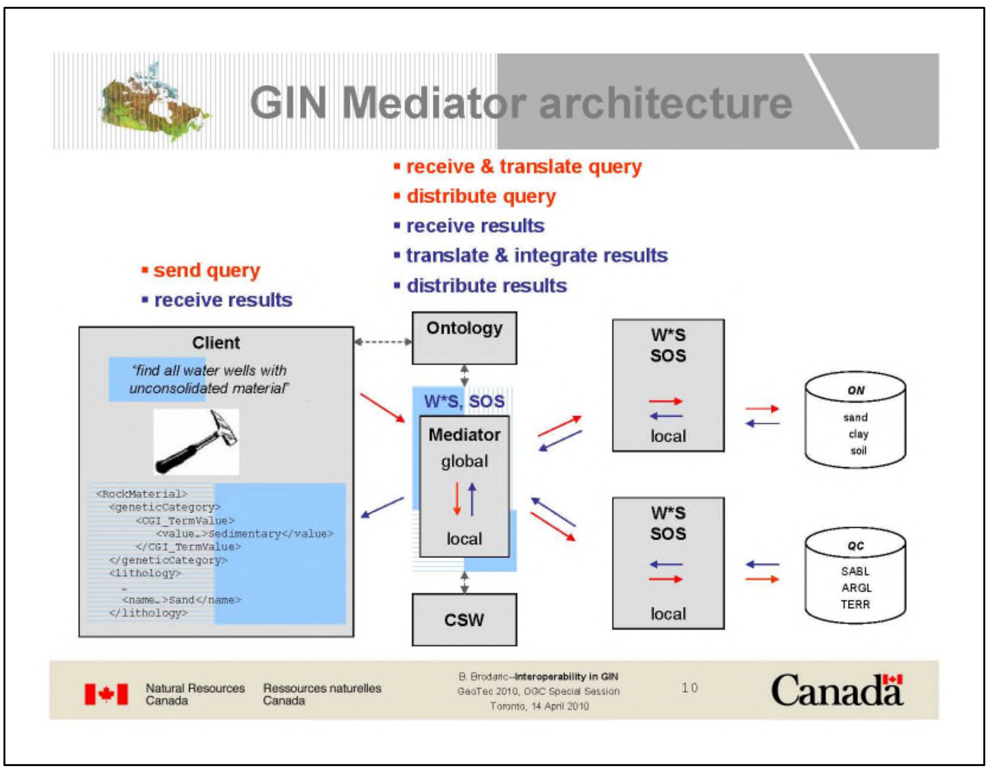


Figure 3: The location of mediators and ontologies in in the architecture of interoperable internet mapping systems.

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).

[6] https://www.seegrid.csiro.au/wiki/CGIModel/GeoSciML
[7] http://www.opengeospatial.org/standards/gml
[8] http://www.cgi-iugs.org/

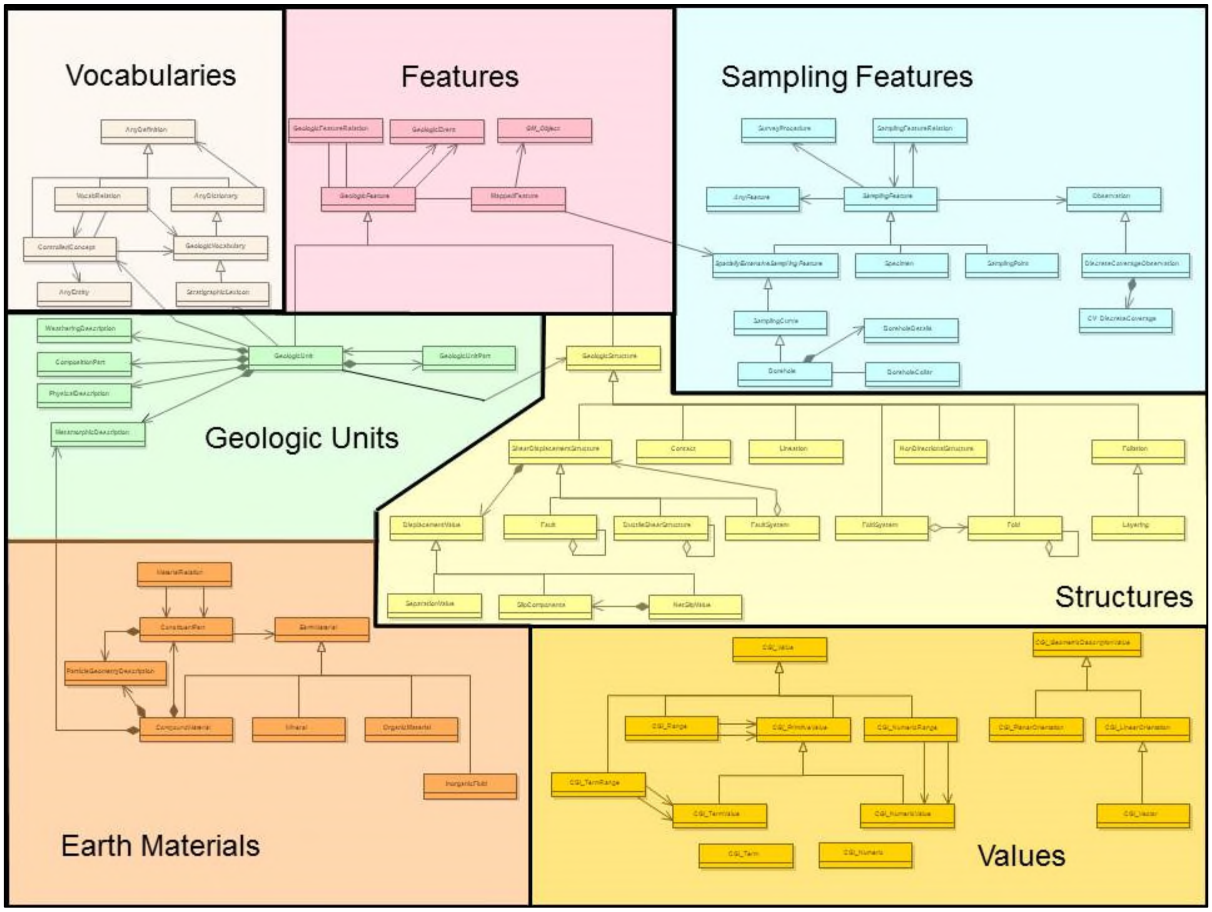


Figure 4: A simplified view of the GeoSciML architecture (Raymond (2008)[9]).

The GeoSciML organisation includes a Concept Working Group[10] which is currently working on Version 3 of the following terminology standards, the "Simple Lithology" standard of which is dealt with in this report:

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

[9] Illustration taken from presentation by O. Raymond to the GeoSciML Workshop at the 33rd IGC in Oslo, Norway in 2008; http://www.cgi-iugs.org/tech_collaboration/docs/Ollie_Raymond_GeoSciML_v2_rc3.ppt

[10] https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG

Fault Movement Type	Simple Lithology
Fault Type	Stratigraphic Rank
Feature Observation Method	Value Qualifier
Foliation Type	Vocabulary Relation

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[11] (and[12]). 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[13] 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

https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG

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

[11] https://www.seegrid.csiro.au/wiki/CGIModel/EarthResourceML
[12] https://www.seegrid.csiro.au/wiki/CGIModel/EdinburghF2F2011EarthResourceMLMeetingNotes
[13] See “Data Specification on Mineral Resources – Draft Guidelines” available at http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_MR_v2.0.pdf

The following[14] 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: http://similar2.com/RockClassifications/RockClassificationMain.aspx?ID=10
(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: https://www.seegrid.csiro.au/wiki/pub/CGIModel/LithologyCategories/SimpleLithology2009xx.xls
(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

4. Standardising Rock Nomenclature in BC Geological Survey Minerals Exploration Data

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[15] ("the *BC Geology Map*") was under revision when the work presented in this report was undertaken, and was available for download[16]. It was

[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/BEDROCKMAPPING/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[17]. 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[18] the same lithology legend as that used by, and distributed with, Geoscience Map 2005-2[19] (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.

Field	Description
AREA	Polygon area in square metres.
PERIMETER	Polygon perimeter in metres.
KEYCODE	Original geological tag; derived from the Mineral Potential geological compilations; also includes new tags assigned during this compilation in updated areas.
TECUNIT	Tectonic assemblage code; derived from GSC Map 1712A and Journeay & Williams (1995) with slight modifications. Codes used are listed in BC_Tecunit.xls.
STRAT_UNIT	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.

[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."
[19] http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2005/Pages/2005-2.aspx

ERA	Geological Era within which the unit lies.
PERIOD	Geological Period within which the unit lies.
STRAT_AGE	Stratigraphic age range of unit.
STRAT_NAME	Stratigraphic name of unit; Group and/or Formation where assigned.
STRAT_AGEC	4-digit age code; first four digits of AGECODE, qv; see BC_Agecodes.xls.
GROUP_SUIT	Group or Suite name.
FORMATION	Formation or lithodeme name.
ROCK_TYPE	**Generalized lithological description; see BC_Lithology.xls.**
ROCK_CODE	One or two letter code for rock type; see BC_Lithology.xls. May be used as a component of the STRAT_UNIT code.
ROCK_CLASS	**Intrusive, volcanic, sedimentary or metamorphic; see BC_Lithology.xls.**
ORIGINAL_D	Original author's description of the unit; from the Mineral Potential Geological Compilations, plus original author's descriptions for new additions and amendments.
AGE_MAX_TE	Maximum age of unit (text); see BC_Agecodes.xls.
AGE_MAX_NU	Maximum age of unit (numerical, Ma); see BC_Agecodes.xls.
AGE_MIN_NU	Minimum age of unit (numerical, Ma); see BC_Agecodes.xls.
PROJECT	Original Mineral Potential Project area, or other major project (Nechako (GSC-GSB) and Queen Charlotte (GSC)), that was the source for the unit.
AGEGROUP	Combination of 3-digit code for Geological Period and ROCK_CLASS.
AGECODE	5-digit code for age; see BC_Agecodes.xls; recommended for querying units or sorting for a geological legend, etc.
LITHCODE	2-digit numerical code for lithology; see BC_Lithology.xls.
SOURCE_ID	Numeric code for data source, see BC_Sources.xls.
UNIT	Concatenation of STRAT_UNIT, ERA, STRAT_NAME and ROCK_TYPE; may be useful for building geological legends.
REMARKS	any significant comments about unit and its attributes.
BELT	Morphotectonic belt.
TERR_CODE	2-letter code/label for tectono-stratigraphic terrane.
TERRANE	Name of tectono-stratigraphic terrane.
TERR_CLR	Colour code for terrane; used in assigning colour in terrane.avl legend file; see BC_Colours.xls for RGB values.
BASIN_CODE	3-letter code/label for sedimentary basin.
BASIN	Name of sedimentary basin.
BASIN_AGE	Age of basin.
BAS_CLR_1	colour code for basin – unique colour for each basin; used in assigning colour in basins1.avl legend file; see BC_Colours.xls for RGB values.
BAS_CLR_2	colour code for basin – grouped by age of basin; used in assigning colour in basins2.avl legend file; see BC_Colours.xls for RGB values.
STRAT1	Stratigraphic tag for use at 1:1,000,000 scale or smaller; see BC_Strat_2M.xls for complete listing.
STRAT1_CLR	colour code for STRAT1; used in assigning colour in strat_2M.avl legend file; see BC_Colours.xls for RGB values.

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[21], 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.

Rock Class
Intrusive rocks
Volcanic rocks
Metamorphic rocks
Sedimentary rocks
Ultramafic rocks

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

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) , together[22] with their closest GeoSciML term.

	Rock_Class	**Rock_Type**	**Original_D(escription)**
1	intrusive rocks	tonalite intrusive rocks	Tonalite: rectangular plagioclase phenocrysts, unfoliated.
2	intrusive rocks	tonalite intrusive rocks	Tonalite; Eagle Tonalite of the Eagle Plutonic Complex (includes Eagle Gneiss)
3	intrusive rocks	tonalite intrusive rocks	Trondhjemite
4	intrusive rocks	tonalite intrusive rocks	Weakly to strongly foliated tonalite
5	metamorphic rocks	blueschist metamorphic rocks	Blueschist

[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.

6	metamorphic rocks	blueschist metamorphic rocks	Blueschist facies: glaucophane schist, metabasalt, dolostone, listwanite, metachert, limestone
7	metamorphic rocks	calcsilicate metamorphic rocks	Amphibolite, calcsilicate and minor marble
8	metamorphic rocks	calcsilicate metamorphic rocks	Calcsilicate gneiss
9	metamorphic rocks	calcsilicate metamorphic rocks	Calc-silicate gneiss, amphibolite, carbonatite, marble;
10	metamorphic rocks	calcsilicate metamorphic rocks	Marble, calc-silicate rock, possible metamorphic equivalent of Pts and PMGm.
11	metamorphic rocks	calcsilicate metamorphic rocks	Skarn
12	metamorphic rocks	calcsilicate metamorphic rocks	Variably schistose epidote-actinolite-quartz and garnet-epidote skarn; lesser amounts of chloritic schist and sericite-quarz shist (Sicamous Formation includes units EBL and EBK of the Eagle Bay assemblage)
13	metamorphic rocks	eclogite/mantle tectonite	Cassiar-Quartzrock Creek Ultramafite:serpentinite, harzburgite tectonite, pyroxenite, gabbro.
14	metamorphic rocks	eclogite/mantle tectonite	Ultramafites of upper mantle origin: tectonized harzburgite, dunite, wehrlite (included with unit CPu where undivided).
15	metamorphic rocks	eclogite/mantle tectonite	Zus Mountain-Blue River Ultramafite: dunite, harzburgite tectonite, serpentinite, pyroxenite.
16	metamorphic rocks	greenstone, greenschist metamorphic rocks	Actinolite-chlorite schist and gneiss (metabasite), locally chlorite more abundant, lesser epidote.
17	metamorphic rocks	greenstone, greenschist metamorphic rocks	amphibolite; minor siliceous mylonite

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”).

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).

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

tonalite intrusive rocks	to	Tonalite
metamorphic rocks ←**Rock Class**		
blueschist metamorphic rocks	bs	Glaucophane lawsonite epidote metamorphic rock
calcsilicate metamorphic rocks	mc	Metmorphic rock
eclogite/mantle tectonite	ec	Eclogite
greenstone, greenschist metamorphic rocks	gs	Chlorite actinolite epidote metamorphic rock
imbricate zone	im	Fault-related material
lower amphibolite/kyanite grade metamorphic rocks	ml	Amphibolite
metamorphic rocks, undivided	m	Metamorphic rock
metasediments	ms	Metamorphic rock
mid amphibolite/andalusite grade metamorphic rocks	mm	Amphibolite
mylonitic metamorphic rocks	my	Mylonitic rock
orthogneiss metamorphic rocks	og	Orthogneiss
paragneiss metamorphic rocks	pg	Paragneiss
serpentinite ultramafic rocks	us	Serpentinite
sedimentary rocks ←**Rock Class**		Sedimentary rock
argillite, greywacke, wacke, conglomerate turbidites	st	Wacke
chert, siliceous argillite, siliciclastic rocks	ch	Chemical sedimentary material
coarse clastic sedimentary rocks	sc	Clastic sedimentary rock
conglomerate, coarse clastic sedimentary rocks	cg	Conglomerate
dolomitic carbonate rocks	do	Carbonate sedimentary rock
evaporite	ev	Evaporite
limestone bioherm/reef	ls	Limestone
limestone, marble, calcareous sedimentary rocks	lm	Impure limestone
limestone, slate, siltstone, argillite	lc	Impure limestone
marine sedimentary and volcanic rocks	sv	Rock
mudstone, siltstone, shale fine clastic sedimentary rocks	sf	Mudstone
mudstone/laminite fine clastic sedimentary rocks	md	Mudstone
quartzite, quartz arenite sedimentary rocks	qz	Quartzite
undivided sedimentary rocks	s	Sedimentary rock
ultramafic rocks ←**Rock Class**		
ultramafic rocks	um	Rocks
volcanic rocks ←**Rock Class**		
alkaline volcanic rocks	vk	Fine grained igneous rock
andesitic volcanic rocks	va	Andesite
basaltic volcanic rocks	vb	Basalt
bimodal volcanic rocks	bm	Fine grained igneous rock
calc-alkaline volcanic rocks	ca	Fine grained igneous rock
coarse volcaniclastic and pyroclastic volcanic rocks	vl	Fine grained igneous rock
dacitic volcanic rocks	vd	Dacite
rhyolite, felsic volcanic rocks	vf	Rhyolite
trachytic volcanic rocks	vt	Trachyte
undivided volcanic rocks	v	Fine grained igneous rock
volcaniclastic rocks	vc	Pyroclastic rock

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.

4.1.3. GeoSciML-compliant WMS delivery of the Geological Map of BC

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.

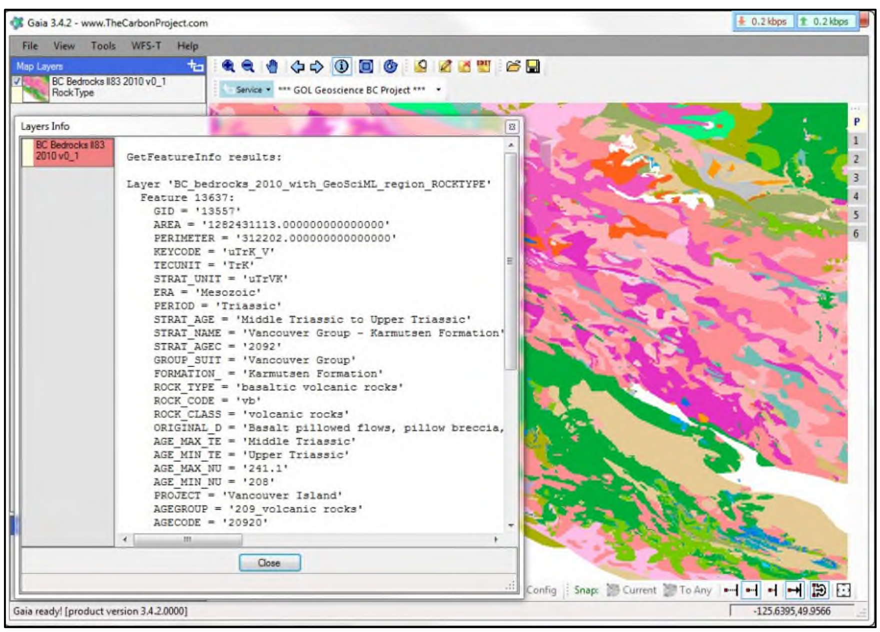


Figure 5: BC Geology Map polygons delivered by WMS to Gaia desktop application, colour-coded by "Rock Code".

[23] Or achieve goals similar to those of the OneGeology initiative, as discussed in Section 2 above.
[24] http://www.opengeospatial.org/standards/wms
[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.
[26] Available free from http://www.thecarbonproject.com/gaia.php

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[27] 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:

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).

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[28]) 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.

[27] 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.

[28] http://www.opengeospatial.org/standards/wfs

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?

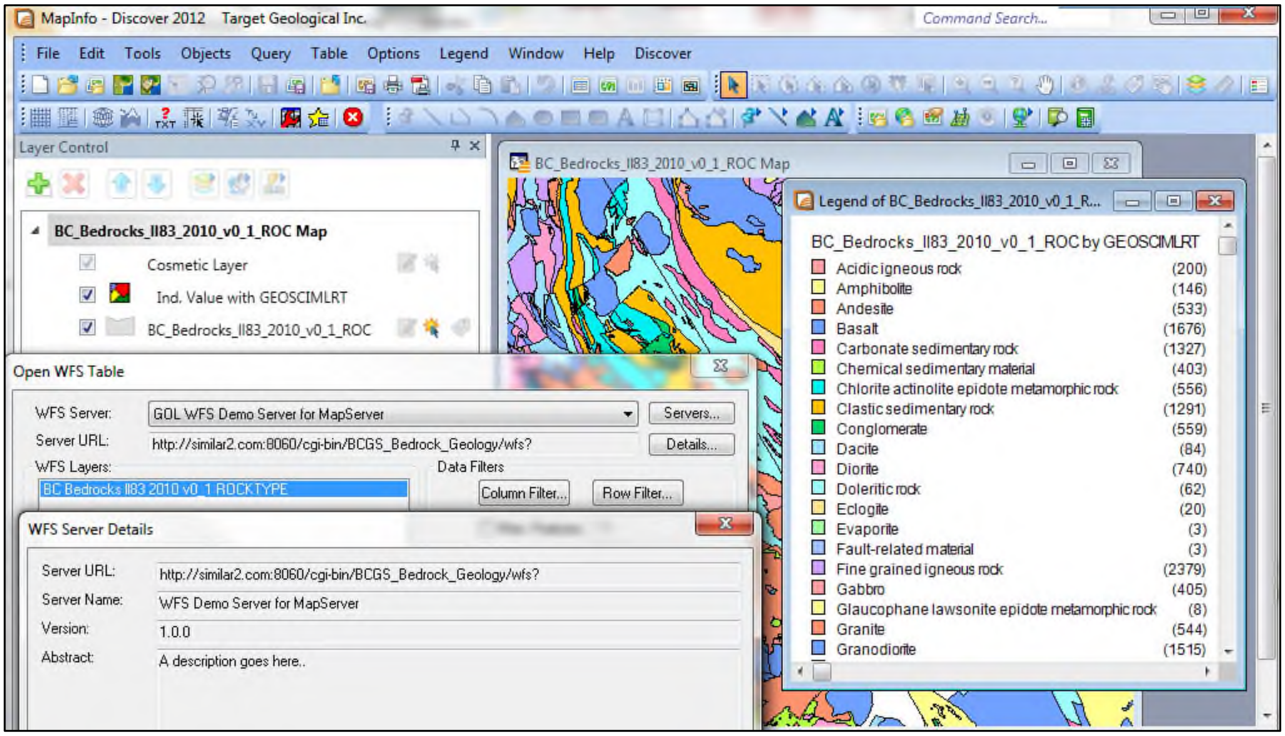


Figure 7: Legend for the GeoSciML rock type (attribute="GEOSCIMLRT") of the BC Geology Map which was delivered to the application by WFS.

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).

GeoSciML/CGI-OneGeology-Europe Term	R	G	B		C	M	Y	K
Metamorphic Rock	103	143	102		28	0	28	44
m1. Anchimetamorphic rock ??	191	194	107		0	0	45	24
m1.2 Spilite								
m2 Sedimentary protolith	255	255	115		0	0	55	0
m2.1 Quartzite								
... Foliated metamorphic rock	166	198	171		16	0	14	22
m5.10 Gneiss								
m2.5 Paragneiss								
m5.4 Mylonitic rock								
m5.3 Phyllite								
m5.1 Slate								
m3.1 Serpentinite	116	198	126		41	0	36	22
m3.3 Porphyroid								
... Glaucophane lawsonite epidote metamorphic rock = (Blueschist)								
m5.2.6 Greenschist								
m5.2 Schist								
m5.2.7 Mica schist								
m5.5 Skarn/Hornfels/Granofels								
m5.6 Granulite								
m5.7 Marble								
m5.8 Amphibolite								
m5.9 Eclogite								
m6 Migmatite								
m8 Impact Metamorphic rock	51	169	126		70	0	25	34

Table 6: Example Colour Mappings to GeoSciML Metamorphic Rock Terms (see Appendix F).

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.

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:

MODIFIER SEARCH CODE(S)	***ROCK TYPE SEARCH CODE***	***ROCK TYPE/LITHOLOGY***
	BSLT	*Basalt*
ALKL	*BSLT*	*Alkali Basalt*
QRTZ FLDP	*PRPR*	*Quartz Feldspar Porphyry*

The complete list of terms acceptable in the "Host Rock" attribute field in MINFILE can be viewed at this URL[29]:
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:
http://similar2.com/RockClassifications/RockClassificationMain.aspx?ID=5

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.

[29] 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

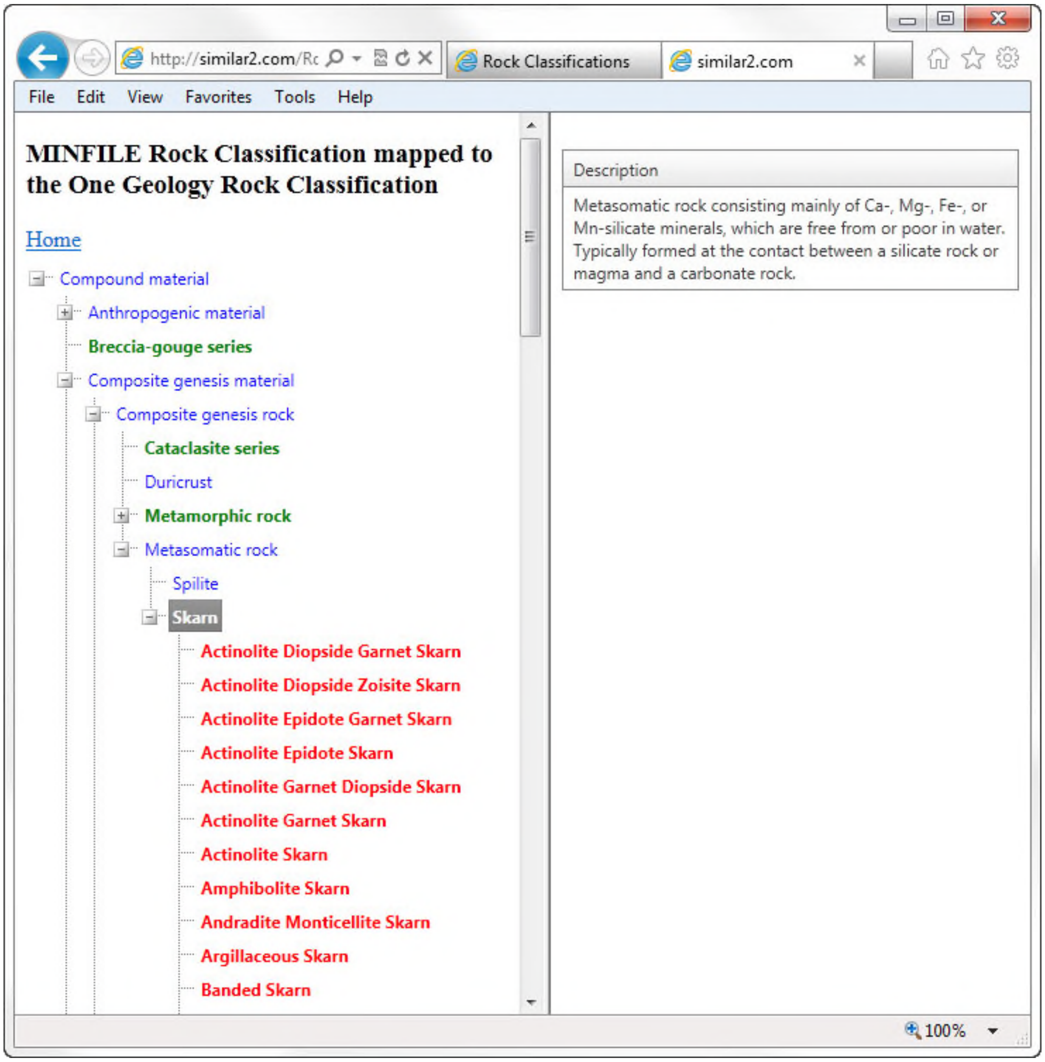


Figure 8: Illustration of web page developed to show mappings between MINFILE and GeoSciML lithology terms.

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)[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."

[30] Paper 72, "Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration" edited by B. Milkereit, 2007, p. 933-938

> "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

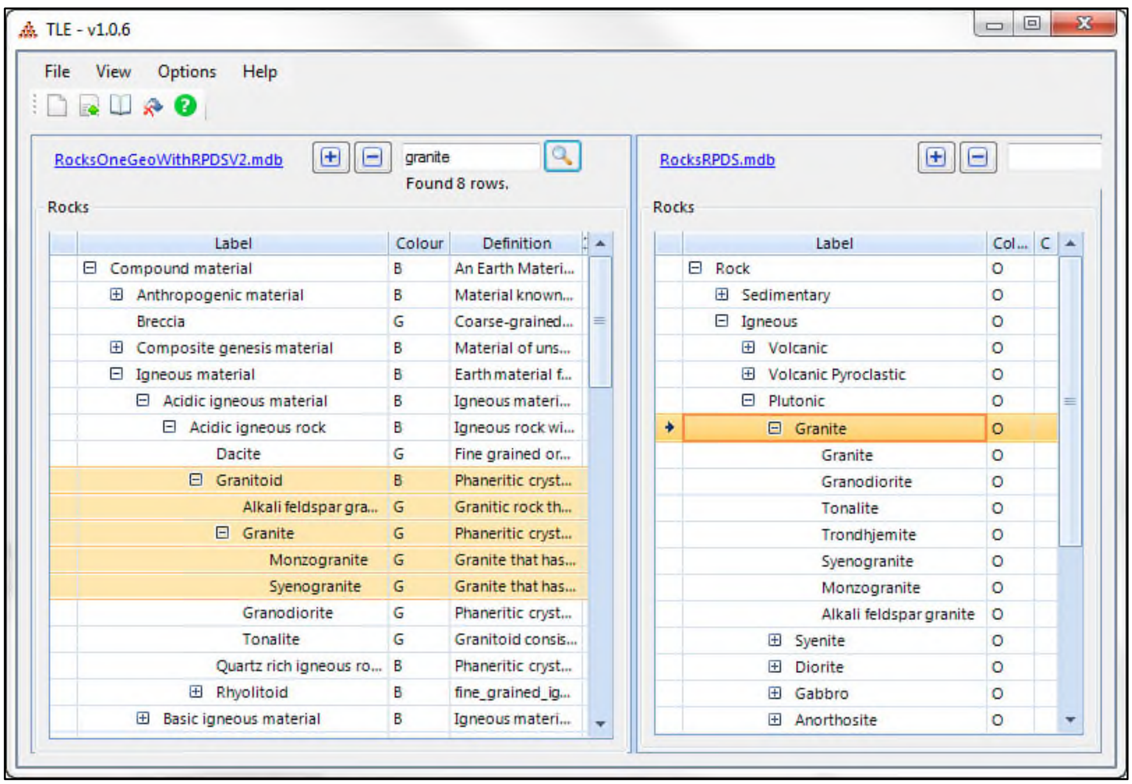


Figure 9: Screenshot of the RPDS rock classification being mapped to GeoSciML terms using the TLE taxonomy editor.

[31] http://similar2.com/RockClassifications/data/RPDSLithologyClassification.pdf

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

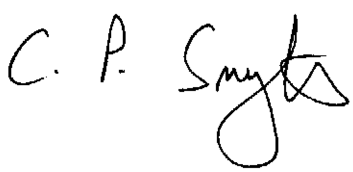
Integrating standards into operations that have run for a long time without them can be a difficult, time-consuming and costly endeavour.

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[32] that use them that a granite is not a mafic rock, but that pyrite is a sulphide mineral (assuming[33] the compound terms "mafic rock" and "sulphide mineral" appear in the taxonomies).

Ontologies[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).

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[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.

[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: http://dsp-psd.pwgsc.gc.ca/collection_2007/nrcan-rncan/M44-2002-E18E.pdf

[34] In computer science and information science. In philosophy, ontology is the study of being, existence and reality.

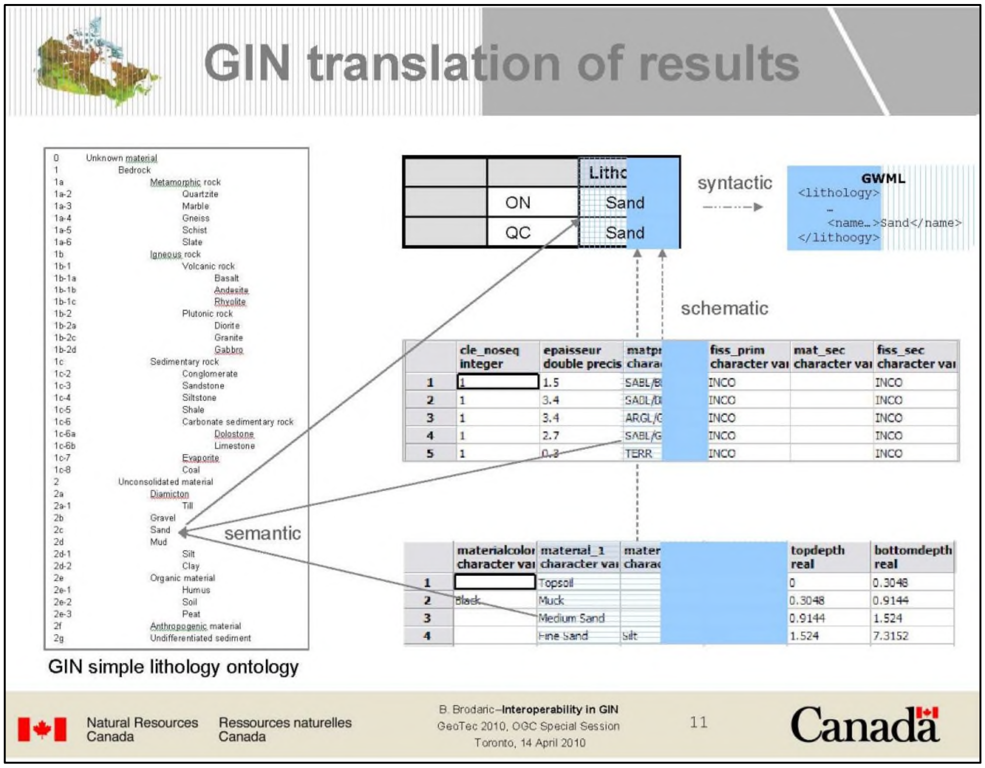


Figure 10: Diagram illustrating the close relationship between terminological and cross-language mapping in interoperable computer systems.

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)[35], [36] and Smyth (2004)[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.

[35] British Columbia Regional Geochemical Cluster Anomalies and Best Matches to Mineral Deposits" http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Documents/2003/27-Smyth-295-304-w.pdf
[36] www.rockstorichesbc.com
[37] www.yukonmineraltargets.com

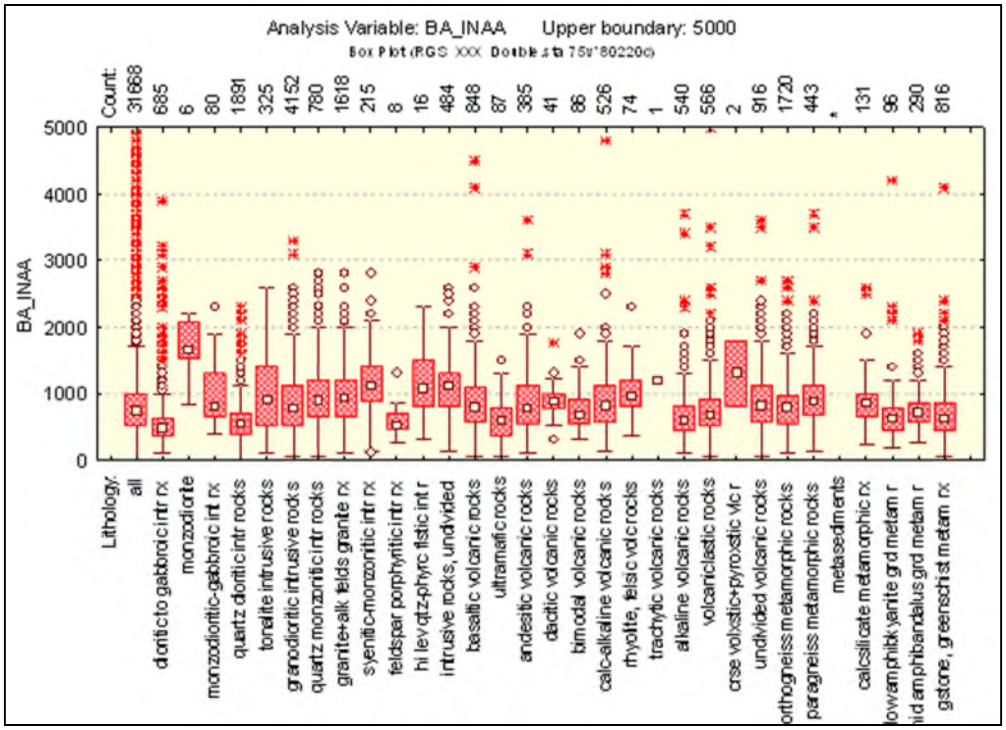


Figure 11: Ba (INAA) levels in streams (-80#) in British Columbia as a function of underlying map unit lithology.

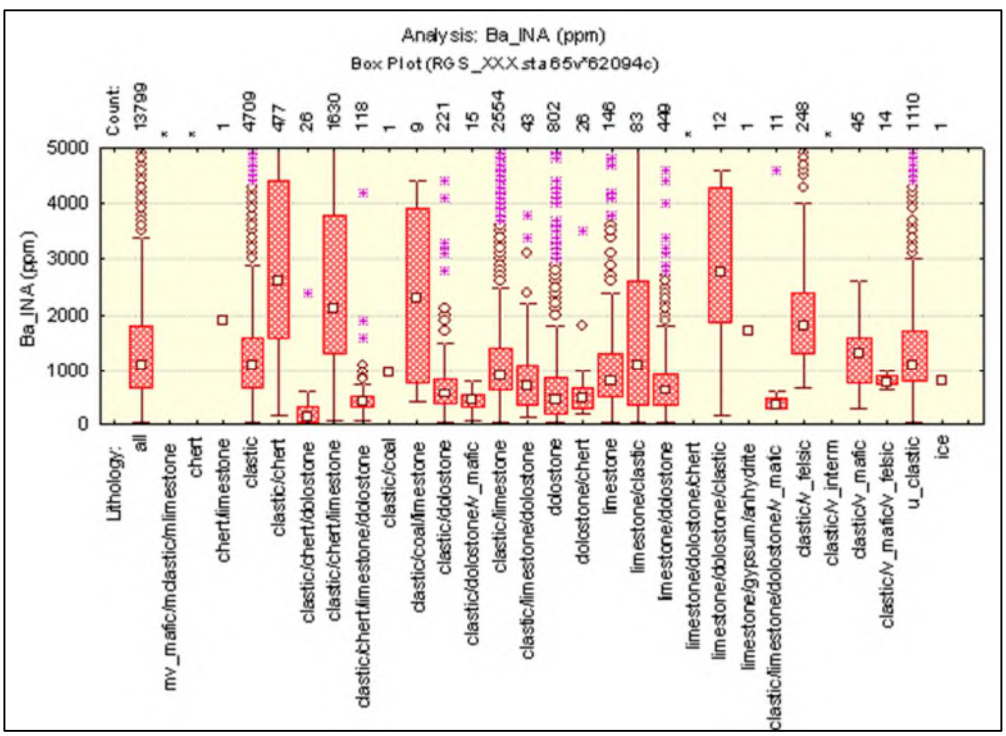


Figure 12: Ba (INAA) levels in streams (-80#) in the Yukon as a function of underlying map unit lithology.

Lithology Terms in the Interpretation of Geophysics

The following extracts from Geoscience BC Project Report 2006-015[38] 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[39] 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[40].

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).

[38] Parsons et al (2009); “Development and Application of a Rock Property Database for British Columbia”; http://www.geosciencebc.com/i/pdf/SummaryofActivities2008/SoA2008-Parsons_original.pdf
[39] http://www.mirageoscience.com/rpds
[40] Tonalite, like granite, is a granitoid.

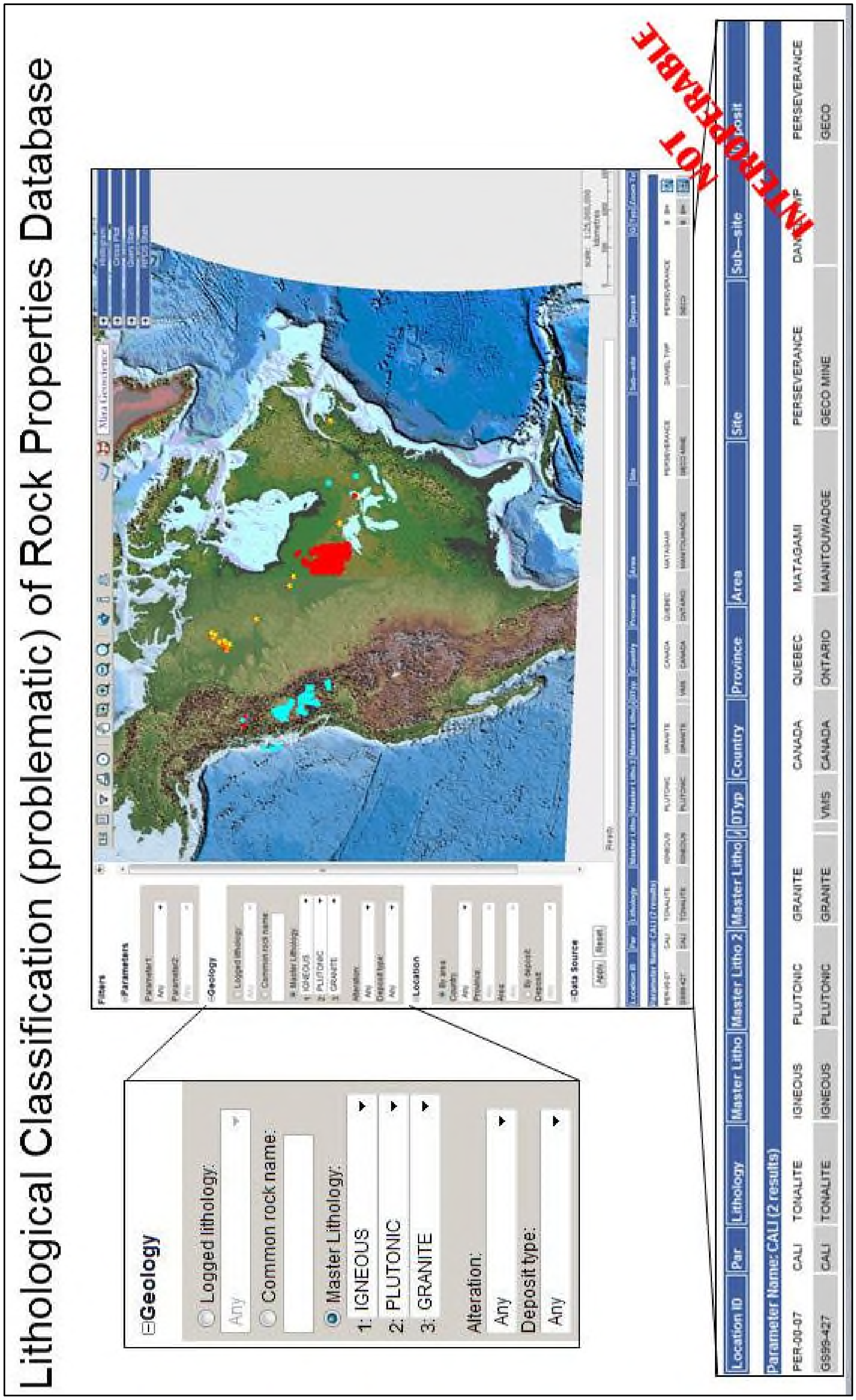


Figure 13: Mira/BC Rock Property Database System web interface illustrating utilisation of lithological grouping of data.

Appendix C *GeoSciML*

[The text below draws heavily from a 2008 CGI document describing GeoSciML, but has been updated to a September 2012 context.]

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.

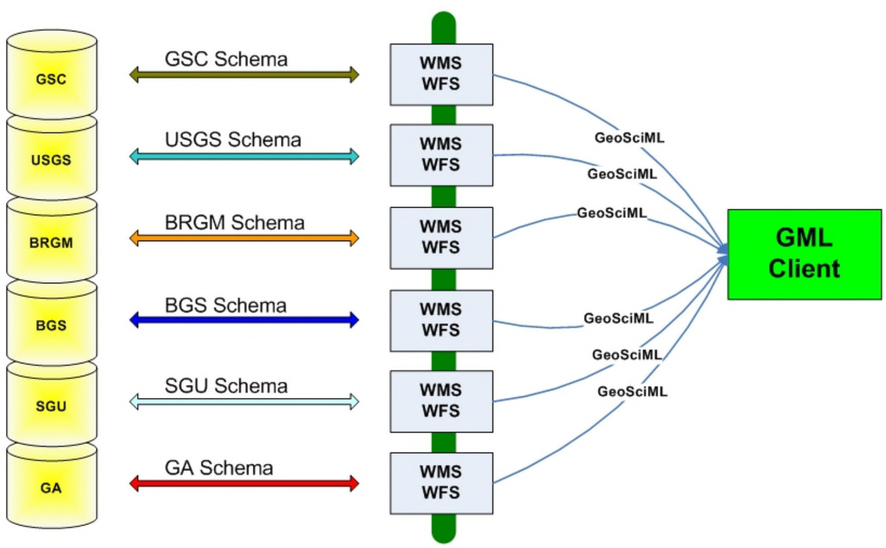
Developing such a conceptual data model is a major piece of work and in the current phase of development the scope has been restricted to those geoscience objects which form the main components of a geological map (geological units, faults, contacts, and their defining concepts) as well as boreholes.

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).



Architecture of the GeoSciML Test Bed 2

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

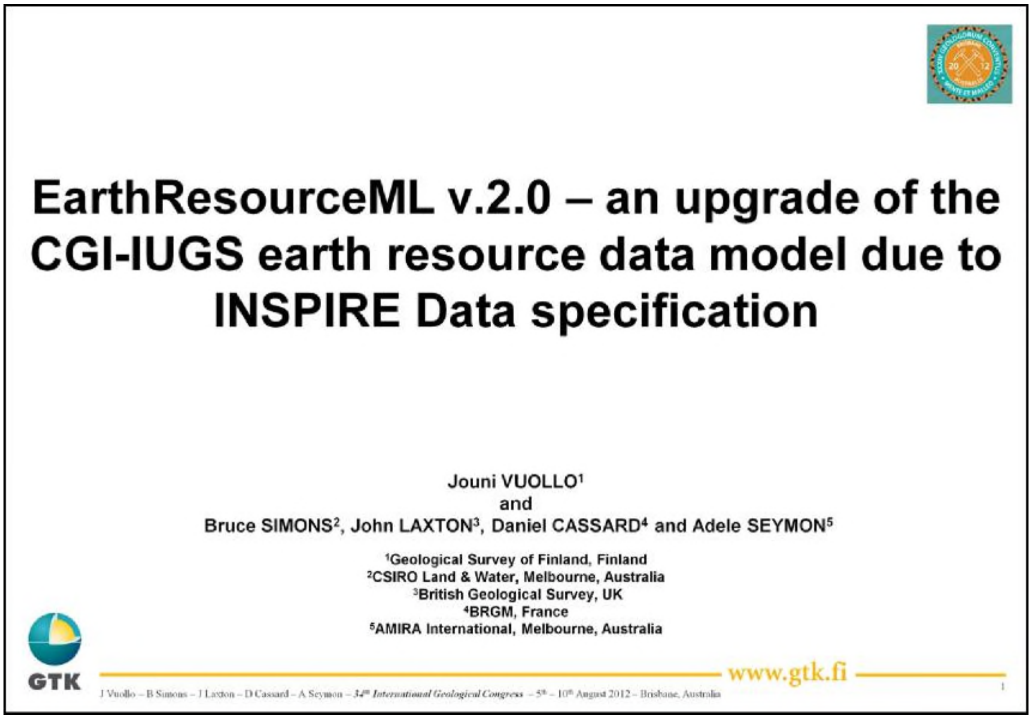
Jouni VUOLLO[1]
and
Bruce SIMONS[2], John LAXTON[3], Daniel CASSARD[4] and Adele SEYMON[5]

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

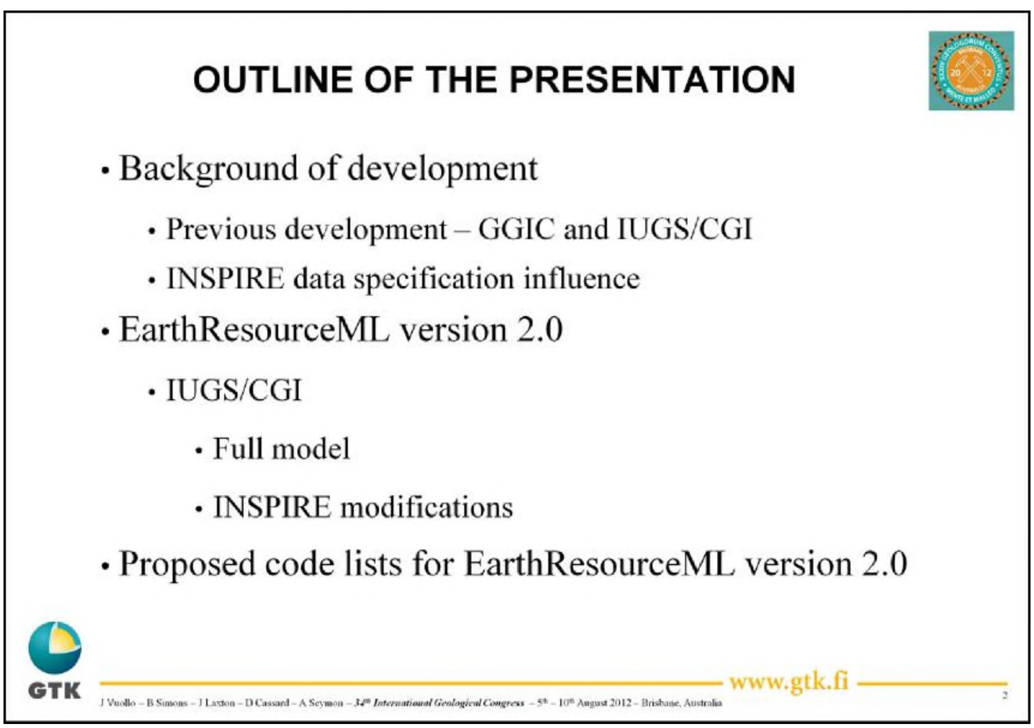
Much additional technical documentation is available from the ERML home page:

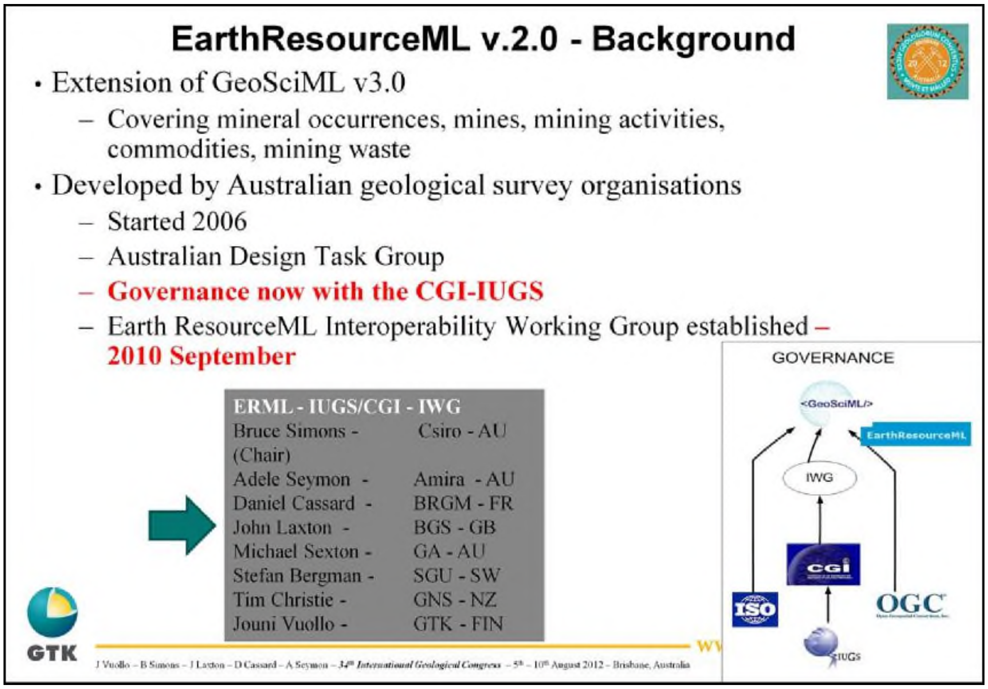
https://www.seegrid.csiro.au/wiki/CGIModel/EarthResourceML



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.

INRPIRE 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), <u>of which one is mineral resources.</u>



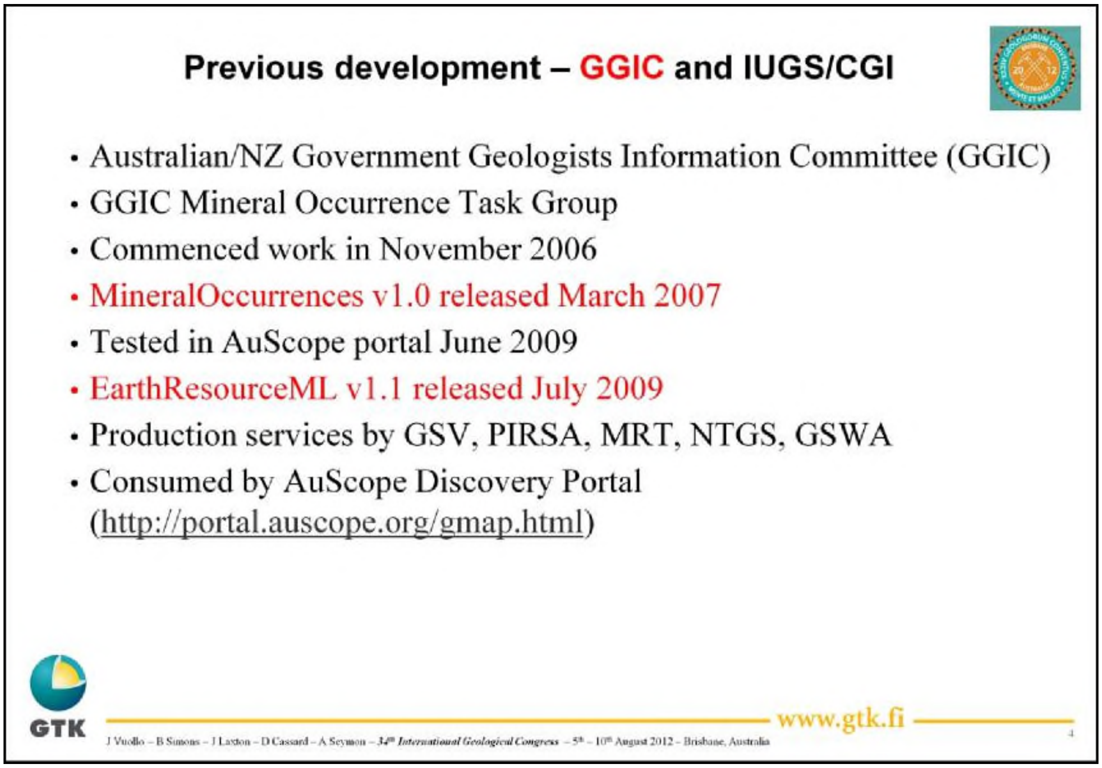


ERML began its life as the **eXploration and Mining Markup Language,** "XMML", in 2000, as described on the XMML project introduction web page:

> "The XMML project was initiated by CSIRO and Fractal Graphics in 2000. The requirement was to develop a data tranfer 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 "GGIC[41] 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.

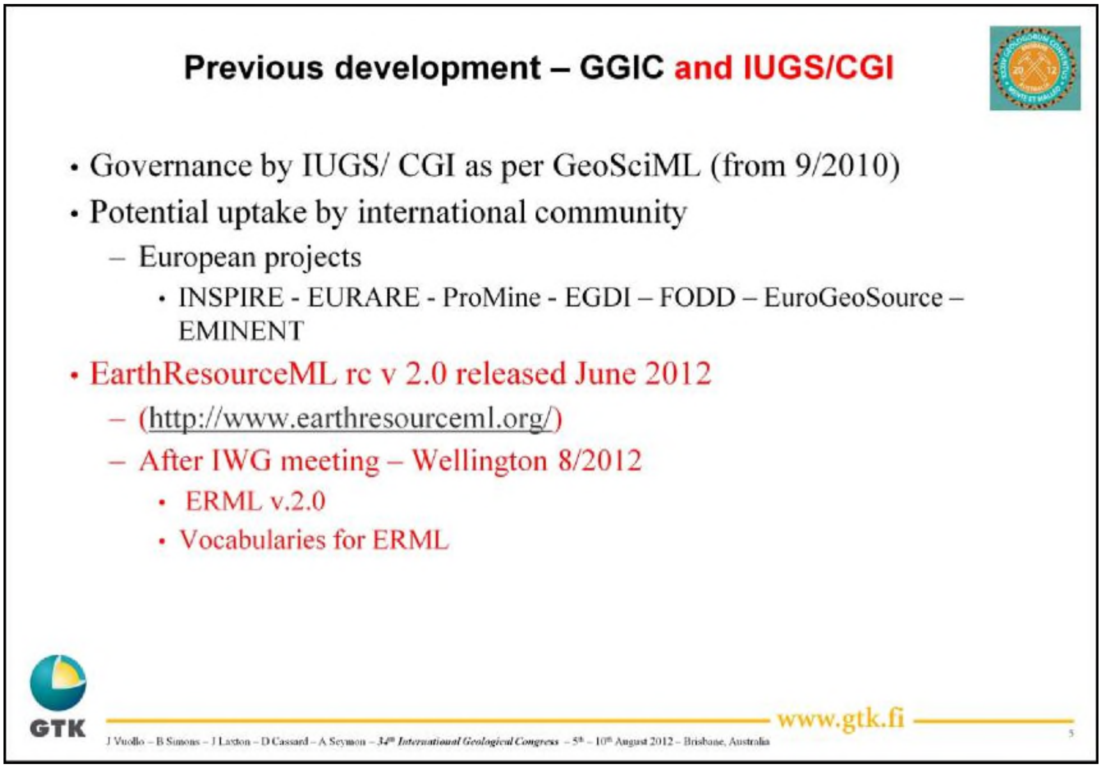


A little more on the critical Australian contribution:

The first Mineral Occurrence Task Group was established in 2006, resulting in a first data model in 2007 which was deployed an 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.



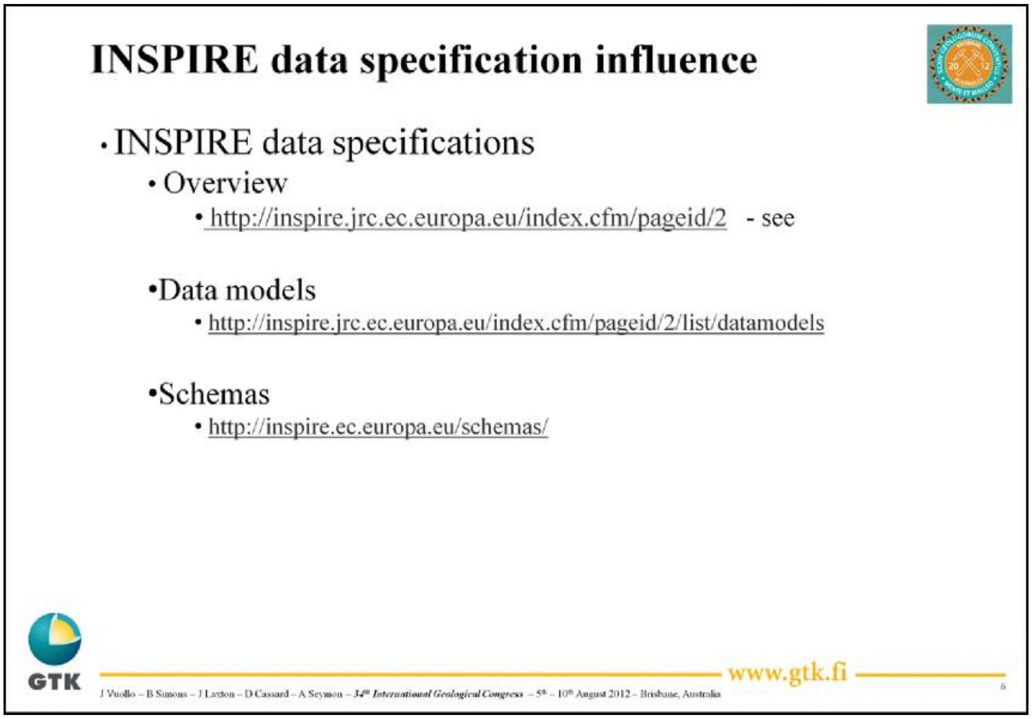
Movement, at the end of 2010, of ERML governance to IUGS/CGI and its interoperability working group marks the emergence of ERML as a global standard.

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.

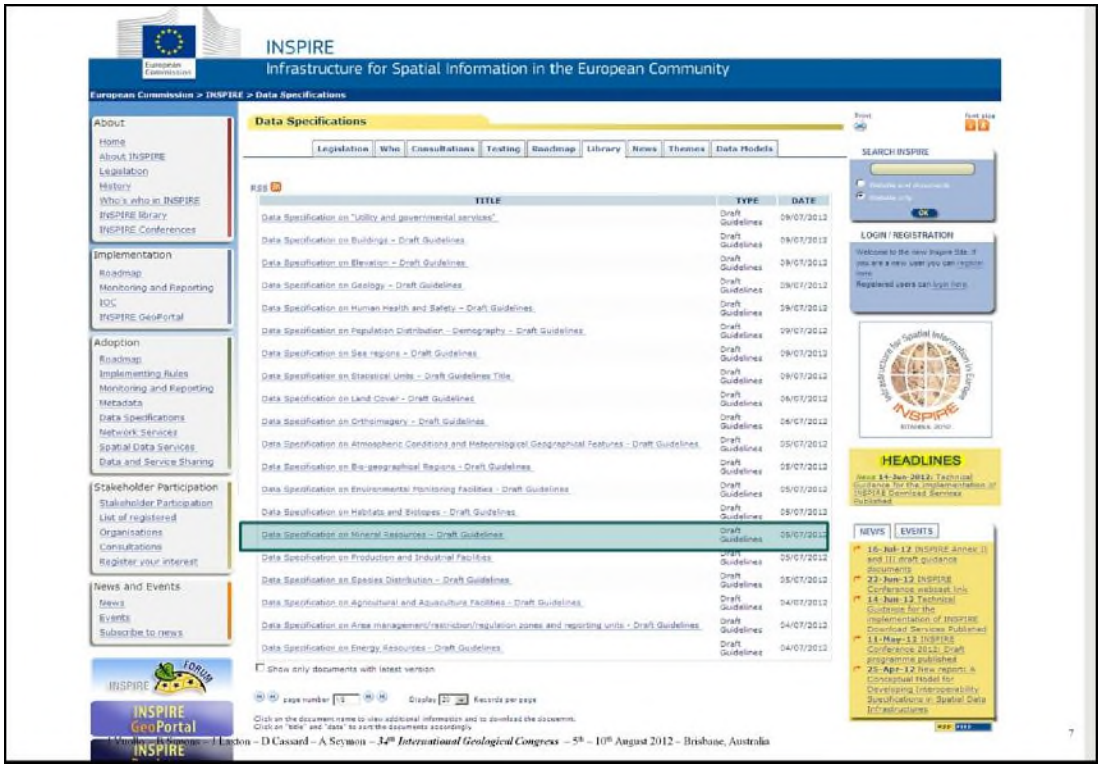
[* In Europe a major recent development has been the adoption of the INSPIRE[42] Directive of May 2007, establishing an infrastructure for spatial information in Europe to support EU environmental policies, and policies or activities which may have an impact on the environment, including geology and 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[43] (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.

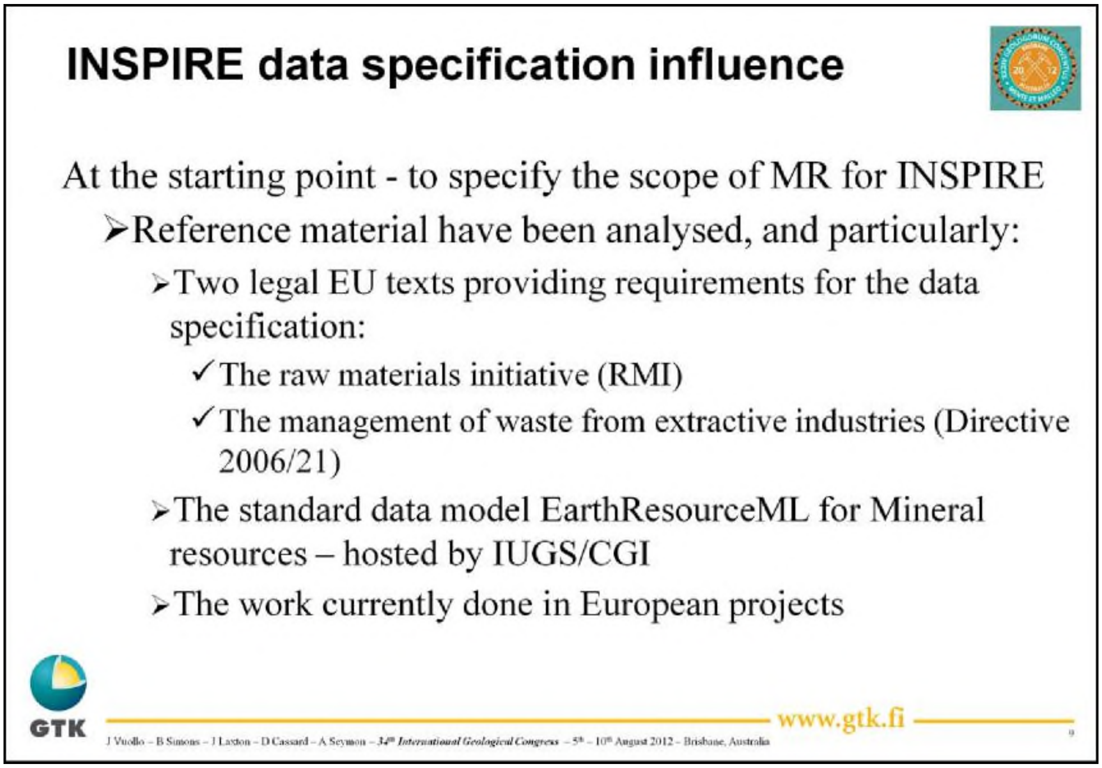
To ensure that the spatial data infrastructures of EU Member States are compatible and usable in a trans-country-boundary context, the Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing 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/
[43] http://inspire.jrc.ec.europa.eu/index.cfm/pageid/201/consultation/45851



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

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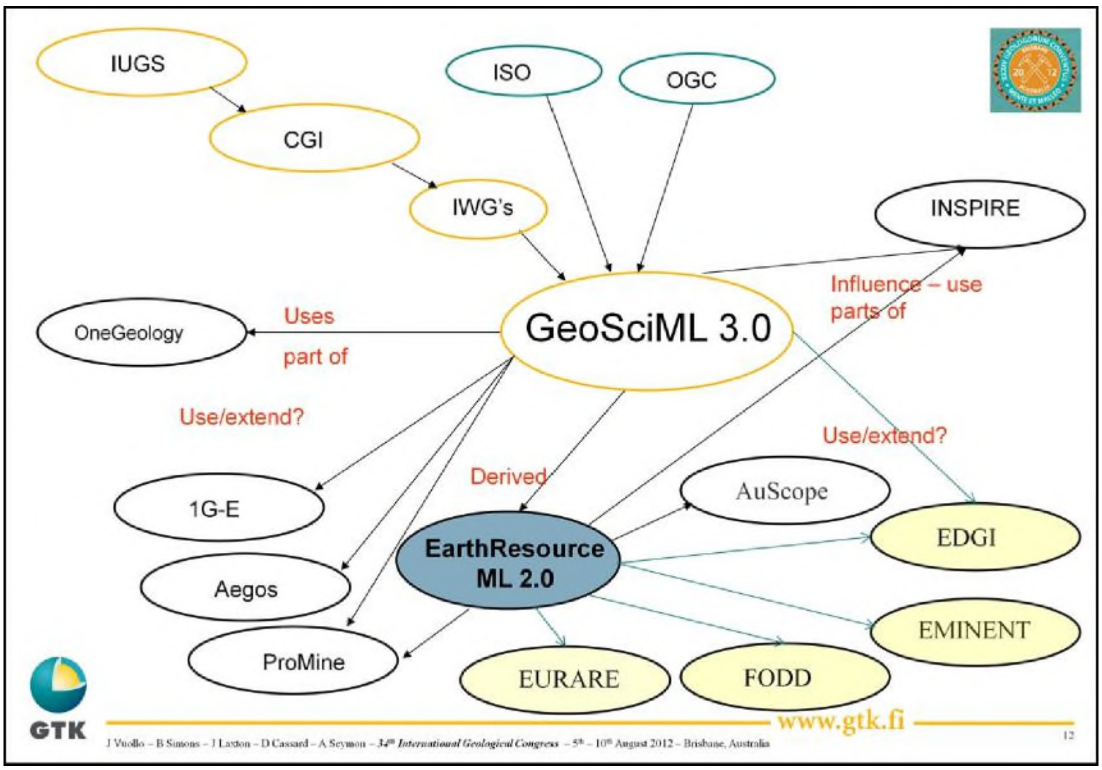
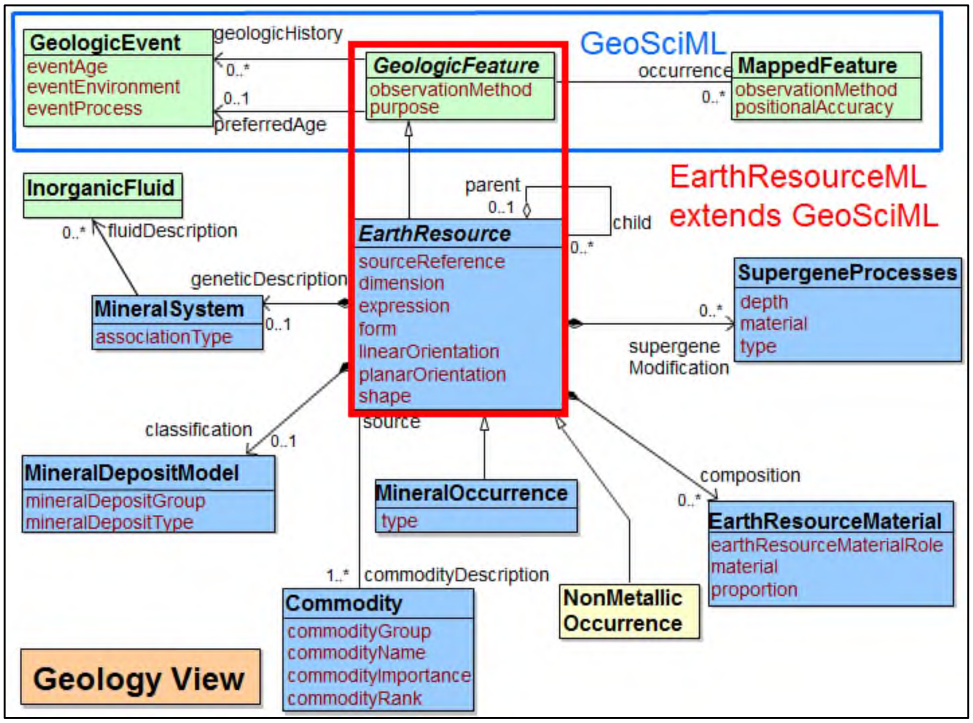
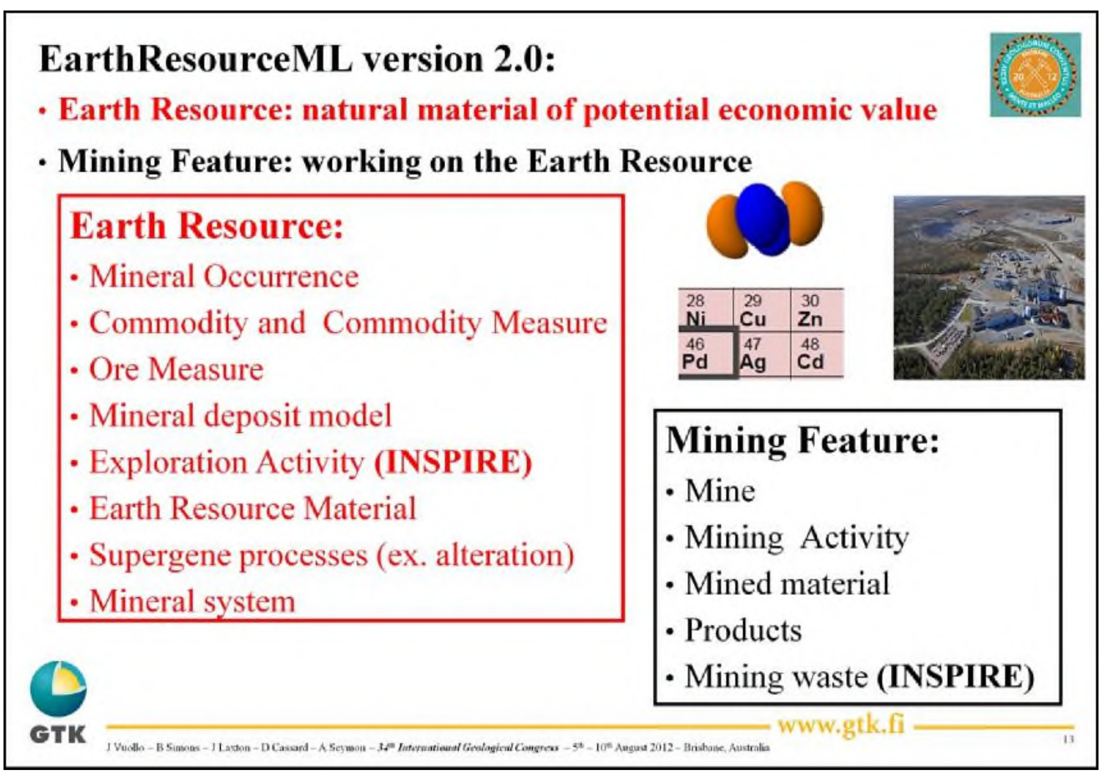
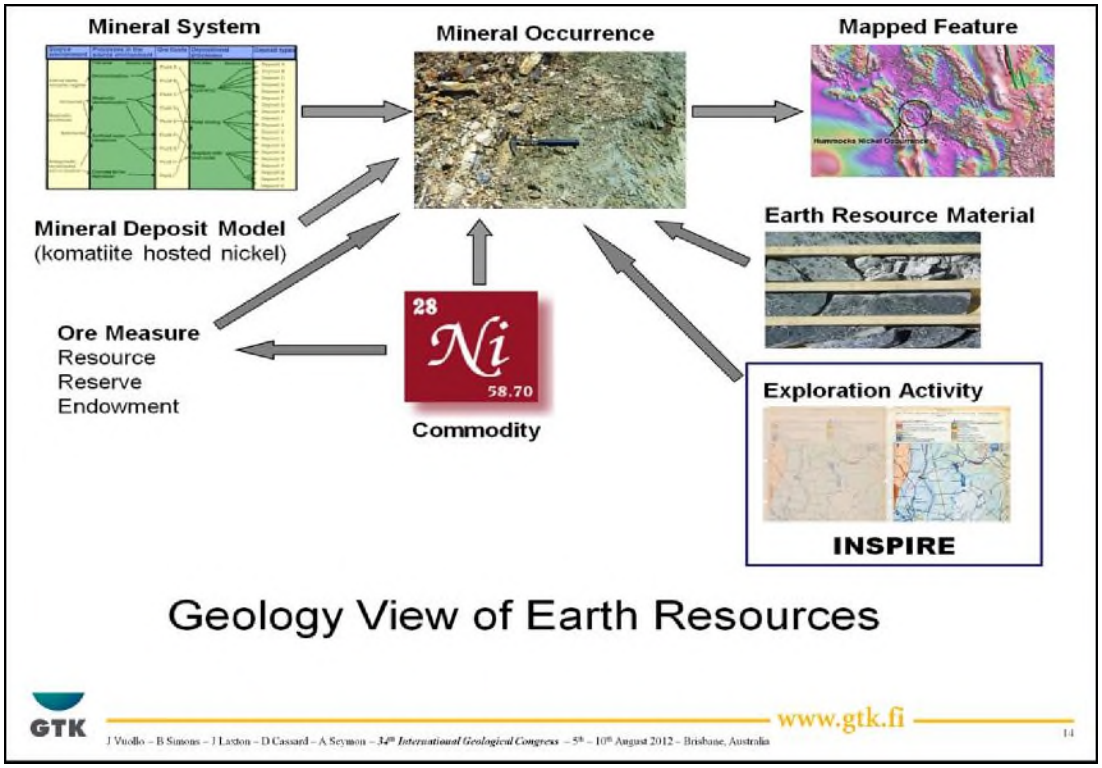


A pictorial view of the relationships between ERML and other standards, organizations and projects.

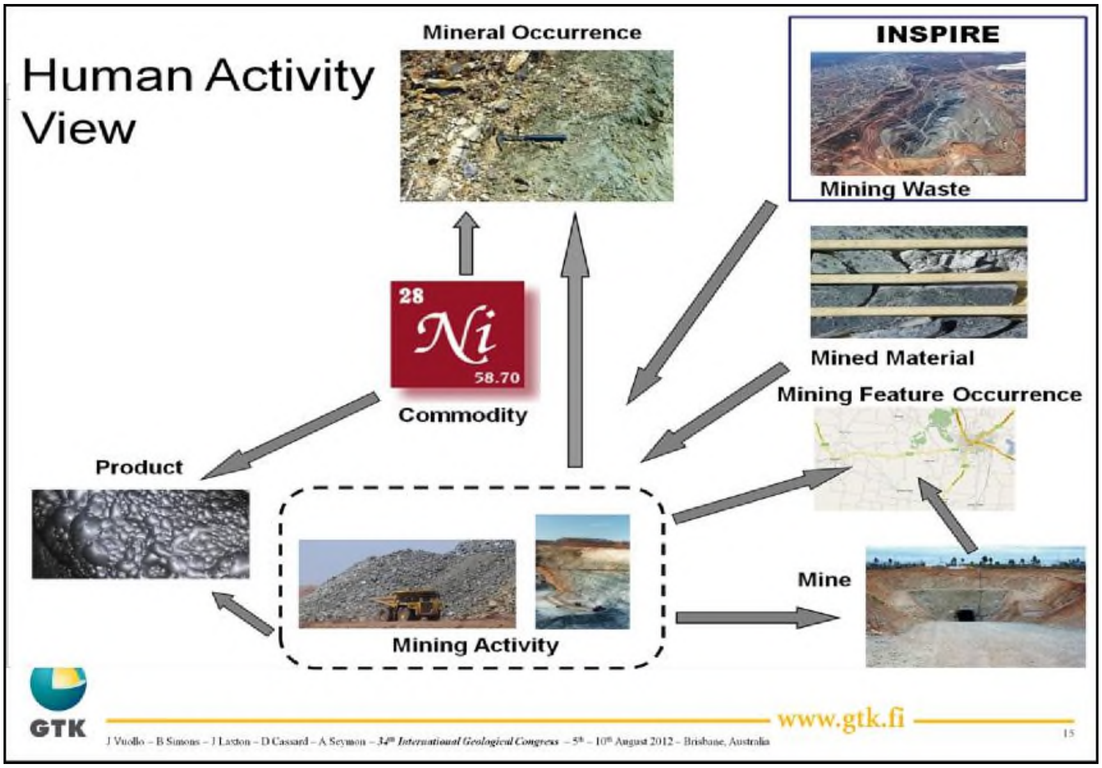


ERML is an extension of GeoSciML, as shown in this graphic of ERML V1 (with a "Geology View", but without a "Human Activity View"), from Bruce Simons' 2010 Powerpoint on ERML. Contrast it with ERML V2 below, which includes mining features and their attributes.





New INSPIRE elements are marked with squares and a dotted oval.



EarthResourceML v 2.0 – Code lists

- Most of the code lists came from the IUGS/CGI (EarthResourceML IWG) - then modified by INSPIRE TWG
- Some have been completed by the INSPIRE TWG
- Some are coming from other international organizations – e.g. mineral names from IMA
- Now the ERML v 2.0 model has 23 code lists
  - 20 proposed to host by IUGS/CGI
    - One code list unfinished – mineral deposit type – group
  - 3 lists from other international organizations
    - mineral names from IMA
    - Products from Gensus.org
    - Mining Waste types from EIONET
- Final governance – open question?

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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).

EarthResourceML v 2.0 – Code lists

Code list_Name	Organisation hosting
1_ImportanceValueMineralResources-Codelists-v1.0.docx	IUGS/CGI
2_CommodityCodeValue	IUGS/CGI
3_EarthResourceExpressionValue	IUGS/CGI
4_EarthResourceFormValue	IUGS/CGI
5_EarthResourceShapeValue	IUGS/CGI
6_EarthResourceMaterialRoleValue	IUGS/CGI
7_ExplorationActivityTypeValue	IUGS/CGI
8_ExplorationResultValue	IUGS/CGI
9_MineStatusValue	IUGS/CGI
10_RawMaterialRoleValue	IUGS/CGI
11_MineralOccurrenceTypeValue	IUGS/CGI
12_MineralDepositTypeGroupValue	IUGS/CGI
13_MiningActivityTypeValue	IUGS/CGI
14_WasteStorageTypeValue	IUGS/CGI
15_ProcessingActivityTypeValue	IUGS/CGI
16_MiningWasteTypeValue	Eionet
17_EnvironmentalImpactValue	IUGS/CGI
18_EndusePotentialValue	IUGS/CGI
19_ProductValue	census.gov
20_ReserveCategoryValue	IUGS/CGI
21_ResourceCategoryValue	IUGS/CGI
22_ClassificationMethodUsedValue	IUGS/CGI
23_MineralNameValue	IMA

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INSPIRE	Reference: D2.8.III.21_v3.0 rc2		
TWG-MR	Data Specification on *Mineral Resources*	2012-07-05	Page 92

Type	Package	Stereotypes	Section
EarthResourceMaterialRoleValue	MineralResourcesExtension	«codeList»	.3.1
EarthResource_Extension	MineralResourcesExtension	«featureType»	.1.1
EnvironmentalImpactValue	MineralResourcesExtension	«codeList»	.3.2
MinedMaterial	MineralResourcesExtension	«dataType»	.2.2
MineralSystem	MineralResourcesExtension	«dataType»	.2.3
MiningActivity_Extension	MineralResourcesExtension	«featureType»	.1.2
MiningWaste	MineralResourcesExtension	«featureType»	.1.3
MiningWasteMeasure	MineralResourcesExtension	«dataType»	.2.4
MiningWasteTypeValue	MineralResourcesExtension	«codeList»	.3.3
Product	MineralResourcesExtension	«featureType»	.1.4
ProductValue	MineralResourcesExtension	«codeList»	.3.4
RawMaterialRoleValue	MineralResourcesExtension	«codeList»	.3.5
SupergeneProcesses	MineralResourcesExtension	«dataType»	.2.5
WasteStorageTypeValue	MineralResourcesExtension	«codeList»	.3.6

Spatial object types

EarthResource_Extension

EarthResource_Extension	
Name:	Earth Resource_ Extension
Subtype of:	EarthResource
Definition:	A sub-type of EarthResource with associations to classes in the Mineral Resources extension model.
Status:	Proposed
Stereotypes:	«featureType»
Identifier:	null
Association role: geneticDescription	
Value type:	MineralSystem
Definition:	Provides a description for how the EarthResource formed
Multiplicity:	1
Stereotypes:	«voidable»
Association role: composition	
Value type:	EarthResourceMaterial
Definition:	The material forming the EarthResource
Multiplicity:	1..*
Stereotypes:	«voidable»
Association role: supergeneModification	
Value type:	SupergeneProcesses
Definition:	A supergene process which would allow a metal enrichment produced by the chemical remobilisation of elements in an oxidised or transitional environment.
Multiplicity:	0..*

MiningActivity_Extension

MiningActivity_Extension	
Name:	Mining Activity_ Extension
Subtype of:	MiningActivity
Definition:	A sub-type of MiningActivity with associations to classes in the Mineral Resources extension model.
Status:	Proposed

Some CodeLists and their definitions, as they appear in the July, 2012 INSPIRE specifications for their Mineral Resources feature layer (conformant with ERML)>

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[44] or **Geoscience Markup Language**[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[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[47] which is currently working on Version 3 of the following terminology standards:

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

44 https://www.seegrid.csiro.au/wiki/CGIModel/GeoSciML
45 http://www.opengeospatial.org/standards/gml
46 http://www.cgi-iugs.org/
47 https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG

Table 7: Listing of terminology standards developed for GeoSciML.

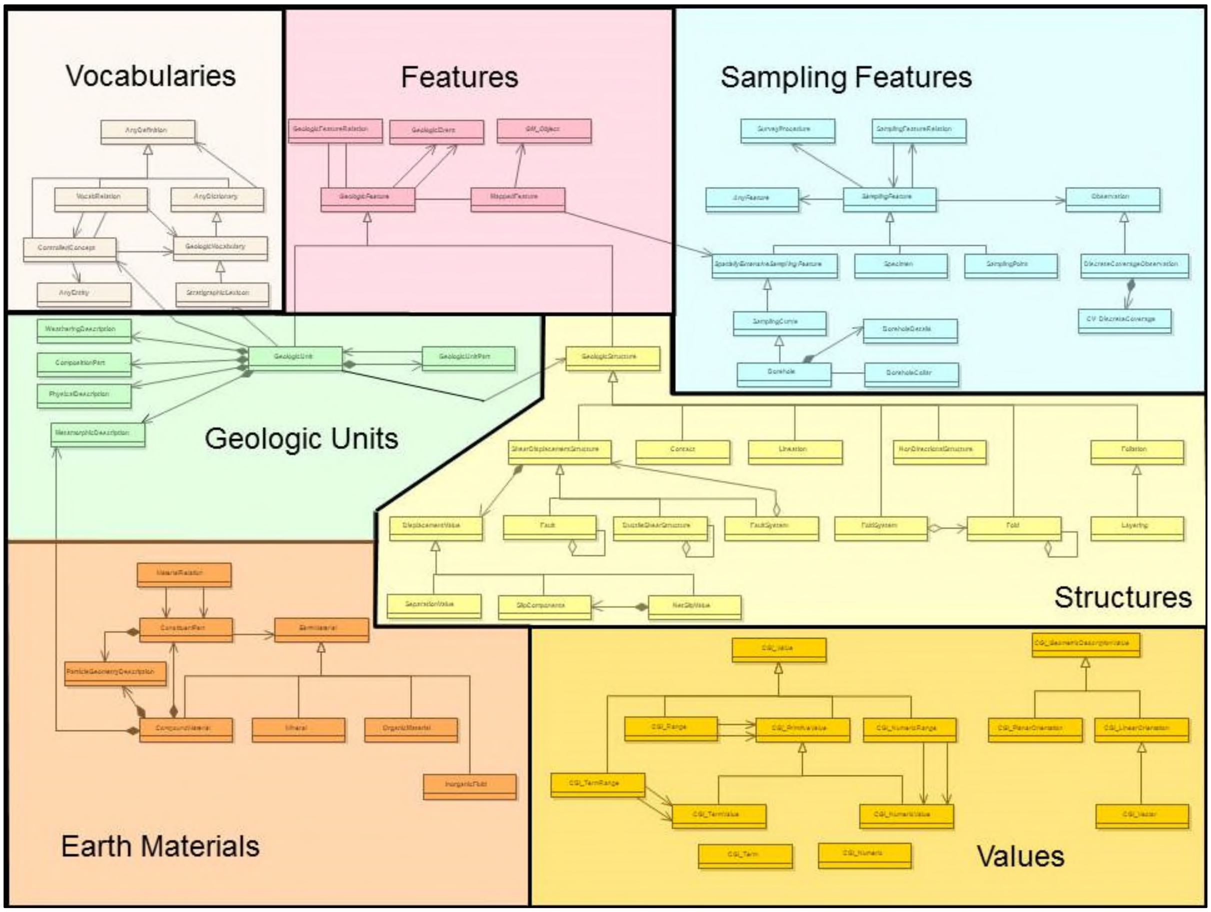

Figure 14: A simplified view of the GeoSciML architecture (Raymond (2008)[48]).

OneGeology

OneGeology[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.

[48] Illustration taken from presentation by O. Raymond to the GeoSciML Workshop at the 33rd IGC in Oslo, Norway in 2008; http://www.cgi-iugs.org/tech_collaboration/docs/Ollie_Raymond_GeoSciML_v2_rc3.ppt

[49] 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.

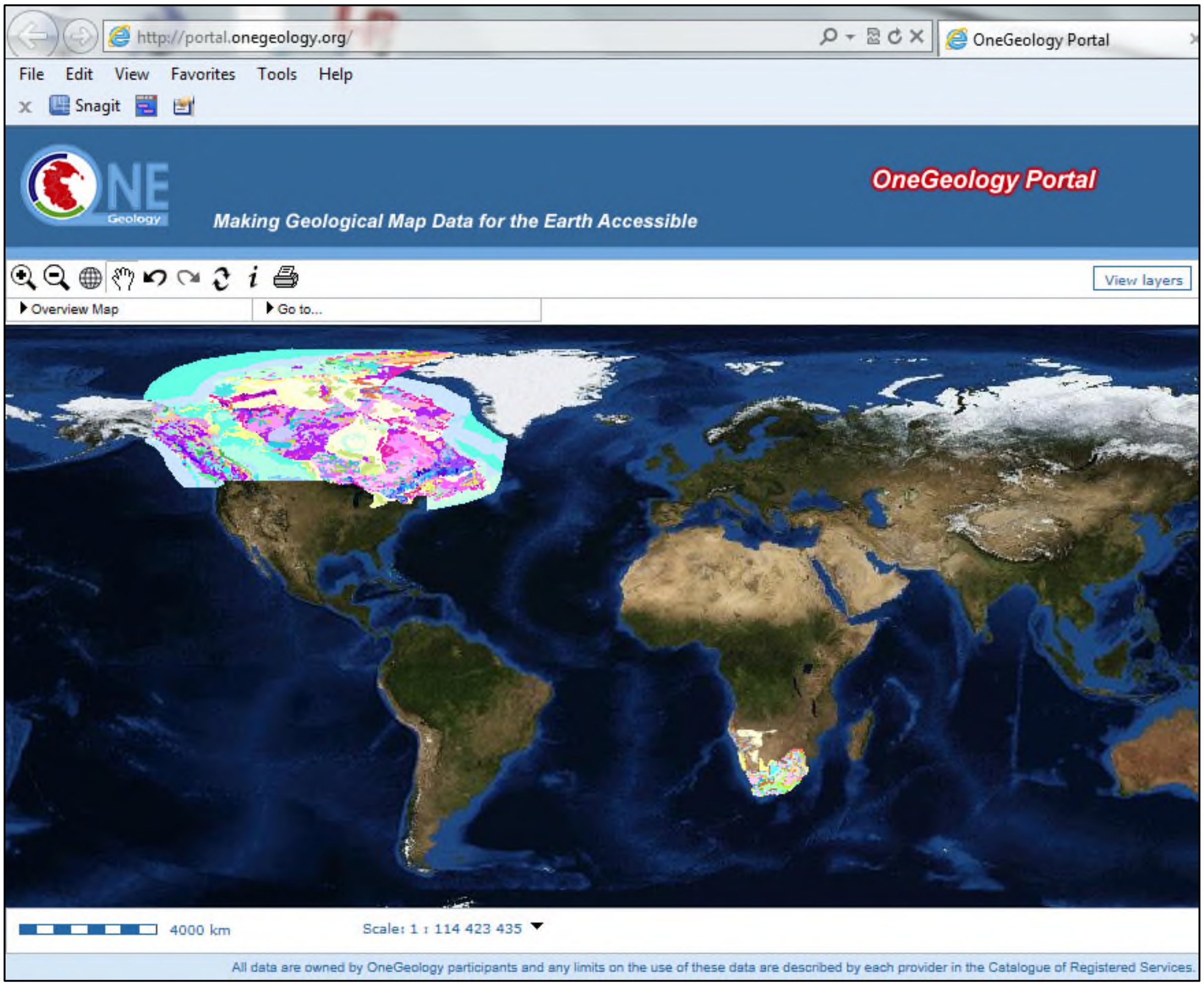

Figure 15: Display of the geological map of Canada by the OneGeology web portal also showing the geology of Namibia and South Africa. Map data is supplied to the British-based portal synchronously from servers in Canada and South Africa.

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/
[51] http://inspire.jrc.ec.europa.eu/index.cfm/pageid/201/consultation/45851

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 Model[52] (and[53]). 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[54] and is appropriate for adoption in Canada as well.

[52] https://www.seegrid.csiro.au/wiki/CGIModel/EarthResourceML

[53] https://www.seegrid.csiro.au/wiki/CGIModel/EdinburghF2F2011EarthResourceMLMeetingNotes

[54] See “Data Specification on Mineral Resources – Draft Guidelines” available at http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_MR_v2.0.pdf

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/

GeoSciML/CGI-OneGeology-Europe Term	R	G	B		C	M	Y	K
Igneous material …	129	43	146		40	80	0	149
v1 Fragmental igneous material	174	2	126		0	99	27	32
v1.1 Tuffite								
Pyroclastic material								
v1.3 Pyroclastic rock								
v1.2.1 Ash tuff, // lapillistone, // and lapilli tuff								
...Tuff breccia, agglomerate or pyroclastic breccia								
... Tephra								
... Ash and lapilli								
... Ash breccia bomb or block tephra								
v2 Fine grained igneous rock	227	185	219		0	19	4	11
... Rhyolitoid								
v2.1 Rhyolitic rock								
v2.1.1 Rhyolite								
... Alkali feldspar rhyolite								
... Dacite								
... Trachytoid								
v2.3 Trachytic rock								
v2.3.1 Trachyte								
... Latitic rock								
v2.3.2 Latite								
... Andesite								
... Boninite								
... Basalt								
v2.5.1.1 Alkali basalt								
v2.5.1.2 Tholeiitic basalt								
v2.5.1.3 Trachybasalt								
... Phonolitoid								
v2.6.1 Phonolite								
... Tephritoid								
v2.7.1 Basanite								
v2.7.2 Tephrite								
... Foiditoid								
v2.8.1 Foidite								
v2.9.1 Komatiitic rock								

See next page for Phaneritic Igneous Rocks, etc

GeoSciML/CGI-OneGeology-Europe Term	R	G	B		C	M	Y	K
… Phaneritic igneous rock	247	53	99		0	79	60	3
… Doleritic rock	254	179	66		0	30	74	0
… Pegmatite	254	204	92		0	20	64	0
… Aplite	253	217	106		0	14	58	1
… Granitoid	248	117	167		0	53	57	3
p1.1 Granite								
p1.1.1 Charnockite								
p1.2 Granodiorite								
p1.3 Tonalite								
… Syenitoid	247	104	211		0	57	15	3
p2 Syenitic rock								
p2.1 Quartz syenite								
p2.2 Syenite								
… Monzonitic rock								
p2.3 Foid-bearing syenite								
p2.4 Quartz monzonite								
p2.5 Monzonite								
… Dioritoid	247	91	137		0	63	45	3
p3 Dioritic rock								
p3.1 Quartz diorite								
p3.2 Diorite								
… Monzodioritic rock								
p3.3 Monzodiorite								
… Gabbroid	247	67	112		0	73	55	3
p4 Gabbroic rock								
p4.1 Monzogabbro								
p4.2 Gabbro								
p4.3 Gabbronorite								
p4.4 Norite								
p5 Anorthositic rock	250	167	200		0	33	20	2
… Foid syenitoid	250	129	181		0	48	28	2
… Foid dioritoid	248	104	178		0	58	28	3
… Foid gabbroid	245	104	178		0	58	28	3
p9 Foidolite	245	104	178		0	58	28	3
p10 Ultramafic phaneritic rock	240	4	127		0	98	47	60
p10.1 Peridotite								
p10.2 Pyroxenite								

GeoSciML/CGI-OneGeology-Europe Term	R	G	B		C	M	Y	K
Metamorphic Rock	103	143	102		28	0	28	44
m1. Anchimetamorphic rock ??	191	194	107		0	0	45	24
m1.2 Spilite								
m2 Sedimentary protolith	255	255	115		0	0	55	0
m2.1 Quartzite								
… Foliated metamorphic rock	166	198	171		16	0	14	22
m5.10 Gneiss								
m2.5 Paragneiss								
m5.4 Mylonitic rock								
m5.3 Phyllite								
m5.1 Slate								
m3.1 Serpentinite	116	198	126		41	0	36	22
m3.3 Porphyroid								
… Glaucophane lawsonite epidote metamorphic rock = (Blueschist)								
m5.2.6 Greenschist								
m5.2 Schist								
m5.2.7 Mica schist								
m5.5 Skarn/Hornfels/Granofels								
m5.6 Granulite								
m5.7 Marble								
m5.8 Amphibolite								
m5.9 Eclogite								
m6 Migmatite								
m8 Impact Metamorphic rock	51	169	126		70	0	25	34

GeoSciML/CGI-OneGeology-Europe Term						R	G	B		C	M	Y	K
Sedimentary Material						255	255	190		0	0	25	0
	s.1 Sediment [unconsolidated material]					255	242	174		0	5	32	0
		s.1.1 Clastic sediment				255	242	211		0	5	17	0
			s.1.1.1 Gravel										
			s1.1.2 Sand										
			s.1.1.5 Mud										
				s.1.1.4 Clay									
				s.1.1.3 Silt									
				... Ooze									
			s.1.1.6 Marl										
			s.1.1.7 Diamicton										
		... biogenic sediment				250	240	205		0	14	16	1
			... Organic rich sediment										
				Ooze									
					Siliceous ooze								
					Calcareous ooze								
				s1.2.5 Peat									
		... Carbonate sediment				52	178	201		74	11	0	21
			... Impure carbonate sediment [alternative label: Marl]										
	s.2 Sedimentary Rock					255	255	115		0	0	55	0
		s.2.1 Clastic sedimentary rock				255	230	25		0	10	90	0
			s.2.1.1 Breccia ??										
			s.2.1.2 Conglomerate										
			s.2.1.3 Sandstone										
				... Arenite									
				s.2.1.3... Arkose									
				s.2.1.3.4 Wacke									
			s.2.1.6 Mudstone										
				s.2.1.4 Siltstone [Silt bearing mudstone ?]									
				s.2.1.5 Claystone									
					s.2.1.5.1 Shale								
			s.2.1.8 Diamictite										
		s1.2 Organic rich sedimentary rock				230	230	230		0	0	0	98
			s1.2.1 Lignite										
			s1.2.2 Coal										
			s1.2.3 Anthracite										
			s1.2.4 Oil shale										
		s.2.2 Carbonate sedimentary rock				80	125	255		68	51	0	0
			... Impure carbonate sedimentary rock										
				s.2.1.7 Marlstone									
				s.2.2.3 Limestone									
					s.2.2.1 Chalk								
					s.2.1.3.3 Calcarenite								
				s.2.2.2 Travertine									
				s.2.2.4 Dolomitic or magnesium sedimentary rock									
				s.2.2.5 dolostone									
		s.2.3 Non-clastic siliceous sedimentary rock				203	140	55		0	40	76	10
			s.2.3.2 Biogenic silica sedimentary rock										
		s.2.4 Iron rich sedimentary rock				215	170	110		0	20	49	16
	... Chemical sedimentary material					153	206	227		32	9	0	11
		s.3 Evaporite											
			s.3.1 Rock salt										
			s.3.2 Gypsum or Anhydrite										
	... Composite genesis material					153	194	181		21	0	7	24
		... Material formed in surficial environment											
			s.4 Duricrust										
			s.5 Bauxite										
			... Residual material										

Appendix G *GeoSciML Working Group suggested Colour Legend for GeoSciML Rock Types*

Reference: https://www.seegrid.csiro.au/wiki/CGIModel/TestBed3UseCase1Profile

GeoSciML Rock Type	Hex	Red	Green	Blue	Fill Colour
acidic igneous material	#FFCCB3	255	204	179	
acidic igneous rock	#FECDB2	254	205	178	
amphibolite	#AC7F50	172	127	80	
andesitic rock	#B14801	177	72	1	
anorthositic rock	#FFA3B9	255	163	185	
anthropogenic material	#C0C0C0	192	192	192	
anthropogenic unconsolidated material	#C8C8C8	200	200	200	
aphanite	#CDCDCD	205	205	205	
aplite	#FFC8BF	255	200	191	
Ash and lapilli	#FFC8C3	255	200	195	
Ash breccia, bomb, or block tephra	#FFF5D9	255	245	217	
Ash tuff, lapillistone, and lapilli tuff	#FFF5DF	255	245	223	
basaltic rock	#DDB397	221	179	151	
basic igneous material	#E69900	230	153	0	
basic igneous rock	#E69900	230	153	0	
bauxite	#FFFFB7	255	255	183	
biogenic sediment	#F7F3A1	247	243	161	
biogenic silica sedimentary rock	#F7F3A1	247	243	161	
boundstone	#E7F6F1	231	246	241	
breccia	#D7A7AD	215	167	173	
breccia-gouge series	#DCAAA0	220	170	160	
calcareous carbonate sediment	#DEEFFE	222	239	254	
calcareous carbonate sedimentary material	#C8E7FA	200	231	250	
calcareous carbonate sedimentary rock	#B2DFF5	178	223	245	
carbonate gravel	#9CD7F0	156	215	240	
carbonate mud	#86CFEB	134	207	235	
carbonate mudstone	#70C7E6	112	199	230	
carbonate sand	#5ABFE1	90	191	225	
carbonate sediment	#44B7DC	68	183	220	
carbonate sedimentary material	#2EAFD2	46	175	210	
carbonate sedimentary rock	#019CCD	1	156	205	
carbonate wackestone	#B7D9CC	183	217	204	
carbonatite	#CC3333	204	51	51	
cataclasite series	#F4FFD5	244	255	213	
chemical sediment	#CDDEFF	205	222	255	
clastic sediment	#D9FDD3	217	253	211	
clastic sedimentary material	#D9FDD3	217	253	211	
clastic sedimentary rock	#D9FDD3	217	253	211	
coal	#6E4900	110	73	0	
composite (transformed) genesis material	#6A006A	106	0	106	

GeoSciML Rock Type	Hex	Red	Green	Blue	Fill Colour
composite (transformed) genesis rock	#5F005F	95	0	95	
conglomerate	#B7D9CC	183	217	204	
crystalline carbonate	#0FFFFF	15	255	255	
dacitic rock	#FECDAC	254	205	172	
diamictite	#597D6E	89	125	110	
diamicton	#597D6E	89	125	110	
diorite	#FF3317	255	51	23	
dioritic rock	#DFC8C8	223	200	200	
doleritic rock	#F4636B	244	99	107	
dolomitic or magnesian sedimentary material	#BFBFFF	191	191	255	
dolomitic or magnesian sedimentary rock	#BFBFFF	191	191	255	
dolomitic sediment	#BFBFFF	191	191	255	
duricrust	#FFA252	255	162	82	
eclogite	#FF4FFF	255	79	255	
evaporite	#9ACEFE	154	206	254	
exotic alkalic igneous rock	#FF6F91	255	111	145	
exotic alkaline rock	#FFD1DC	255	209	220	
exotic composition igneous rock	#A6FCAA	166	252	170	
fault-related material	#D0CBB2	208	203	178	
fine grained igneous rock	#FF00FF	255	0	255	
foid dioritic rock	#E88CA0	232	140	160	
foid gabbroic rock	#CE929F	206	146	159	
foid syenitic rock	#FF9EBE	255	158	190	
foiditic rock	#FF7357	255	115	87	
foidolite	#FD1D68	253	29	104	
foliated metamorphic rock	#EE7CE8	238	124	232	
fragmental igneous material	#EEA0AA	238	160	170	
fragmental igneous rock	#EEA0AA	238	160	170	
framestone	#A7A7FF	167	167	255	
gabbro	#E9935A	233	147	90	
gabbroic rock	#FF5B5B	255	91	91	
glassy igneous rock	#FFE5F3	255	229	243	
gneiss	#9F00CA	159	0	202	
grainstone	#FFE389	255	227	137	
granite	#FB2338	251	35	56	
granitic rock	#EE68A6	238	104	166	
granodiorite	#E979A6	233	121	166	
granofels	#A337DF	163	55	223	
gravel	#ECB400	236	180	0	
hornblendite	#A30109	163	1	9	
hornfels	#EAAFFF	234	175	255	
igneous material	#F84D4D	248	77	77	
igneous rock	#F84D4D	248	77	77	
impact metamorphic rock	#9063FF	144	99	255	
intermediate composition igneous material	#FFE699	255	230	153	
intermediate composition igneous rock	#FFE699	255	230	153	
iron rich sediment	#B99598	185	149	152	

GeoSciML Rock Type	Hex	Red	Green	Blue	Fill Colour
iron rich sedimentary material	#B99598	185	149	152	
iron rich sedimentary rock	#B99598	185	149	152	
komatiitic rock	#B33000	179	48	0	
lapillistone, agglomerate, tuff breccia	#FFE6D9	255	230	217	
marble	#0000FF	0	0	255	
metamorphic rock	#E6CDFF	230	205	255	
migmatite	#AC0000	172	0	0	
monzodiorite	#FFA99D	255	169	157	
monzogabbro	#FFD6D1	255	214	209	
monzonite	#FF275A	255	39	90	
mud	#AFE6CA	175	230	202	
mudstone	#ACE4C8	172	228	200	
mylonitic rock	#D0CBB0	208	203	176	
natural unconsolidated material	#FDF43F	253	244	63	
non-clastic siliceous sediment	#6363EB	99	99	235	
non-clastic siliceous sedimentary material	#6363EB	99	99	235	
non-clastic siliceous sedimentary rock	#6363EB	99	99	235	
ooze	#9696B9	150	150	185	
organic rich sediment	#42413C	66	65	60	
organic rich sedimentary material	#42413C	66	65	60	
organic rich sedimentary rock	#42413C	66	65	60	
packstone	#2727E3	39	39	227	
peat	#FFCC99	255	204	153	
pegmatite	#FFD1DC	255	209	220	
peridotite	#CE0031	206	0	49	
phaneritic igneous rock	#FF70B5	255	112	181	
phonolitic rock	#5F391F	95	57	31	
phosphate rich sedimentary material	#9ED7C2	158	215	194	
phosphatic sediment	#9ED7C2	158	215	194	
phosphorite	#BFE3DC	191	227	220	
phyllite	#EDEDF3	237	237	243	
phyllonite	#339966	51	153	102	
porphyry	#FFFFE8	255	255	232	
pyroclastic material	#FFEDBF	255	237	191	
pyroclastic rock	#FFEDBF	255	237	191	
pyroxenite	#C1010A	193	1	10	
quartz rich phaneritic igneous rock	#EEA0AA	238	160	170	
quartzite	#9FFF9F	159	255	159	
rhyolitic rock	#FED768	254	215	104	
rock	#FF0000	255	0	0	
sand	#FFCB23	255	203	35	
sandstone	#CDFFD9	205	255	217	
schist	#DBDBE7	219	219	231	
sediment	#FFFF00	255	255	0	
sedimentary material	#F5F500	245	245	0	
sedimentary rock	#CFEFDF	207	239	223	
serpentinite	#005C00	0	92	0	

GeoSciML Rock Type	Hex	Red	Green	Blue	Fill Colour
shale	#C0D0C0	192	208	192	
slate	#A7A7FF	167	167	255	
syenite	#CD3278	205	50	120	
syenitic rock	#CD3278	205	50	120	
tephra	#C84100	200	65	0	
tephritic rock	#C24100	194	65	0	
tonalite	#FF6F6B	255	111	107	
trachytic rock	#FEA060	254	160	96	
tuff-breccia, agglomerate, or pyroclastic breccia	#FFEFD9	255	239	217	
ultrabasic igneous rock	#CC0000	204	0	0	
unconsolidated material	#FFF900	255	249	0	
wackestone	#BDDBF1	189	219	241	