Loop3D GeoScience Ontology

Version 1, Draft 2020-02-10 11:21 AM

Stephen M. Richard, US Geoscience Information Network smrTucson@gmail.com

Boyan Brodaric, Geological Survey of Canada boyan.brodaric@canada.ca

Table of Contents

Introduction

The Loop3D Geoscience Ontology is intended to enable implementation of a 3-D geologic data system in a linked data environment that can be integrated with other national and global environmental and geoscience information systems. The model was developed first in UML using the Sparx Enterprise Architect tool, and then implemented in OWL using a combination of text editing and the TopQuadrant TopBraid Composer tool. The OWL implementation is serialized using Turtle notation. The Turtle files have been tested to open in TopBraid Composer and Protégé v.5.5. One of the design goals is to harmonize the NADM C1 model and the GeoSciML v3.2 conceptual model, with the DOLCE high-level ontology. The scope of the model includes Earth Materials, Geologic Units, and Geologic Structure, and Geologic Relationships.

The ontology implementation is modularized to enable development of application-specific profiles that bring a minimum of unneeded classes and properties. There are two top-level ontologies, 'Common' for high-level cross domain concepts mostly inherited from DOLCE (with some BFO modifications), and 'Geology', which contains the basic framework for geoscience concepts. A collection of module are implemented to extend the content of the base modules. The Modules add detailed subclasses and properties of classes in the top level ontologies, bind properties to classes. Vocabularies that define terminology for some property values have been adopted from the CGI Geoscience Terminology vocabularies by converting SKOS representations to OWL. The vocabularies are loosely coupled to the modules, allowing profiles to use of different terminology. Much of the detailed content in the extensions is based on GeoSciML v3.2.

The idea is that any Loop3D dataset would use the base Common and Geology ontology, and set up a 'Master' ontology defining a profile that imports those base ontologies, along with the modules and vocabularies that are needed for that profile. The package of owl files in the Version 1 delivery includes a 'Master' ontology that imports all modules and vocabularies to enable the entire model, and this is the profile used to implement the included example instances.
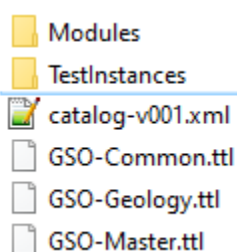
Modules:

Figure 1. Github repository layout.

The Ontology is being developed in a GitHub repository, with the sub directories and files shown in Figure 1. The top level Common and Geology ontology files are at the top level, along with the master import file that brings all the components togtether. The Modules folder contain the thematic modules and a subdirectory 'ComponentVocabs' that contains the ontology files for the property value terminology. Each of the main folders contains an OASIS catalog file (catalog-v001.xml in Figure 1), which provides a mapping from ontology URIs used in import statements to the file locations in the repository.

This is necessary because the URIs do not currently resolve on the Web, but must be accessed locally; the OWL editors use the catalog file to find the imports.

Ontology Classes

The following sections present the main classes in the ontology with some explanation of the logical approach and semantics of the classes.
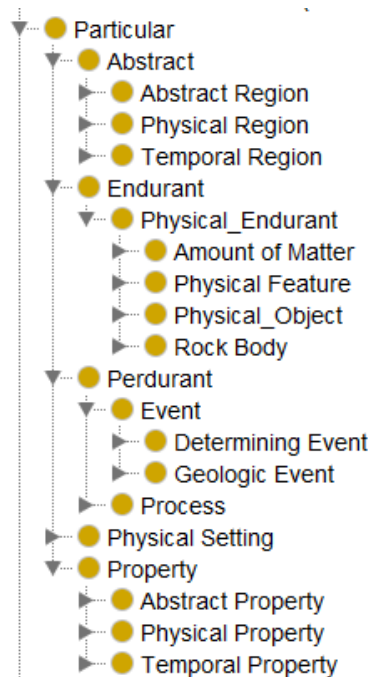

Figure 2. Top Level Classes.

Top Level Classes

'Particular' is a top level concept in DOLCE, corresponding to 'thing' or 'entity' in other schemes. The Abstract classes represent conceptual spaces or 'regions' that are given identifiers and labels for quantifying property values. An Endurant is wholly present at any time at which they exist, and can change in time. An Endurant can survive the loss and/or replacement of parts. A Physical Endurant is an endurant having a direct physical (at least spatial) quality. Perdurants (AKA occurrences) comprise what are variously called events, processes, phenomena, activities and states. They can have temporal parts or spatial parts. A Physical Setting is a notional place that might be defined with parts that are endurants or perdurants, and also with particular qualities/properties, and is thus a direct subtype of Particular. Property subclasses are concepts that specifies some aspect that inheres in instances of some Particular.

Abstract Classes

The Abstract category has three subclasses. The Abstract Region group are for values that describe information objects. The Physical Region group includes conceptual spaces for values that characterize things in the world. In a complete ontology there would be a sub class for each property that is quantified using a controlled vocabulary, but only a sampling of vocabularies have been implemented in this version. Except for Color, and Spatial Region, and State of Matter these are all adopted from the CGI vocabularies that support GeoSciML.
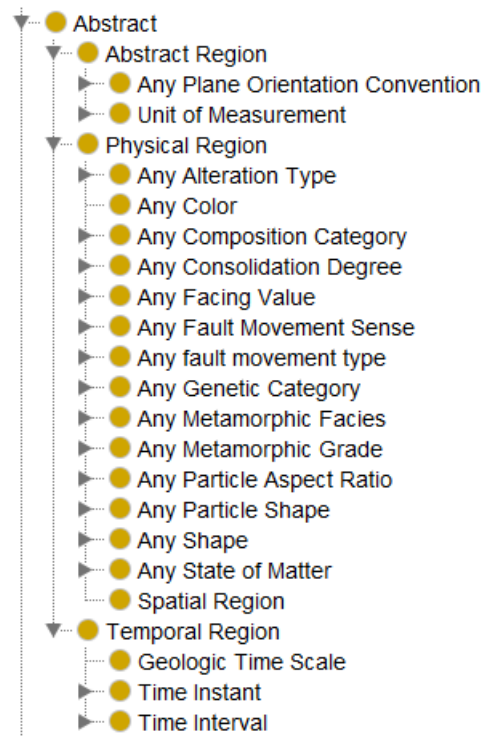

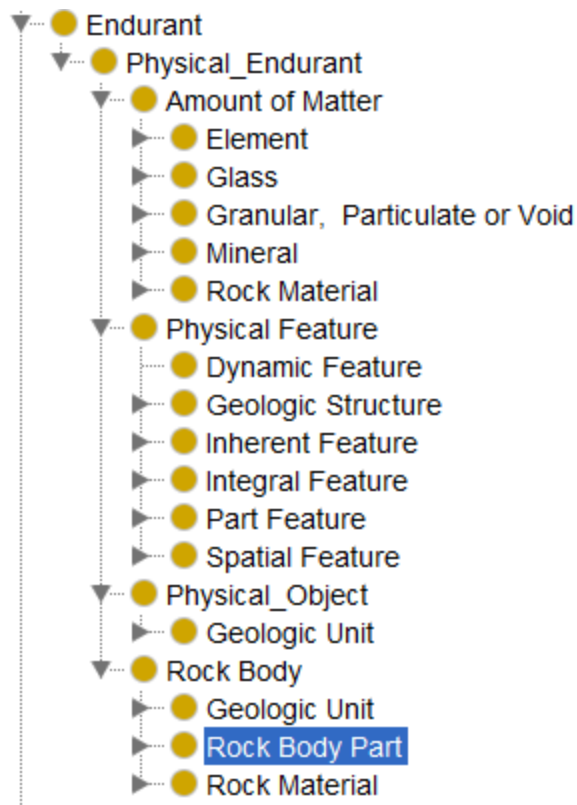*Figure 3. Subclasses of Top Level 'Abstract' Class*

Figure 4. Subclasses of Top Level 'Endurant' Class

Physical Endurants

Physical Endurants are the only subclass of Endurant considered in this model. 'Amount of Matter' includes endurants with no unity - 'stuffs' referred to by mass nouns like 'gold', 'iron', 'wood', 'sand'. A physical feature is an endurant that is specifically dependent on some host endurant. Different subclasses are defined depending on the kind of host. The Geologic Structure subclass is defined because of its relavence to geologic data, but all its subclasses map into one of the Physical Feature Subclasses. Physical_Object is an endurants with a unity property. In contrast to 'Amount of Matter', most physical objects can change some of their parts while keeping their identity; they can have temporary parts. 'Rock Body' is an endurant in which some Rock Material inheres, either as an 'amount of matter' (disembodied matter), or as a geologic unit. 'Rock Body Part' is included to represent the various informal kinds of rock bodies used in geologic description, e.g. clasts, facies, pendants, tectonic blocks, lithosome, outcrop, specimen, stratigraphic section.
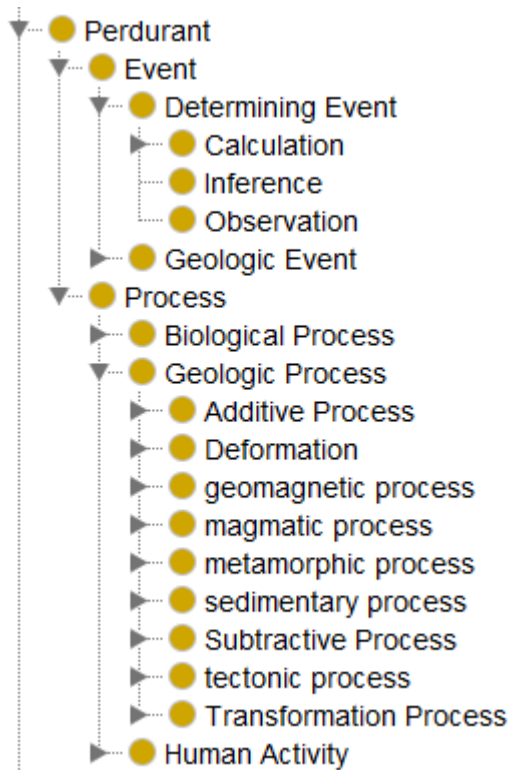
Figure 5. Subclasses of Top-Level Perdurant class

Perdurants

Perdurants, or occurrences, comprise what are variously called events, processes, phenomena, activities and states. They can have temporal parts or spatial parts; Perdurants extend in time by accumulating different temporal parts, so that, at any time they are present, they are only partially present. The Event subclass represents an occurence that involves a change in state of some system, something that occurs in a certain place during a particular interval of time[1]. Process subclass represents a series of events to produce a result [2]; in BFO a process has temporal (proper) parts, and always depends on some material (continuant) entity (Arp et al., 2015, p. 121)

Any Particular has a determinedBy relationship to a 'Determining Event', which is a hook to provenance metadata for how a class instance was detrmined. The process vocabualry shown includes classes defined in the Geologic Process module (GSO-Geologic_Process.ttl). Geologic Process Classes are defined along two axes. 1) Geologic categories like magmatic, metamorphic, sedimentary, tectonic; these are from the CGI GeologicProcess vocabulary. 2) functional categories based on whether the process adds, removes, transforms, or deforms material

---

[1] https://www.dictionary.com/browse/event
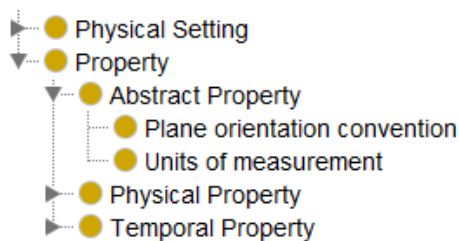[2] https://wikidiff.com/event/process

Figure 6. Subclasses of Top-Level Physical Setting and Property

Physical settings included in the model are sedimentary or tectonic environments that are the context in which geologic processes operate. The detailed hierarchy of settings is defined in the Physical Setting module (GSO-Physical_Setting.ttl). Properties are classes representing qualities that characterize geologic entities. The Property hierarchy is elucidated below (Figure 7).

Physical Properties

Figure 7 is a list of all the properties aggregated from the modules in the Loop3D model. Most of the properties are based on the GeoSciML v3.2 conceptual model. One of the advantages of an RDF implementation of the model is the open world asumption, which allows introduction of other properties as necessary. In order to preserve interoperability between different model instances, some govenance of the property classes and associated vocabularies used to specify property instances is necessary. Properties currently have values that are either free text, a class from one of the Abstract_Regions (i.e. a controlled vocabulary), or decimal numeric values.
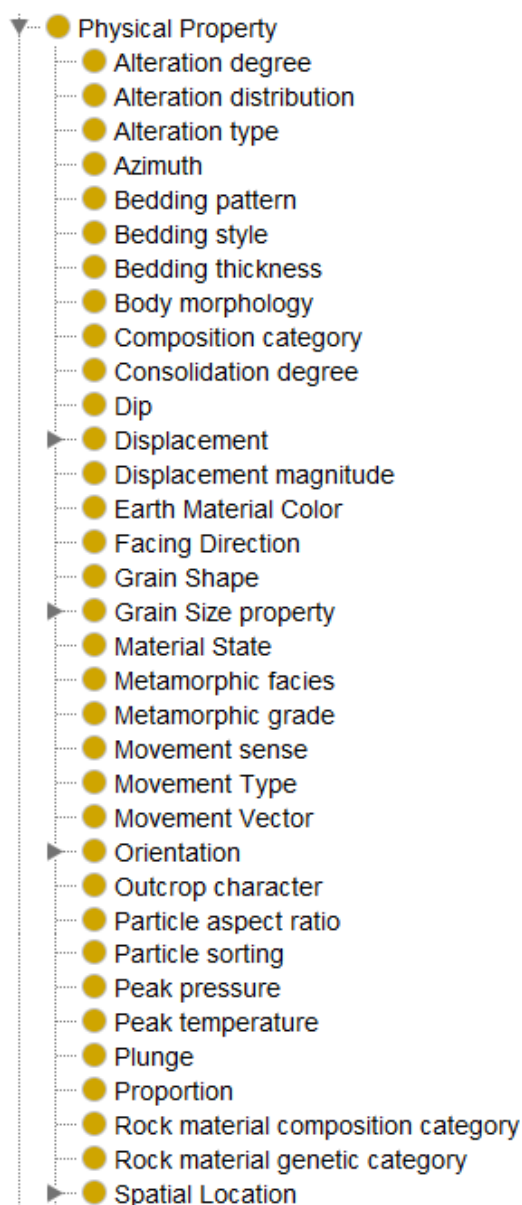

Figure 7. Physical Property classes.

6

Geology Modules

The detailed geoscience model is packaged in a set of modules that have dependencies only on the top level Common (GSO-Common.ttl) and Geology (GSO-Geology.ttl) ontologies. They can thus be imported as necessary depending on the requirements of a particular application.

Geology Base.

This is the core geology module, serialized in GSO-Geology.ttl.

Table 1. Classes defined in GSO-Geology (gsog: namespace)

Label	parent	comment
Additive Process	gsog:Geologic_Process	process that introduces new matter into the model space
Age (time scale rank)	gsog:Geologic_Time_Interval	most granular geochronologic time interval; one or more Ages are grouped into an Epoch
Bedding Package	gsoc:Integral_Feature	A sub-map scale sequence of strata, e.g. bouma sequence, fining-upward sequence, interbedded sandstone and mudstone...
bolide impact	gsog:Geologic_Event	The impact of an extraterrestrial body on the surface of the earth
Boundary Stratotype	gsog:Stratotype	A stratigraphic section that contains a designated point in a stratigraphic sequence of essentially continuous deposition, preferably marine, chosen for its correlation potential. http://www.stratigraphy.org/upload/bak/chron.htm
Chronostratigraphic unit	gsog:Geologic_Unit	A body of rocks that includes all rocks, layered or unlayered, formed during a specific interval of geologic time, and only those rocks formed during that time span. Chronostratigraphic units are bounded by synchronous horizons. The rank and relative magnitude of the units in the chronostratigraphic hierarchy are a function of the length of the time interval that their rocks subtend, rather than of their physical thickness. (http://www.stratigraphy.org/upload/bak/chron.htm).
Clast	gsog:Rock_Body_Part	
cometary impact	gsog:bolide_impact	The impact of a comet on the surface of the earth
Complex	gsog:Lithostratigraphic_Unit	
Contact	gsog:Geologic_Structure, gsoc:Low_Dimension_Feature	A surface that separates geologic units. Very general concept representing any kind of surface separating two geologic units, including primary boundaries such as depositional contacts, all kinds of unconformities, intrusive contacts, and gradational contacts, as well as faults that separate geologic units. (CGI ContactType vocabulary, adapted from Jackson, 1997, page 137, NADM C1 2004). Contact (CT): Feature hosted by 2 or more rock bodies that touch; not a part of any of the touching rock bodies. A contact is realizedBy 2 Rock Body Surfaces; each is a part of a different Rock Body host that is in contact. Contact(x) <--> exists y,z [host(y,x) ^ host(z,x) ^ touches (y,z) ^ RBS (y) ^ RBS (z)]

Label	parent	comment
Ductile Shear Zone	gsog:Geologic_Structure, gsoc:Material_Spatial_Feature	
Epoch	gsog:Geologic_Time_Interval	An Epoch may be subdivided into Ages. Epochs are grouped into Periods. Example epochs: Eocene, Pleistocene
Facies	gsog:Rock_Body_Part	
Fault	gsog:Geologic_Structure, gsoc:Low_Dimension_Feature	A discrete surface, or zone of discrete surfaces, with some thickness, separating two rock masses across which one mass has slid past the other and characterized by brittle deformation.
Fault Zone	gsoc:Material_Spatial_Feature	A material spatial feature that contains one or more fault surfaces as well as deformed rocks related to the faults located between and adjacent to the fault traces
Fold	gsog:Geologic_Structure, gsoc:Morphologic_Feature	
Fold	gsog:Geologic_Structure	
Foliation	gsog:Geologic_Structure, gsoc:Integral_Feature	Fabric defined by the planar arrangement of textural or structural features (fabric elements).
Fossil	gsog:Rock_Body_Part	
Fracture	gsog:Geologic_Structure, gsoc:Low_Dimension_Feature	
Geochronologic Boundary	gsog:Geologic_Time_Date	
Geologic Age Instant	gsog:Geologic_Age	A Geologic age that is specified by either a numeric temporal coordinate or correlation with a stratigraphic point via GeochronologicBoundary/isRealizedBy/StratigraphicPoint
Geologic Event	gsoc:Event	If an event is caused by a process, then any restrictions on participants of the process also apply to participants of the event causedBy (x,y) ^ GeologicEvent (x) ^ GeologicProcess (y) --> forall z [participates(z,x) --> participates (z,y)]
Geologic Process	gsoc:Process	
Geologic Structure	gsoc:Physical_Feature	
Geologic Time Date	gsoc:Time_Instant	A temporal coordinate value, located either by a point position (with uncertainty) on a time line, specified by a numeric coordinate (generally MYPB, but definitions of 'present' vary). Can be a GeochronologicBoundary if it is associated with a location in a particular stratigraphic section, or a GSSA if the numeric time coordinate is arbitrarily assigned. Probably should specify a Temporal Reference System used to assign coordinate values.
Geologic Time Interval	gsoc:Time_Interval	
Geologic Time Scale	gsoc:Temporal_Region	A collection of Geochronologic Age entities that obey a special topology (Cox and Richard, 2010).

Label	parent	comment
Geologic Unit	gsog:Rock_Body, gsoc:Physical_Object	Type of geologic unit is unknown, unspecified, irrelevant, or some type not included in the vocabulary. Type makes no implication for required properties or cardinalities. This is the root concept for the type hierarchy. A geologic unit and (the amount of) its rock material are co-located, but different entities. They can share properties, e.g. porosity, thickness, density, but also have differences: - different persistence conditions: the material can exist without the unit; e.g. a unit can be cease to exist due to natural (seismic) or artificial (explosion) means, but the material can persist - different parthood conditions: -- a unit can be part of a stratigraphic lexicon, but its material cannot be part of the lexicon. -- parts of the unit are not parts of the material, e.g. the western arm of formation X is not a part of its sandstone - the sandstone making up the western part of X is a part of the sandstone -- different identity conditions: a unit can have some material added or removed and retain identity, but the material changes identity with the addition or removal of some material
Gradational Contact Zone	gsoc:Material_Spatial_Feature	
Granular, Particulate or Void constituents	gsoc:Amount_Of_Matter	example top level subclasses are included in the Base Geology ontology (these are not complete), differentiated based on genesis for the most part. Detailed subclasses are defined by CGI particle type vocabulary and are imported in the Rock_Material module. Represents a rock body constituent composed of particles that share a set of characteristics, e.g. particle size (distribution), mineralogy, shape. E.g. the sand that is a constituent in a sandstone, or the feldspar phenocrysts that are a constituent in a granite. Note-- this class also includes various types of cavities or voids that are useful to characterize as a constituent in a Rock_material.
GSSA	gsog:Geologic_Time_Date	A Geochronologic Age defined by the International Stratigraphic Commission, based on fiat selection of defined older and younger bounding time coordinates
GSSP	gsog:Stratigraphic_Point	A stratigraphic point that is hosted by a top and bottom segment of adjacent chronostratigraphic units. The top and bottom are part of an outcrop and part of a stratotype (type section) for the unit.
Inclusion	gsog:Rock_Body_Part	
Joint	gsog:Fracture	
Lineation	gsog:Geologic_Structure, gsoc:Integral_Feature	Nongenetic term for a penetrative linear structure.
Lithosome	gsog:Rock_Body_Part	A kind of rock body that has multiple occurrences in a single geologic unit. A mass of rock of uniform character, characterized by geometry, composition, and internal structure. (http://inspire.ec.europa.eu/codelist/CompositionPartRoleValue/lithosome)
Lithostratigraphic Unit	gsog:Geologic_Unit	Geologic unit defined on the basis of observable and distinctive lithologic properties or combination of lithologic properties and stratigraphic relationships. Denotes a particular body of rock.

Label	parent	comment
magnetic field reversal	gsog:Geologic_Event	A geomagnetic event in which the Earth's magnetic field reverses direction.
meteorite im-pact	gsog:bolide_impact	The impact of a meteorite on the surface of the earth
Mineral	gsoc:Amount_Of_Matter	A mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological pro-cesses. Nickel, Ernest H. (1995), The definition of a mineral, The Canadian Mineralogist. 33 (3): 689–90.
Pendant	gsog:Rock_Body_Part	a mass of country rock that is entirely surrounded by an igneous intrusion such as a batholith or other pluton.
Rock Body	gsoc:Physical_Endurant	An endurant in which some Rock Material inheres, either as an 'amount of matter' (disembodied matter), or as a geologic unit.
Rock Body Bottom	gsog:Rock_Body_Bound-ary	Rock Body Bottom (RBB): The bottom surface of a rock body. RBT (x) <--> RBD (x) ^ exists z forall y [isPartOf (y,z) ^ hasHost (z,x) -> above (y,x) v isPartOf (y,x)]
Rock Body Boundary	gsoc:Physical_Boundary, gsog:Rock_Body_Part	a physical boundary hosted by a rock body. RBD (x) <--> SF (x) ^ exists y [RB (y) ^ hosts (y,x)] The exterior-facing material of a rock body.
Rock Body Part	gsog:Rock_Body	
Rock Body Top	gsog:Rock_Body_Bound-ary	Rock Body Top (RBT): The top surface of a rock body. RBT (x) <--> RBD (x) ^ exists z forall y [(isPartOf (y,z) ^ hasHost (z,x)) -> (be-low (y,x) v isPartOf (y,x))]
Rock Body Void	gsoc:Physical_Void	
Rock Material	gsoc:Amount_Of_Matter, gsog:Rock_Body	hook into CGI simple lithology ontology. SMR has one, and Clin-ton Smyth has an extension of that with more rock types.
Rock Material Outcrop	gsog:Rock_Body_Part	
Rock Material Specimen	gsog:Rock_Body_Part	
Stratigraphic Point	gsog:Contact	A spatially restricted part of a Contact feature, typically located by a point location. Could be thought of as an instance of a Con-tact, or a sample of a Contact.
Stratigraphic Section	gsog:Rock_Body_Part	
Stratotype	gsog:Stratigraphic_Sec-tion	
Subtractive Process	gsog:Geologic_Process	
Supereon	gsog:Geologic_Time_In-terval	hight ranking geochronlogic time interval, parts are eons
Transfor-mation Pro-cess	gsog:Geologic_Process	process that changes the characteristics of matter within the model space
Xenolith	gsog:Rock_Body_Part	

Geologic Structure Modules

Geologic structure classes are implemented in five separate sub modules.

- GSO-Structure-Contact.ttl contains the CGI contact type classes. No properties specific to contacts are currently defined.
- GSO-Structure-Fault.ttl contains the CGI Fault Type, Fault Movement Sense and Fault Movement Type classes, and defines the Displacement property and its components Fault_Movement_Magnitude, Fault_Movement_Sense, Fault_Movement_Type, and Fault_Movement_Vector.
- GSO-Structure-Fold.ttl defines a set of properties and classes for describing Folds, Fold Systems, and Fold Hinge and Fold Limb as parts of a fold. Physical properties defined and bound here include: Fold_Amplitude, Fold_Axial_Surface_Orientation, Fold_Genetic_Model, Fold_Hinge_Orientation, Fold_Hinge_Plunge, Fold_Hinge_Surface_Orientation, Fold_InterLimb_Angle, Fold_Limb_Shape, Fold_Profile_Type, Fold_Span, Fold_Symmetry, Fold_Wavelength, Hinge_Line_Curvature, Hinge_Shape, and Is_Periodic. Vocabularies for the terminological properties are not currently implemented, and property values ares specified as free text.
- GSO-Structure-Foliation defines classes for planar fabrics in rocks, as defined by the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group CGI foliation-type SKOS vocabulary 2018-08-03. Includes primary (eg, sedimentary and igneous) and deformation-related (eg, metamorphic and tectonic) planar fabrics. No foliation-specific properties are defined.
- GSO-Structure-Lineation defines classes for linear fabrics in rocks, as defined by the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group CGI lineation-type SKOS vocabulary 2016-11-21. No lineation-specific properties are defined.

Rock material

This module includes classes for rock type categories modified from CGI SimpleLithology SKOS vocabulary, along with properties based on GeoSciML v3.2 conceptual model. Scope includes gsog:Rock_Material and gsog:Granular Material. GSO granular material is analogous to GeoSciMLv3.2 compound material particle geometry description. Physical Properties defined include Consolidation_Degree, Grain_Shape, Grain_Size_Average, Grain_Size_Min, Grain_Size_Max, Particle_Aspect_Ratio_Category, Particle_Sorting_Category, Rock_Material_Color, Rock_Material_Composition_Category, Rock_Material_Genetic_Category. This module imports component vocabulary modules for consolidation degree, composition category, genetic category, metamorphic facies, metamorphic grade, particle shape, and particle type.

Elements

An ontology module defining URIs for Chemical elements. Extracted from WikiData via SPARQL query, with local URIs defined in the http://loop3d.org/GSO/ontology/2020/1/ space. Properties for each element include atomic number, abbreviation, WikiData URI, CHEBI URI and Encyclopedia Britannica link.

Minerals

An ontology module defining URIs in the http://loop3d.org/GSO/ontology/2020/1/ for some 4600 mineral species extracted from the RRUFF database. Content has been enhanced with links mined from WikiData mineral list, which only yielded about 3600 species. Properties on each species include a list of

elements present in the mineral (chemistryelements), the crystal system, fleischer's Group classification, a URL link to the handbook of mineralogy, the IMA chemical formula (html encoded), the IMA mineral number, IMA status, IUPAC chemical name, the Mindat.org ID number, URL link to Mindat.org, the RRUFF chemical formula (HTML encoded), the RRUFF name (with extended character set), RRUFF name html encoded, RRUFF name plain (plain ASCII characters substituted for special characters), status notes, structural group (provided by RRUFF), Strunz (version 10) class code, Label for the Strunz class, URL for mineral in WebMineral, and adoption date from Wikipedia. Not all fields are populated for all species. Some subclass relations were added in this ontology for feldspars and clay minerals to facilitate rock mineralogy descriptions. Additional work needs to be done to define useful mineral groups for rock de-scription, and also to select a reduced set of perhaps 500 minerals that are likely to show up in actual 3-D model descriptions.

Geologic Process

This ontology defines classes for geologic processes, as well some anthropogenic or biologic processes that impact geology. It is based on terms and definitions from the 2016 SKOS-RDF version of the CGI Event Process vocabulary, but some revisions have been made in the hierarchy, along with mapping to the functional process categories additive, subtractive, transformation, and deformation.

Physical Setting

This ontology contains terms and definitions based on the 2016 SKOS-RDF version of the IUGS Commis-sion for Geoscience Information (CGI) Geoscience Terminology Working Group Event Environment vo-cabulary to describe the physical setting within which a GeologicEvent takes place. GeologicEnvironment is construed broadly to include physical settings (places) on the Earth surface specified by climate, tec-tonics, physiography or geography, and settings in the Earth's interior specified by pressure, tempera-ture, chemical environment, or tectonics.

Geologic Unit

The Geologic Unit module extends the base unit types Chronostratigraphic Unit and Lithostratigraphic unit defined in the Geology Base module with additional subclasses for kinds of geologic units, as de-fined in the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group Geologic Unit type vocabulary. Additional Rock Body Part subclasses are also defined based on the 2016 SKOS-RDF version of the CGI Geologic Unit Part Role vocabulary. Properties for Geologic Units defined based on GeoSciML 3.2 include Bedding_Pattern, Bedding_Style, Bedding_Thickness_Category, Geo-logic_Unit_Body_Morphology, Geologic_Unit_Composition_Category, and Geologic_Unit_Out-crop_Character. Vocabularies for these properties have not been implemented, so property values are currently specified as free text. The Alteration type, Metamorphic Facies and Metamorphic Grade com-ponent vocabularies are imported.

Geologic Time Interval

This ontology is a adaptation of the [OWL implementation of the International Chronostratigraphic Chart 2017](#), simplified to reduce the voluminous import dependencies in the full implemenation. Named time intervals from the time scale are instances of the Geologic_Time_Interval subclasses lik Eon, Era, Period, as appropriate. The bounding time positions for the named time ordinal eras are implemented as Geo-chronologic_Boundary instances or as GSSA instances.

Physical Property

This ontology includes some physical properties that are used in multiple other Modules, mostly related to orientation and metamorphic description. Orientation properties will be refactored into the Geologic Structure module in a future verision. The metamorphic descriptions apply to rock material or to rock body, and could be refactored into the Geology base. This refactoring would render this module unnecessary.

Hydrology

This module includes hook classes for hydrology classes. Currently it only defines hydrologic event and hydrologic process as subclasses of Perdurant.

Namespaces

Abbrev.	Namespace URI	Scope
dcterms	http://purl.org/dc/terms/	Dublin core metadata vocabulary
gsel	http://loop3d.org/GSO/ontology/2020/1/element/	Classes for each element by atomic number. Isotopes not distinguished.
gsen	http://loop3d.org/GSO/ontology/2020/1/eventenvironment	Event Environment Classes; SubClass from gsoc:Physical_Setting
gsfa	http://loop3d.org/GSO/ontology/2020/1/geologicstructure/fault/	Classes and properties for describing faults
gsfo	http://loop3d.org/GSO/ontology/2020/1/geologicstructure/foliation/	Classes and properties for describing foliation, including sedimentary bedding and tectonic foliation
gsgu	http://loop3d.org/GSO/ontology/2020/1/geologicunit/	Classes and properties for describing geologic units
gslth	http://loop3d.org/GSO/ontology/2020/1/lithology/	Classes and properties for describing Earth materials including gsog:Rock_Material and gso:Granular_Material. Includes CGI simple lithology categories as sub-class of Rock_Material
gsmin	http://loop3d.org/GSO/ontology/2020/1/mineral/	Classes and properties for describing Minerals. Properties mostly inherited from RRUFF datbase. Includes Mineral species from RRUFF as classes.
gsoc	http://loop3d.org/GSO/ontology/2020/1/common/	objectProperties and high level classes that apply globally, based on DOLCE
gsog	http://loop3d.org/GSO/ontology/2020/1/geologicfeature/	High level classes and properties that are used in multiple thematic modules, and provide the framework for geoscience representation.
gsol	http://loop3d.org/GSO/ontology/2020/1/geologicstructure/lineation/	Classes and properties for describing lineation, both primary and tectonic.
gsop	http://loop3d.org/GSO/ontology/2020/1/geologicproperty/	Properties for base geology namespace, shared with multiple modules. [TBD—refactor into gsog and geologic structure]

gspr	http://loop3d.org/GSO/ontol-ogy/2020/1/geologicprocess/	Classes for geologic processes, subClass from gsoc:Process or gsog:Geologic_Process. Based on CGI geologic process vocabulary
gssf	http://loop3d.org/GSO/ontol-ogy/2020/1/geologicstruc-ture/fold/	Classes and properties for describing fold struc-tures
gstime	http://loop3d.org/GSO/ontol-ogy/2020/1/ischart/	Classes for the Internataional Commission on Stratigraphy geologic time scale
gsuom	http://loop3d.org/GSO/ontol-ogy/2020/1/uom/	Classes for units of measure.

Vocabularies

CGI vocabularies were converted from SKOS to owl with the following mapping:

- skos:Concept → owl:Class
- skos:broader → rdfs:subClassOf
- skos:prefLabel → rdfs:label
- skos:description → rdfs:comment
- Add dcterms:modified with current date,
- skos:topConceptOf → rdfs:subClassOf {the class for the gsoc:Abstract/gsoc:Physical_Region representing the concept space
- remove all skos:inScheme triples, and skos:Collection class
- skos:ConceptScheme → owl:ontology

Property Pattern

Properties are defined as subclasses of the Top Level Property class defined in common. Properties are defined in modules that correspond to the scope of the property domain. Properties that are not spe-cific to geoscience, having a global scope, are defined in the Common module. Properties with domains spanning multiple geoscience modules are defined in the Property module. Properties specific to the theme of a module are defined in that module.

Properties are bound to classes using the owl:ObjectProperty gsoc:hasProperty, or one of its subtypes.

For example, in the Geologic Unit module (RDF notation is Turtle):

```
gsog:Geologic_Unit
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:onProperty gsoc:hasPhysicalProperty ;
    owl:someValuesFrom gsop:Metamorphic_Grade ;
  ] .
```

gsop:Metamorphic_Grade is a property defined in Property module (gsop: namesapce). (Note that note all of the triples included in the definition are shown here.)

gsop:Metamorphic_Grade

```
  rdfs:subClassOf gsoc:Physical_Property ;
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:onProperty gsoc:hasValue ;
    owl:someValuesFrom gsop:Metamorphic_Grade_Space ;
  ] .
```

This definition asserts that values for the gsop:Metamorphic_Grade property must be instances of gsop:Metamorphic_Grade_Space, or one of its subclasses. Along with the definition of the property, the Property module also defines a class that represents the concept space for values of metamorphic grade:

```
gsop:Metamorphic_Grade_Space
  a owl:Class ;
  rdfs:label "Any Metamorphic Grade"@en ;
  rdfs:subClassOf gsoc:Physical_Region .
```

gsoc:Physical_Region is the top level category for value 'spaces'.

Finally, the metamorphic grade vocabulary is defined in a separate ontology (ComponentVocabs/ Meta-morphic_Grade.ttl), with the top-level classes subClassed from gsop:Metamorphic_Grade_Space. The CGI Metamorphic grade vocabulary was mapped to OWL (see mapping process described below). Here are the top concepts in the vocabulary :

```
gsmg:metamorphic_grade_not_specified
  a owl:Class ;
  dcterms:source "CGI metamorphicgrade SKOS vocabulary 2016-11-22"@en ;
  rdfs:comment "for use in normative descriptions to explicitly indicate that any metamorphic condition is allowed (in-
        cluding non-metamorphosed)."@en ;
  rdfs:label "metamorphic grade not specified"@en ;
  rdfs:subClassOf gsop:Metamorphic_Grade_Space .
gsmg:metamorphic_grade_unknown
  a owl:Class ;
  dcterms:source "CGI metamorphicgrade SKOS vocabulary 2016-11-22"@en ;
  rdfs:comment "For use in instance descriptions to indicate that no information is available on metamorphic
        grade"@en ;
  rdfs:label "metamorphic grade unknown"@en ;
  rdfs:subClassOf gsop:Metamorphic_Grade_Space .
```

In a data instance (e.g. ejs:), values are assigned using blank nodes, unless there is specific instance level information about metamorphic grade:

```
ejs:JsFormation
  a gsog:Formation ;
  gsoc:hasPhysicalProperty [
    a gsop:Metamorphic_Facies ;
    gsop:hasValue [
      a gsmf:no_metamorphic_minerals ;
    ] ;
  ] .
```

Where gsmf:no_metamorphic_minerals is a subClassOf gsmg:metamorphic_grade_not_specified

URI pattern

Base host name for namespaces:

http://loop3d.org/GSO/ontology/2020/1

the terminal /1 part indicates a version, and should be incremented for non-backward compatible versions that are released.

{base host name}/{theme} where theme is the subject of a module.

{base host name}/{theme}/{vocabulary} where {vocabulary} is the name of a vocabulary used as the value space (range) for a property in that module

{base host name}/{vocabulary} – where {vocabulary} is a vocabulary used in more than one module.
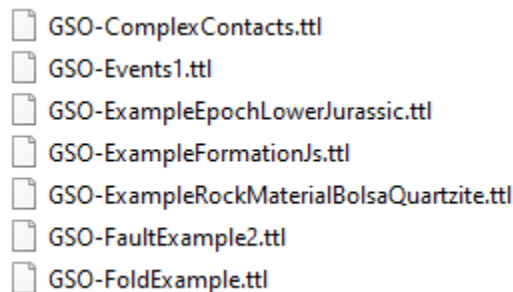
Test Instances

- GSO-ComplexContacts.ttl
- GSO-Events1.ttl
- GSO-ExampleEpochLowerJurassic.ttl
- GSO-ExampleFormationJs.ttl
- GSO-ExampleRockMaterialBolsaQuartzite.ttl
- GSO-FaultExample2.ttl
- GSO-FoldExample.ttl

Figure 8. Example instances included in the version one package.

A set of example instances has been constructed in parallel with development of the ontology to test the implementation patterns used. These should be reviewed to evaluate the implemenation.

References

Arp, Robert, Smith, Barry, and Spear, Andrew D., 2015, Building Ontologies with Basic Formal Ontology: MIT Press, Cambridge, MA, 220 pages.

Masolo, C., Borgo, S., Gangemi, A., Guarino, N., and Oltramari, A., 2003, WonderWeb deliverable D18: Technical report, Laboratory for Applied Ontology, ISTC-CNR, Trento, Italy.

Gangemi, A., Guarino, N., Masolo, C., Oltramari, A., Schneider, L., 2002, Sweetening ontologies with DOLCE: Proceedings Knowledge Engineering and Knowledge Management, Ontologies and the Semantic Web, 13th International Conference, EKAW 2002, Siguenza, Spain, October 1-4, 2002, DOI: 10.1007/3-540-45810-7_18.

North American Geologic Map Data Model (NADM) Steering Committee Data Model Design Team, 2004, NADM Conceptual Model 1.0—A Conceptual Model for Geologic Map Information: U.S. Geological Survey Open-File Report 2004-1334, accessed at https://pubs.usgs.gov/of/2004/1334/.