Loop3D
Geoscience Knowledge Representation Conceptual Model

Progress report

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Introduction

This is a progress report on development of a geoscience knowledge representation model for the Loop3D project. The report presents a collection of UML diagrams developed by Boyan Brodaric and Stephen Richard that represent the current state of the conceptual model guiding OWL implementation of a data model for Loop3D geologic data. The work has focused on harmonizing previous models, including the NADM C1 model (https://pubs.usgs.gov/of/2004/1334/) and the GeoSciML v3.2 (http://geosciml.org/doc/geosciml/3.2/documentation/html/) conceptual model, with the DOLCE high-level ontology (https://www.researchgate.net/publication/221630979_Sweetening_ontologies_with_DOLCE). This will 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.
Accompanying instance documents in the appendices use an informal Turtle-like syntax to test the basic design framework, antecedent to developing and OWL implementation for prototype deployment.

Geology Top

GKO-Geologic Top diagram

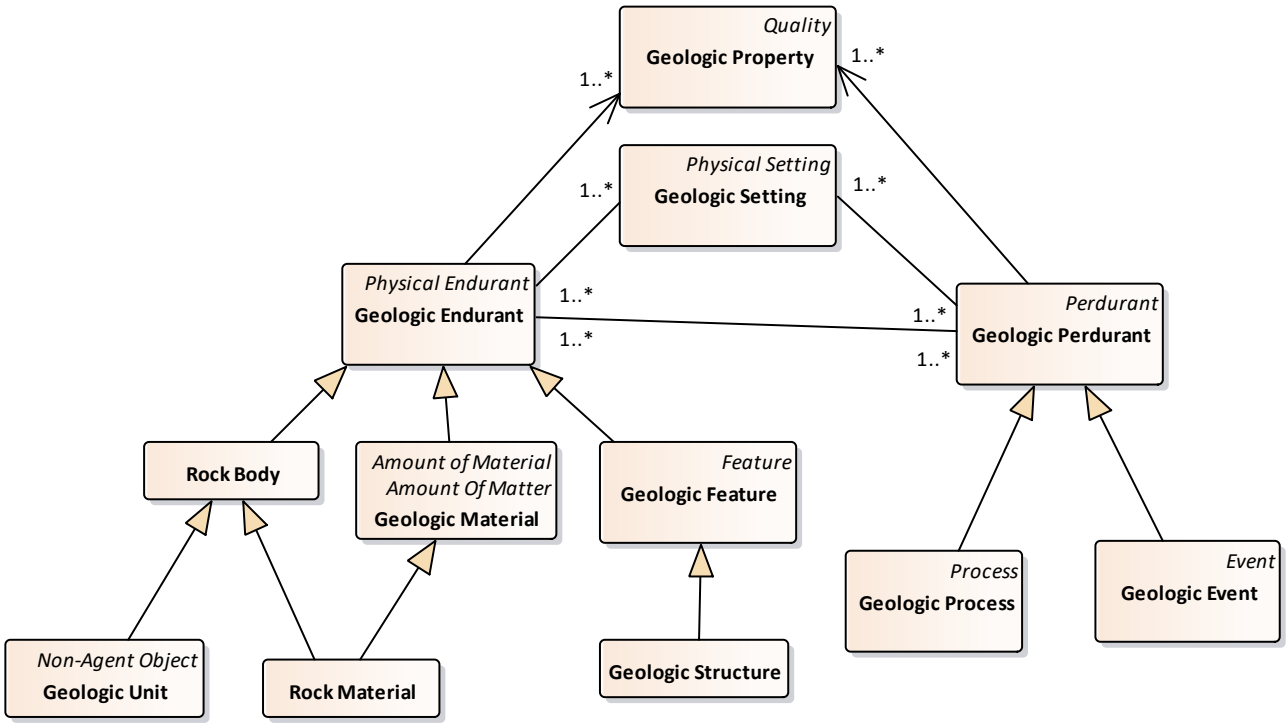


Figure 1: GKO-Geologic Top

GKO-Geologic Feature diagram

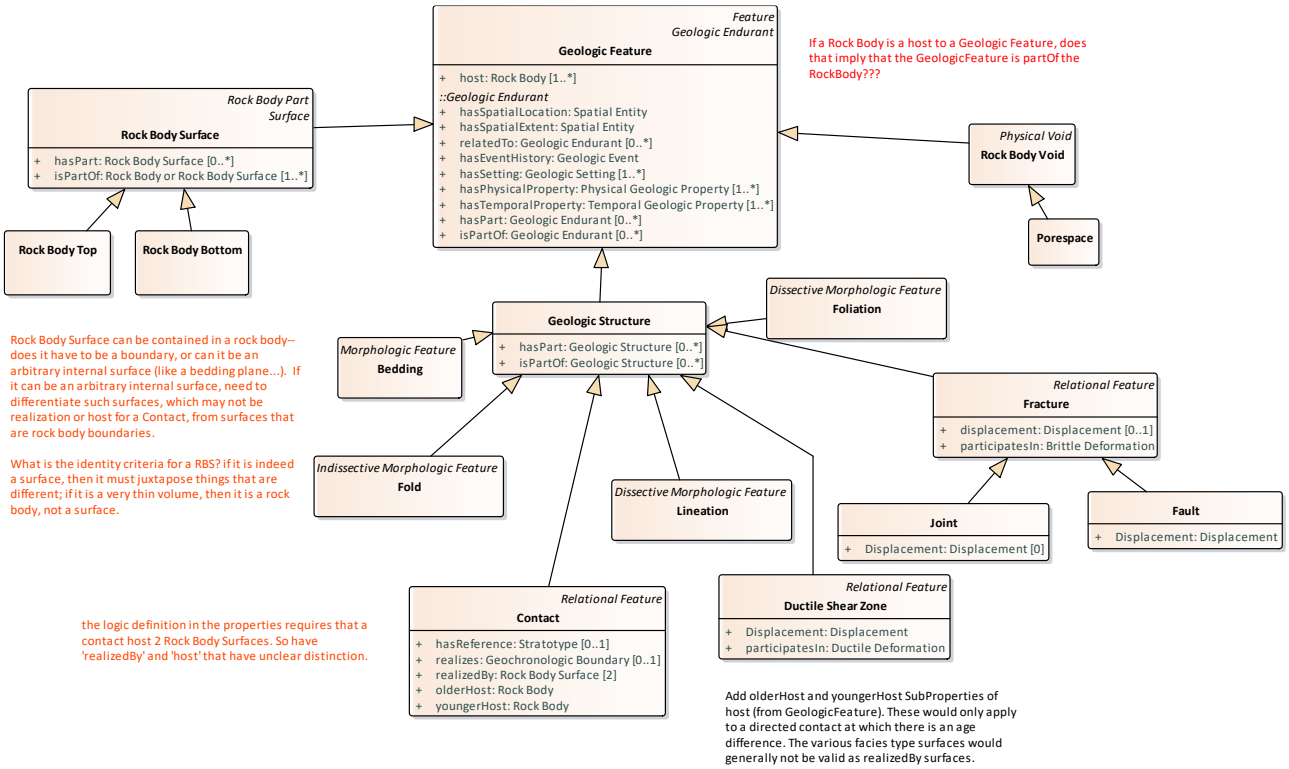
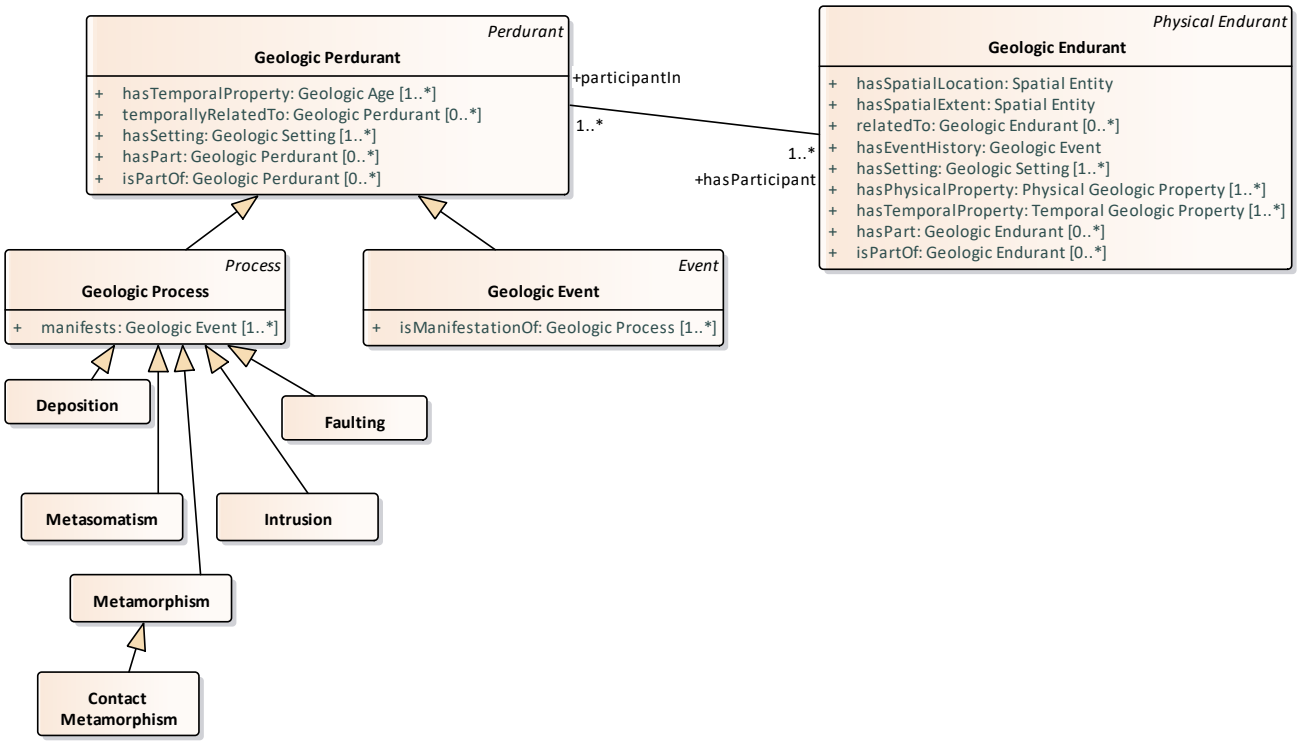


Figure 2: GKO-Geologic Feature

GKO-Geologic Perdurant diagram

An entity that only exists partially at any given point in time.



Does a Geologic Process have a Geologic Age; seems that process is a concept that is not bound to a specific time interval until it is manifested in a Geologic Event.

Shouldn't a Process have inputs and outputs?

Figure 3: GKO-Geologic Perdurant

GKO-Geologic Setting diagram

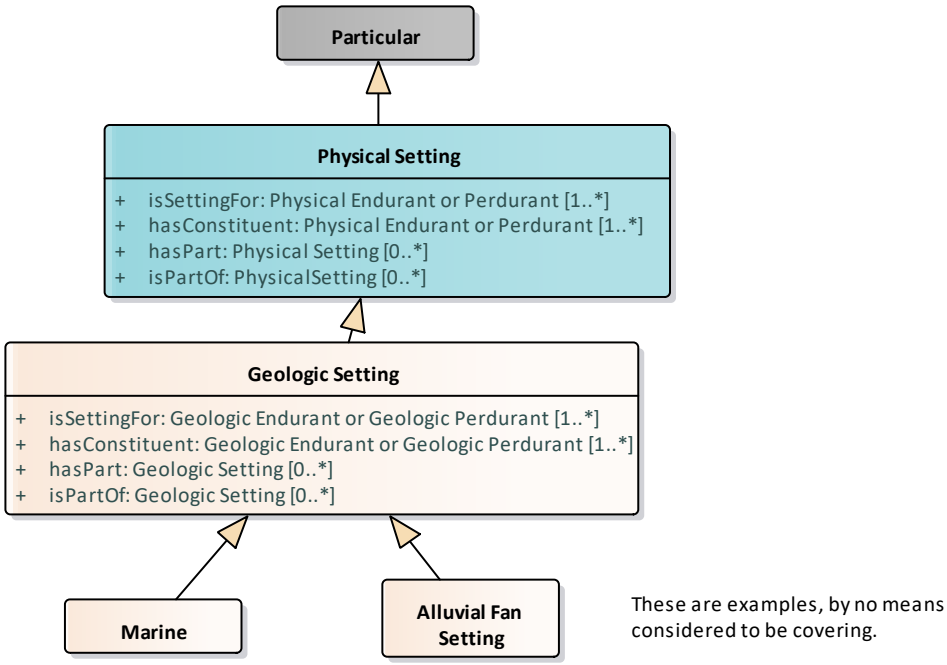


Figure 4: GKO-Geologic Setting

Classes

Contact Metamorphism

Extends Metamorphism

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Contact Metamorphism to Metamorphism

Metamorphism

Extends Geologic Process

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Metamorphism to Geologic Process

INCOMING STRUCTURAL RELATIONSHIPS
⇨ Generalization from Contact Metamorphism to Metamorphism

Intrusion

Extends Geologic Process

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Intrusion to Geologic Process

Metasomatism

Metasomatism: *is a metamorphic process by which the chemical composition of a rock or rock portion is altered in a pervasive manner and which involves the introduction and/or removal of chemical components as a result of the interaction of the rock with aqueous fluids (solutions). During metasomatism the rock remains in a solid state. (*V.A. ZharikovF, F, N.N. Pertsev, V.L. Rusinov, E. Callegari, and D.J. Fettes; 2017-01-02, Metasomatism and metasomatic rocks, Recommendations by the IUGS Subcommission on the Systematics of Metamorphic Rocks.

Extends Geologic Process

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Metasomatism to Geologic Process

Esker

An example of an Indissective Morphological Feature.
Extends Indissective Morphologic Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Esker to Indissective Morphologic Feature

Physical Geologic Property

A geologic property that a property of a Geologic Endurant.
Extends Geologic Property, Physical Quality

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Physical Geologic Property to Geologic Property
Generalization from Physical Geologic Property to Physical Quality

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Numeric Physical Geologic Property to Physical Geologic Property
Generalization from Complex Physical Geologic Property to Physical Geologic Property
Generalization from Categorical Physical Geologic Property to Physical Geologic Property

ATTRIBUTES
isPropertyOf : Geologic Endurant

Alluvial Fan Setting

An example of a Geologic Setting
Extends Geologic Setting

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Alluvial Fan Setting to Geologic Setting

Marine

An example Geologic Setting
Extends Geologic Setting

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Marine to Geologic Setting

Geologic Setting

Extends Physical Setting

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Setting to Physical Setting

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Alluvial Fan Setting to Geologic Setting
Generalization from Marine to Geologic Setting

ATTRIBUTES
isSettingFor : Geologic Endurant or Geologic Perdurant Multiplicity: ([1..*])
hasConstituent : Geologic Endurant or Geologic Perdurant Multiplicity: ([1..*])

ATTRIBUTES
hasPart : Geologic Setting Multiplicity: ([0..*])
isPartOf : Geologic Setting Multiplicity: ([0..*])

ASSOCIATIONS	
Association	
Source: Geologic Endurant Cardinality: [1..*]	Target: Geologic Setting Cardinality: [1..*]
Association	
Source: Geologic Perdurant Cardinality: [1..*]	Target: Geologic Setting Cardinality: [1..*]

Geologic Perdurant

A perdurant that has one or more Geologic Endurants as participants. A Geologic Perdurant must have a specified Geologic Age and one or more manifested setting(s) or process(es).
Extends Perdurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Perdurant to Perdurant

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Event to Geologic Perdurant
Generalization from Geologic Process to Geologic Perdurant

ATTRIBUTES
hasTemporalProperty : Geologic Age Multiplicity: ([1..*])
temporallyRelatedTo : Geologic Perdurant Multiplicity: ([0..*])
hasSetting : Geologic Setting Multiplicity: ([1..*])
hasPart : Geologic Perdurant Multiplicity: ([0..*])
isPartOf : Geologic Perdurant Multiplicity: ([0..*])

ASSOCIATIONS	
Association	
Source: Geologic Perdurant Cardinality: [1..*]	Target: Geologic Setting Cardinality: [1..*]
Association participates relation has subrelations such as - produces (participant>product) - inputs (participant>input)	
Source: hasParticipant Geologic Endurant Cardinality: [1..*]	Target: participantIn Geologic Perdurant Cardinality: [1..*]
Association (direction: Destination -> Source)	
Source: Geologic Property Cardinality: [1..*]	Target: Geologic Perdurant

Geologic Endurant

A Physical Endurant that is part of the Earth.
Extends Physical Endurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Endurant to Physical Endurant

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Feature to Geologic Endurant
Generalization from Rock Body to Geologic Endurant
Generalization from Geologic Material to Geologic Endurant

ATTRIBUTES
hasSpatialLocation : Spatial Entity Location of the entity on or in the Earth, specified in some spatial reference system anchored to Earth.
hasSpatialExtent : Spatial Entity Boundaries of the entity specified in a coordinate reference system anchored to the Earth.
relatedTo : Geologic Endurant Multiplicity: ([0..*]) General objectProperty for specifying relationships between Geologic Endurants.
hasEventHistory : Geologic Event

ATTRIBUTES
hasSetting : Geologic Setting Multiplicity: ([1..*])
hasPhysicalProperty : Physical Geologic Property Multiplicity: ([1..*])
hasTemporalProperty : Temporal Geologic Property Multiplicity: ([1..*])
hasPart : Geologic Endurant Multiplicity: ([0..*])
isPartOf : Geologic Endurant Multiplicity: ([0..*])

ASSOCIATIONS	
Association participates relation has subrelations such as - produces (participant>product) - inputs (participant>input) Source: hasParticipant Geologic Endurant Cardinality: [1..*]	Target: participantIn Geologic Perdurant Cardinality: [1..*]
Association Source: Geologic Endurant Cardinality: [1..*]	Target: Geologic Setting Cardinality: [1..*]
Association (direction: Destination -> Source) Source: Geologic Property Cardinality: [1..*]	Target: Geologic Endurant

Faulting

An example of a Geologic Process
Extends Geologic Process

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Faulting to Geologic Process

Deposition

An example of a Geologic Process
Extends Geologic Process

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Deposition to Geologic Process

Geologic Feature

Feature hosted by a rock body
Extends Feature, Geologic Endurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Feature to Geologic Endurant
Generalization from Geologic Feature to Feature

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Structure to Geologic Feature
Generalization from Rock Body Surface to Geologic Feature
Generalization from Rock Body Void to Geologic Feature

ATTRIBUTES
host : Rock Body Multiplicity: ([1..*])

Geologic Event

A Geologic Perdurant that is the manifestation of one or more Geologic Processes. Any restrictions on participants of the manifested process also apply to participants of the event.
GeoSciML 3.2: An identifiable event during which one or more geological processes act to modify geological entities. A Geologic Event must have a specified Geologic Age and may have specified setting and process(es). An example might be a cratonic uplift event during which erosion, sedimentation, and volcanism all take place.
causedBy (x,y) ^ GeologicEvent (x) ^ GeologicProcess (y) --> forall z [participates(z,x) --> participates (z,y)]
Extends Event, Geologic Perdurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Event to Geologic Perdurant
Generalization from Geologic Event to Event

ATTRIBUTES
isManifestationOf : Geologic Process Multiplicity: ([1..*])

Process

A sequence of one or more activities that results in a change of state in one or more entities. A process is manifested in an event. A given process can be manifested in many events.
Extends Perdurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Process to Perdurant

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Process to Process

Geologic Process

Extends Geologic Perdurant, Process

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Process to Geologic Perdurant
Generalization from Geologic Process to Process

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Deposition to Geologic Process
Generalization from Intrusion to Geologic Process
Generalization from Metamorphism to Geologic Process
Generalization from Faulting to Geologic Process
Generalization from Metasomatism to Geologic Process

ATTRIBUTES
manifests : Geologic Event Multiplicity: ([1..*])

Geologic Structure

Geologic Structure (GS):
A pattern in a rock body (foliation, fold), or a feature occurring between rock bodies (contact, fracture).
GeoSciML 3.2: A configuration of matter in the Earth based on describable inhomogeneity, pattern, or fracture in a Rock Body.
The identity of a GeologicStructure is independent of the material that is the substrate for the structure.
Properties like "clast-supported", "matrix-supported", and "graded bed" that do not involve orientation are considered kinds of GeologicStructure because they depend on the configuration of parts of a rock body. Includes sedimentary structures.
Extends Geologic Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Structure to Geologic Feature

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Fold to Geologic Structure
Generalization from Foliation to Geologic Structure
Generalization from Ductile Shear Zone to Geologic Structure
Generalization from Bedding to Geologic Structure
Generalization from Contact to Geologic Structure

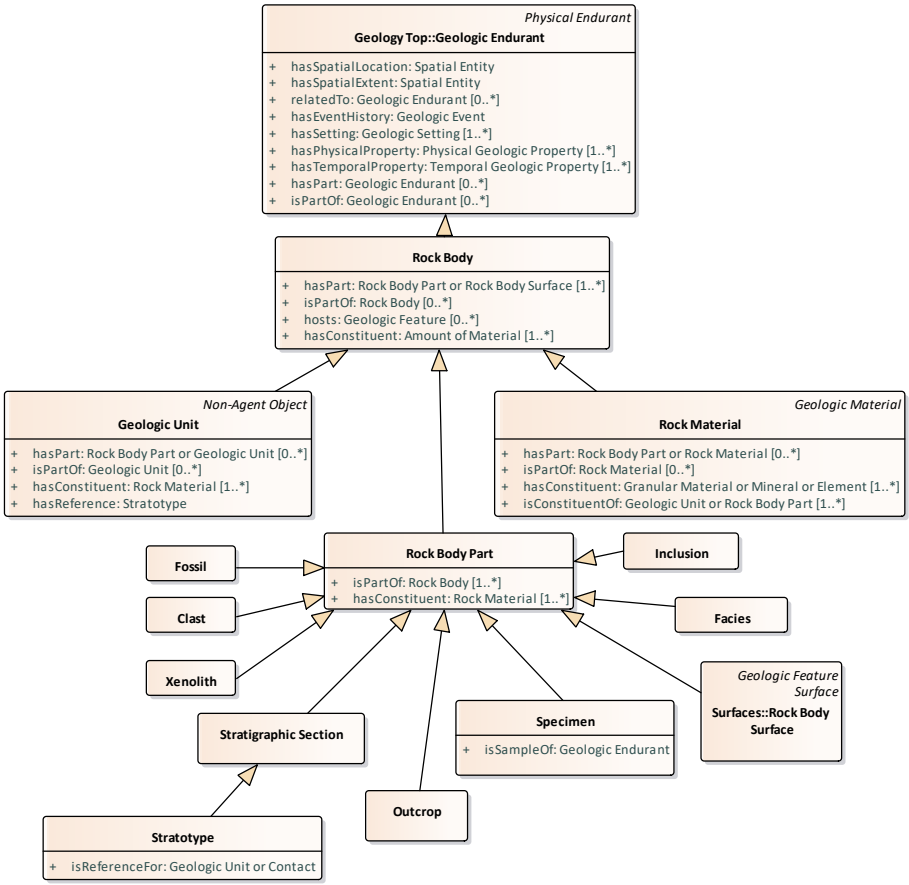
INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Lineation to Geologic Structure
Generalization from Fracture to Geologic Structure

ATTRIBUTES
hasPart : Geologic Structure Multiplicity: ([0..*])
isPartOf : Geologic Structure Multiplicity: ([0..*])

Rock Body and Material

GKO-Rock Body diagram

A rock body part that is a fragment of a pre-existing rock body.



stratotype is a property linking an abstract thing, specifically for our purposes, a time interval, with a physical thing that manifests that time interval. In the geologic time scale, a GeochronologicBoundary (temporal thing) has a stratotype association with a StratigraphicPoint that is the 'prototype' record of a geologicEvent that marks the temporal boundary.

Figure 5: GKO-Rock Body

GKO-Geologic Unit diagram

A kind of geologic unit defined by particular characteristics resulting from hydrothermal interaction with a pre-existing rock body.

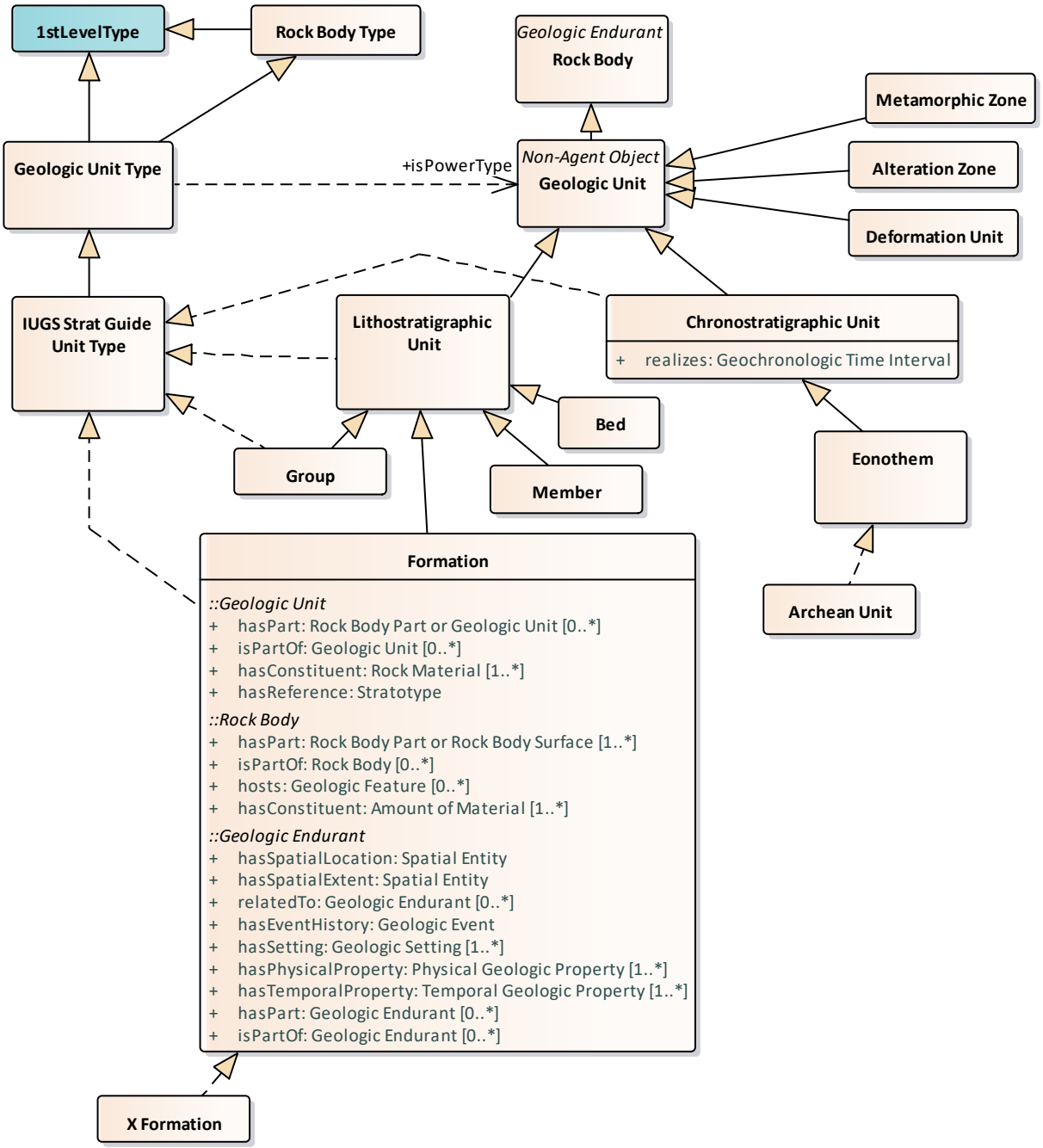


Figure 6: GKO-Geologic Unit

GKO-Amount of Matter diagram

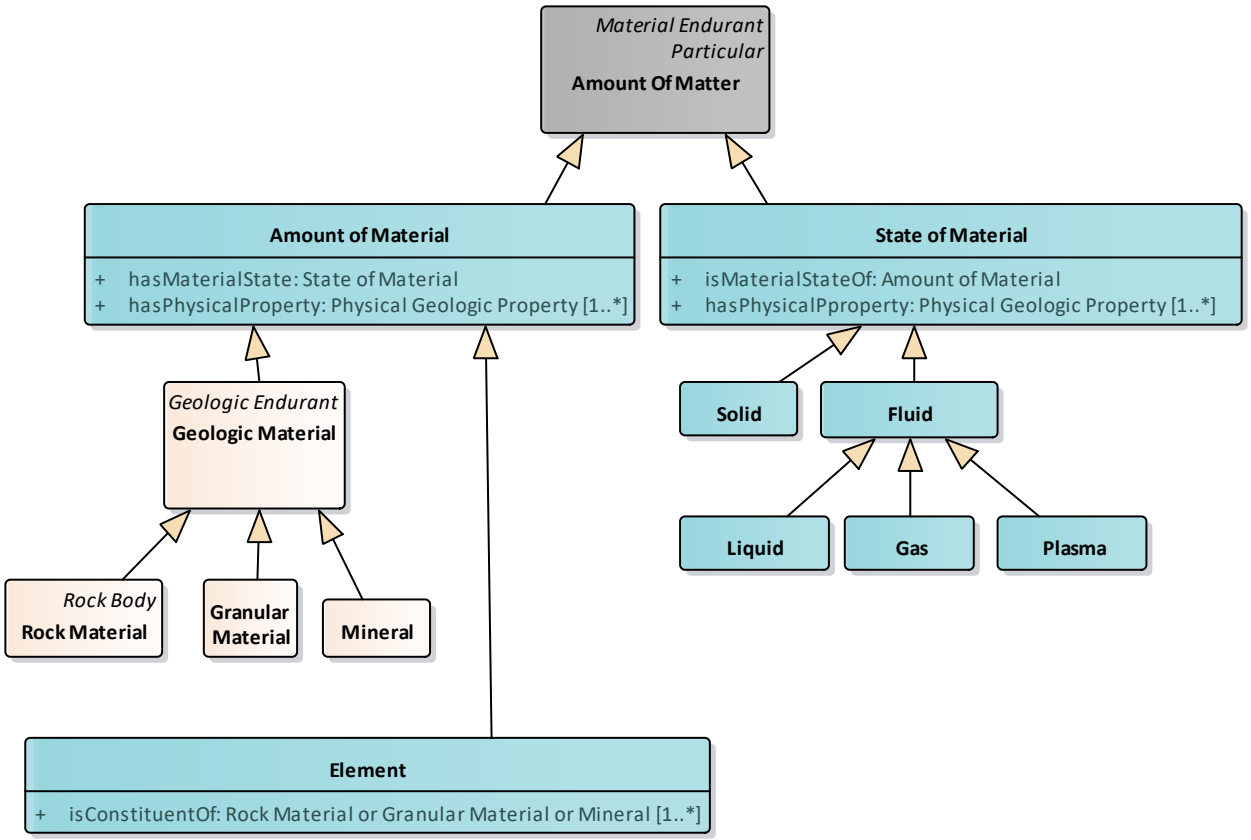


Figure 7: GKO-Amount of Matter

GKO-Geologic Material diagram

A granular material composed of fossilized skeletal fragments from Crinoid columnals.

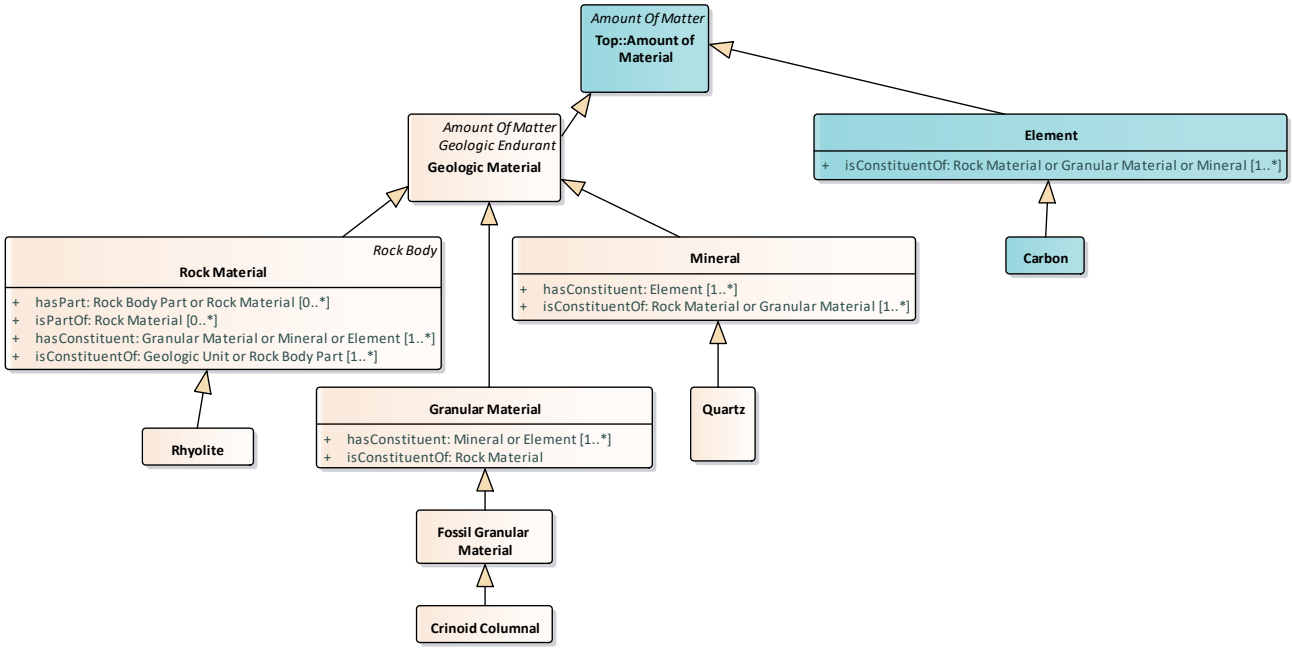


Figure 8: GKO-Geologic Material

GKO-Rock Material diagram

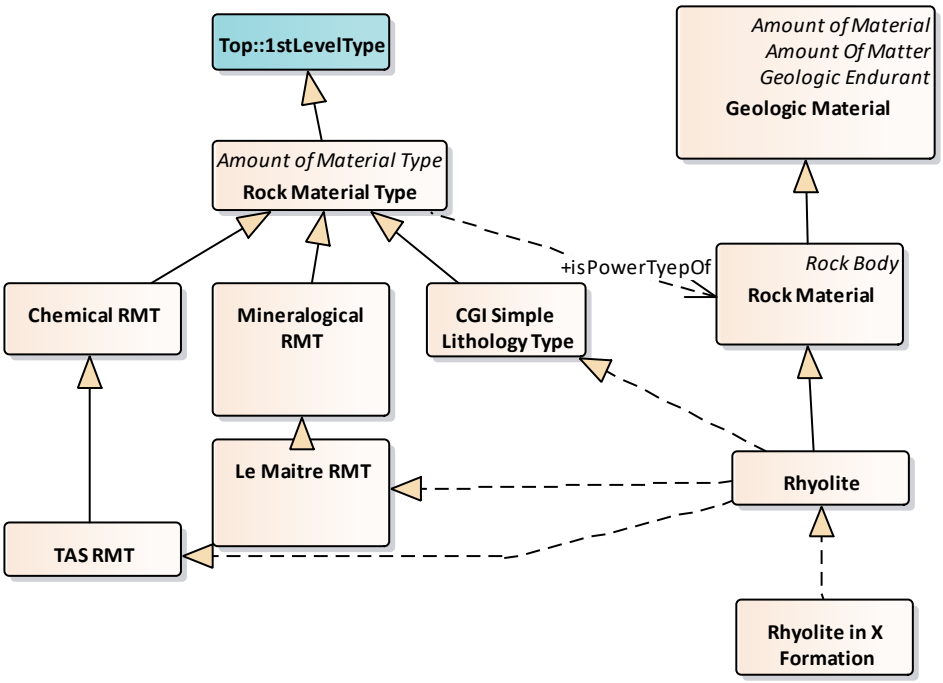
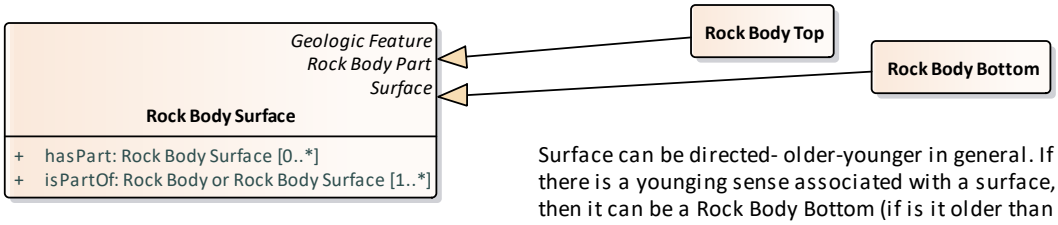


Figure 9: GKO-Rock Material

GKO-Surface Notes diagram

Class diagram in package 'Surfaces'

GKO-Surface Notes
Version 1.0
Stephen Richard created on 3/26/2019. Last modified 3/28/2019



Surface can be directed- older-younger in general. If there is a younging sense associated with a surface, then it can be a Rock Body Bottom (if is it older than the body of its host rock body), or a Rock Body Top (if it is younger than the body of the host rock body) Draft here also suggests adding 'olderHost' and 'youngerHost' Rock Body on the Contact Feature.

Use participatesIn binding to associate a process or a specific event as the mechanism to distingui An unconformity (Contact) has an eroded surface below and a depositional surface above. A conformable or disconformable Contact has a depositional surface below and above. An intrusive contact has two intrusive surfaces.
Fault -- {Rock Body > Displacement Surface} > Deformation Unit > {Displacement Surface > Rock Body} OR {Rock Body > Displacement Surface} > {Displacement Surface> Rock Body}. A Fault is hosted by Rock Body1, Rock Body2, surface1, surface 2.

eroded surface --> process is Erosion
Depositional Surface --> process is Deposition
Displacement surface --> process is Displacement
intrusive surface --> process is Intrusion

Gradational vs. Sharp distinction is based on the thickness/width of the zone of transition between adjacent units. Current thinking is to make Gradational and Sharp subtypes of Contact, and have boundaryThickness property on Gradational Contact.

Figure 10: GKO-Surface Notes

Rock Body Bottom

Class in package 'Surfaces'
Rock Body Bottom (RBB):
The outer and older surface of a rock body.
RBT (x) <--> RBS (x) ^ exists z forall y [partOf (y,z) ^ hosts (z,x) -> above (y,x) v partOf (y,x)]
Extends Rock Body Surface

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Bottom to Rock Body Surface

Rock Body Surface

Class in package 'Surfaces'
Rock Body Surface (RBS):
RBS is a physical surface hosted by a rock body.
RBS (x) <--> SF (x) ^ exists y [RB (y) ^ hosts (y,x)]
A surface within or at the boundary of a rock body, identified by some observable characteristics.
Extends Geologic Feature, Rock Body Part, Surface

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Surface to Geologic Feature
Generalization from Rock Body Surface to Rock Body Part
Generalization from Rock Body Surface to Surface

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Bottom to Rock Body Surface
Generalization from Rock Body Top to Rock Body Surface

ATTRIBUTES
hasPart : Rock Body Surface Multiplicity: ([0..*])
isPartOf : Rock Body or Rock Body Surface Multiplicity: ([1..*])

Rock Body Top

Class in package 'Surfaces'
Rock Body Top (RBT):
The younger surface of a rock body.
RBT (x) <--> RBS (x) ^ exists z forall y [(partOf (y,z) ^ hosts (z,x)) -> (below (y,x) v partOf (y,x))]
Extends Rock Body Surface

Classes

Alteration Zone

A geologic unit defined by observable effects of an alteration event in a rock body. Alteration is changes in rock texture and mineralogy resulting from metasomatic processes.
Extends Geologic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Alteration Zone to Geologic Unit

Bed

A lithostratigraphic unit rank.
Extends Lithostratigraphic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Bed to Lithostratigraphic Unit

Carbon

Example Element
Extends Element

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Carbon to Element

CGI Simple Lithology Type

Classification scheme for lithology
Extends Rock Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Generalization from CGI Simple Lithology Type to Rock Material Type

INCOMING STRUCTURAL RELATIONSHIPS
⇒ Realization from Rhyolite to CGI Simple Lithology Type

Chemical RMT

Classification scheme for rock materials based on chemical composition
Extends Rock Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Generalization from Chemical RMT to Rock Material Type

INCOMING STRUCTURAL RELATIONSHIPS
⇒ Generalization from TAS RMT to Chemical RMT

Clast

Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Realization from Clast to Rock Body Part Type
⇐ Generalization from Clast to Rock Body Part

Crinoid Columnal

Extends Fossil Granular Material

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Generalization from Crinoid Columnal to Fossil Granular Material

Deformation Unit

A geologic unit defined by observable effects of a deformation event in a rock body.
Extends Geologic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Generalization from Deformation Unit to Geologic Unit

Element

Extends Amount of Material

OUTGOING STRUCTURAL RELATIONSHIPS
⇐ Generalization from Element to Amount of Material

INCOMING STRUCTURAL RELATIONSHIPS
⇒ Generalization from Carbon to Element

ATTRIBUTES
isConstituentOf : Rock Material or Granular Material or Mineral Multiplicity: ([1..*])

Element Type

Extends Amount of Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Element Type to Amount of Material Type

Facies

A part of a rock body that is differentiated based on observable characteristics, but is interpreted to be broadly coeval with other parts of the unit. Facies can be defined based on interpretations of depositional environment, metamorphic or alteration conditions, or variations in mineralogy in igneous rock.
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Facies to Rock Body Part

Fluid

Extends State of Material

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Fluid to State of Material

INCOMING STRUCTURAL RELATIONSHIPS
⇨ Generalization from Gas to Fluid
⇨ Generalization from Plasma to Fluid
⇨ Generalization from Liquid to Fluid

Formation

A lithostratigraphic unit rank.
Extends Lithostratigraphic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Realization from Formation to IUGS Strat Guide Unit Type
⇦ Generalization from Formation to Lithostratigraphic Unit

INCOMING STRUCTURAL RELATIONSHIPS
⇨ Realization from X Formation to Formation

Fossil

A constituent part of a rock body that is a preserved part of a living organism, its exoskeleton, or a shell.
Note this concept does not include Fossil Molds and Trace Fossils, which are considered types of non-directional Geologic Structures.
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Fossil to Rock Body Part

Fossil Granular Material

A granular material composed of preserved body parts, exoskeleton or shell from living organisms.
Extends Granular Material

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Fossil Granular Material to Granular Material

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Crinoid Columnal to Fossil Granular Material

Gas

a state of matter that has no fixed shape and no fixed volume. Gases have lower density than other states of matter, such as solids and liquids. https://www.livescience.com/53304-gases.html
Extends Fluid

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Gas to Fluid

Geologic Material

General class for kinds of material that can be constituents of Rock Bodies.
Extends Amount of Material, Amount Of Matter, Geologic Endurant

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Material to Amount Of Matter
Generalization from Geologic Material to Amount of Material
Generalization from Geologic Material to Geologic Endurant

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Granular Material to Geologic Material
Generalization from Mineral to Geologic Material
Generalization from Rock Material to Geologic Material

Geologic Unit

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
Extends Non-Agent Object, Rock Body

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Unit to Rock Body
Generalization from Geologic Unit to Non-Agent Object

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Alteration Zone to Geologic Unit
Generalization from Chronostratigraphic Unit to Geologic Unit
Generalization from Lithostratigraphic Unit to Geologic Unit
Generalization from Metamorphic Zone to Geologic Unit
Generalization from Deformation Unit to Geologic Unit

CONNECTORS
Dependency Source -> Destination From:Geologic Unit Type : Class, To: Geologic Unit : Class, isPowerType

ATTRIBUTES
hasPart : Rock Body Part or Geologic Unit Multiplicity: ([0..*])
isPartOf : Geologic Unit Multiplicity: ([0..*])

ATTRIBUTES
hasConstituent : Rock Material Multiplicity: ([1..*])
hasReference : Stratotype

Geologic Unit Type

A geological unit classification, including stratigraphic (e.g. formation), lithodemic (e.g. suite), and tectonic (e.g. terrane). is an instance of 2ndLevelType.
Extends 1stLevelType, Rock Body Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Unit Type to 1stLevelType
Generalization from Geologic Unit Type to Rock Body Type

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from IUGS Strat Guide Unit Type to Geologic Unit Type

CONNECTORS
Dependency Source -> Destination From:Geologic Unit Type : Class, To: Geologic Unit : Class, isPowerType

Grain Type

Extends Amount of Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Grain Type to Amount of Material Type

Granular Material

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.
Extends Geologic Material

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Granular Material to Geologic Material

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Fossil Granular Material to Granular Material

ATTRIBUTES
hasConstituent : Mineral or Element Multiplicity: ([1..*])
isConstituentOf : Rock Material

Group

A lithostratigraphic unit rank.
Extends Lithostratigraphic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Group to Lithostratigraphic Unit
Realization from Group to IUGS Strat Guide Unit Type

Inclusion

A rock body part that is an incidental occurrence of
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Inclusion to Rock Body Part

Le Maitre RMT

Igneous Rock material classification based on Quart-feldspar and mafic mineral modal composition, LeMaitre et al, IUGS
Extends Mineralogical RMT

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Le Maitre RMT to Mineralogical RMT

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Rhyolite to Le Maitre RMT

Liquid

Extends Fluid

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Liquid to Fluid

Lithostratigraphic Unit

Stratified geologic unit defined based on the properties of its rock material constituents and their arrangement within the confines of the unit.
Extends Geologic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Realization from Lithostratigraphic Unit to IUGS Strat Guide Unit Type
Generalization from Lithostratigraphic Unit to Geologic Unit

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Member to Lithostratigraphic Unit
Generalization from Group to Lithostratigraphic Unit
Generalization from Bed to Lithostratigraphic Unit
Generalization from Formation to Lithostratigraphic Unit

Member

A lithostratigraphic rank.
Extends Lithostratigraphic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Member to Lithostratigraphic Unit

Metamorphic Zone

A geologic unit defined by observable effects of a metamorphic event in a rock body.
Extends Geologic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Metamorphic Zone to Geologic Unit

Mineral

"A mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological processes." Nickel, Ernest H. (1995), The definition of a mineral, The Canadian Mineralogist. 33 (3): 689–90.
Extends Geologic Material

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Mineral to Geologic Material

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Quartz to Mineral

ATTRIBUTES
hasConstituent : Element Multiplicity: ([1..*])
isConstituentOf : Rock Material or Granular Material Multiplicity: ([1..*])

Mineral Type

Extends Amount of Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Mineral Type to Amount of Material Type

Mineralogical RMT

A rock material classification based on mineralogy.
Extends Rock Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Mineralogical RMT to Rock Material Type

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Le Maitre RMT to Mineralogical RMT

Outcrop

An outcrop is a part of a rock body that is visible at the Earth Surface. The size of an outcrop depends on the intention of its identification, and can range from a specific contact point (e.g. a Global Stratigraphic Point) to and exposure that extends 1-10 m. An outcrop is unified by some particular observational intention to represent an aspect of a geologic unit. It is a kind of O&M sampling feature.
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Outcrop to Rock Body Part

Physical Void

Physical Void (V):
An empty physical space in 3D. Distinct from abstract mathematical spaces, which include spaces made from various reference frames, including coordinate systems imposed on the earth (these are abstract imposed on real space).
V(x) <--> IPF(x) ^ exists y [hosts-v (y,x)]
Extends Immaterial Place Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Physical Void to Immaterial Place Feature

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Hole to Physical Void
Generalization from Rock Body Void to Physical Void
Generalization from Gap to Physical Void

Plasma

A state of matter.

Extends Fluid

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Plasma to Fluid

Porespace

Porespace (PS):
The gaps hosted within a rock body.
Formally: (after Hahman & Brodaric 2012):
PS (x) <--> G(x) ^ exists y [RB (y) ^ porespace (y) = x]
Extends Rock Body Void

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Porespace to Rock Body Void

Quartz

Example of a Mineral
Extends Mineral

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Quartz to Mineral

Rhyolite

Example Class of Rock Material.
Extends Rock Material

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Rhyolite to Rock Material
⇦ Realization from Rhyolite to Le Maitre RMT
⇦ Realization from Rhyolite to CGI Simple Lithology Type
⇦ Realization from Rhyolite to Rock Material Type
⇦ Realization from Rhyolite to TAS RMT

INCOMING STRUCTURAL RELATIONSHIPS
⇨ Realization from Rhyolite in X Formation to Rhyolite

Rhyolite in X Formation

Specific instance of Rhyolite, in a specific location and context.

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Realization from Rhyolite in X Formation to Rhyolite

Rock Body

A any body composed Rock Material, either identified as a Geologic Unit or other object (sosa.Sample, ISO19156 SamplingFeature), or an amount of rock material not associated with an identified object, e.g. Dakota Sandstone Formation, or the sandstone of the Chalma basin.
Rock Body has at least one geneticProcess that is a Process. Each Rock Body particular has a preferred age assigned through the min and max NumAgeMa (numerical age in Ma) fields and the min and max StratAge fields. Strat ages are named time ordinal eras from the stratigraphic time scale selected for use in GKO. If the history of the Rock Body as a more detailed sequence of events is desired, it can be represented using the optional hasEventHistory property with a Geologic Event instance.
Extends Geologic Endurant

OUTGOING STRUCTURAL RELATIONSHIPS

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body to Geologic Endurant

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Unit to Rock Body
Generalization from Rock Body Part to Rock Body
Generalization from Rock Material to Rock Body

ATTRIBUTES
hasPart : Rock Body Part or Rock Body Surface Multiplicity: ([1..*])
isPartOf : Rock Body Multiplicity: ([0..*])
hosts : Geologic Feature Multiplicity: ([0..*])
hasConstituent : Amount of Material Multiplicity: ([1..*])

Rock Body Part

A part of a rock body, either a geologic unit, amount of rock material, or Rock Body Surface.
All subtypes of Rock Body Part are instances of Rock Body Part Type.
If the part is a piece of another unit (e.g. xenolith in intrusion, block in melange), then the other unit can be found by inspecting the event history. Alternatively, a relation can be added to Geologic Unit to designate the original unit.
Extends Rock Body

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Part to Rock Body

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Outcrop to Rock Body Part
Generalization from Stratigraphic Section to Rock Body Part
Generalization from Facies to Rock Body Part
Generalization from Xenolith to Rock Body Part
Generalization from Fossil to Rock Body Part
Generalization from Clast to Rock Body Part
Generalization from Specimen to Rock Body Part
Generalization from Rock Body Surface to Rock Body Part
Generalization from Inclusion to Rock Body Part

CONNECTORS
Dependency Source -> Destination From:Rock Body Part Type : Class, To: Rock Body Part : Class, isPowerTypeOf

ATTRIBUTES
isPartOf : Rock Body Multiplicity: ([1..*])
hasConstituent : Rock Material Multiplicity: ([1..*])

Rock Body Part Type

Artifact of experimental multilevel modeling. The Rock Body Part Type would be a template for a set of properties and identity criteria (a Power Type) for a kind of Rock Body Part.
Extends 1stLevelType

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Part Type to 1stLevelType

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Clast to Rock Body Part Type

CONNECTORS

CONNECTORS
Dependency Source -> Destination From:Rock Body Part Type : Class, `To: Rock Body Part : Class, isPowerTypeOf

Rock Body Type

Artifact of experimental multilevel modeling. The Rock Body Type would be a template for a set of properties and identity criteria (a Power Type) for a kind of Rock Body. Geologic Unit Type is a specialization for that defines types of geologic unit
Extends 1stLevelType

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Type to 1stLevelType

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Unit Type to Rock Body Type

Rock Body Void

Rock Body Void (RBV):
RBV is a gap within a Rock Body, or between rock bodies, or hole in the Rock Body.
RBV (x) <--> G(x) ^ exists y [hosts-v(y,x) ^ RB(x)]
Extends Geologic Feature, Physical Void

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Body Void to Physical Void
Generalization from Rock Body Void to Geologic Feature

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Porespace to Rock Body Void

Rock Material

As an amount of matter, instances of rock material are located in space and time. From a philosophical point of view, if matter (including rock material) is abstract, as per GeoSciML, then there would be no physical or temporal manifestation of it. It is difficult to defend the position that matter does not physically exist in the world. This leads to absurdities, e.g. a geological unit having abstract parts (its rock materials) - this is like saying matter is the soul of the unit, not its physical constituent.
From a practical point of view, physical matter is always a constituent in some object, represented in this model as the other subtypes of Rock Body. Inclusion of a class for Rock Material allows description of material without association to an object.
In the GeoSciML model, participation of a Rock Material (named EarthMaterial in that model) as a constituent in a gsml.GeologicUnit has a role and proportion property.
Extends Geologic Material, Rock Body

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Material to Geologic Material
Generalization from Rock Material to Rock Body

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Rhyolite to Rock Material

CONNECTORS
Dependency Source -> Destination From:Rock Material Type : Class, To: Rock Material : Class, isPowerTyepOf

ATTRIBUTES
hasPart : Rock Body Part or Rock Material Multiplicity: ([0..*])

ATTRIBUTES
isPartOf : Rock Material Multiplicity: ([0..*])
hasConstituent : Granular Material or Mineral or Element Multiplicity: ([1..*])
isConstituentOf : Geologic Unit or Rock Body Part Multiplicity: ([1..*])

Rock Material Type

multilevel model class, supertype for various types of rock material representation.
Extends 1stLevelType, Amount of Material Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Rock Material Type to 1stLevelType
Realization from Rock Material Type to 2ndtLevelType
Generalization from Rock Material Type to Amount of Material Type

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from CGI Simple Lithology Type to Rock Material Type
Realization from Rhyolite to Rock Material Type
Generalization from Chemical RMT to Rock Material Type
Generalization from Mineralogical RMT to Rock Material Type

CONNECTORS
Dependency Source -> Destination From:Rock Material Type : Class, To: Rock Material : Class, isPowerTyepOf

Solid

state of matter
Extends State of Material

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Solid to State of Material

Specimen

A piece of material removed from a Rock Body with the intention of representing some aspect of the Rock Body.
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Specimen to Rock Body Part

ATTRIBUTES
isSampleOf : Geologic Endurant

Stratigraphic Section

A rock body that represents a transect through a sequence of stratified rocks. Although a section is typically observed and described along a linear traverse on the EarthSurface or in a borehole, the description applies to the rock volume in the vicinity of that transect. Operationally, a section might be constructed by a linked set of traverses in the same area, or using segments from multiple boreholes in the same area.
The stratigraphic section concept is in contrast to the cross-section or profile concept, which represents a typically (but not necessarily) vertical mapping horizon surface through a rock body used for depicting geologic relationships. A cross section would be a kind of geologic surface in this model.
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Stratigraphic Section to Rock Body Part

INCOMING STRUCTURAL RELATIONSHIPS

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Stratotype to Stratigraphic Section

Stratotype

A particular stratigraphic section used a reference (prototype) to define a stratigraphic unit; a stratotype section might contain a Stratigraphic Point that is the reference for a particular Contact.
Extends Stratigraphic Section

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Stratotype to Stratigraphic Section

ATTRIBUTES
isReferenceFor : Geologic Unit or Contact

TAS RMT

A chemical rock material type that defines rock materials based on plotting chemical analyses in a Total Alkali-Silica diagram; typically used to classify volcanic rocks that are too fine grained for modal mineral composition to be determined reliably.
Extends Chemical RMT

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from TAS RMT to Chemical RMT

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Rhyolite to TAS RMT

X Formation

example instance of Formation

OUTGOING STRUCTURAL RELATIONSHIPS
Realization from X Formation to Formation

Xenolith

a rock fragment that becomes enveloped in a larger rock during the latter's development and solidification. In geology, the term xenolith is almost exclusively used to describe inclusions in igneous rock during magma emplacement and eruption. https://en.wikipedia.org/wiki/Xenolith
Extends Rock Body Part

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Xenolith to Rock Body Part

Geologic Structure

Geologic Structure diagram

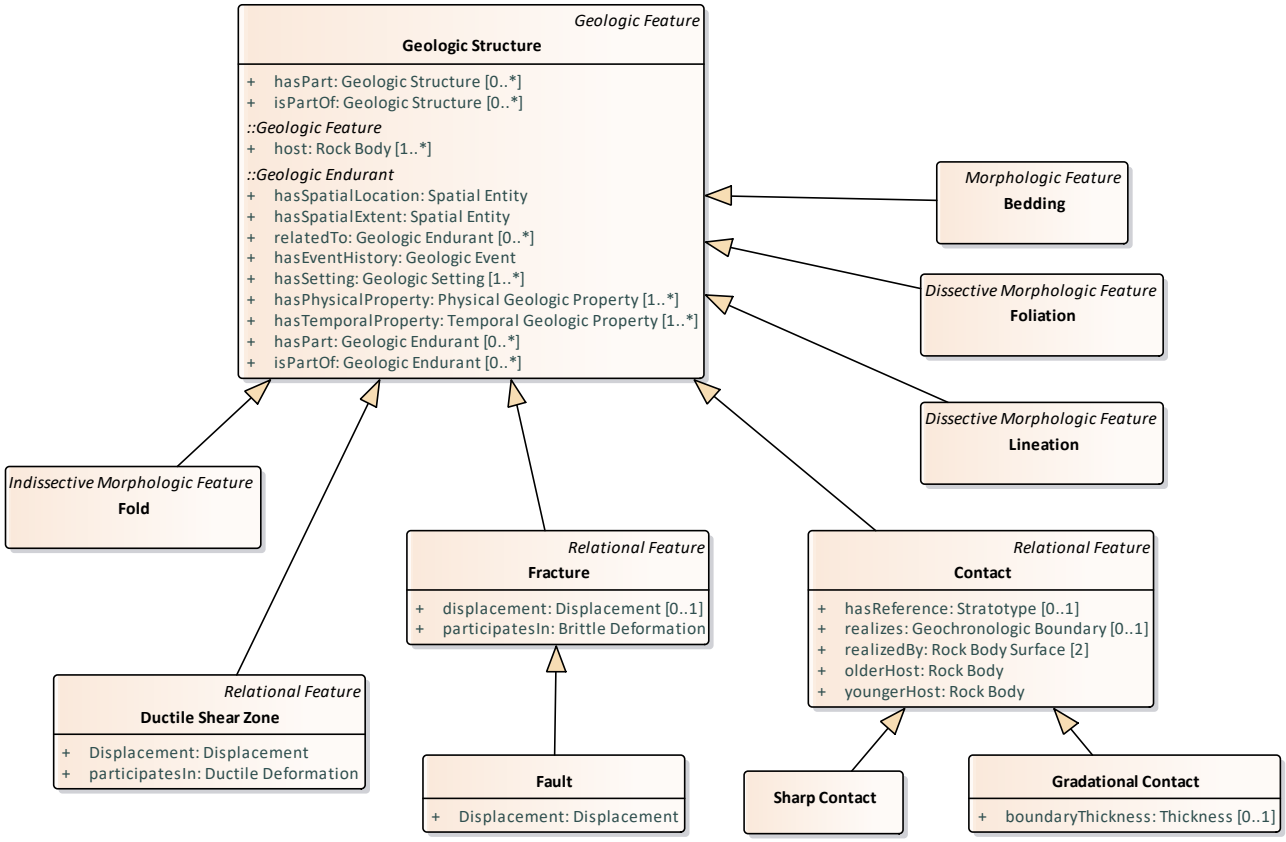


Figure 11: Geologic Structure

Classes

Bedding

Class in package 'Geologic Structure'
Bedding as a fabric representing the average orientation of paleodepositional surface should be encoded through the foliationType; might apply to bedding that is layering or a foliation without layering (e.g. clast alignment in amalgamated beds).
Can be dissective (penetrative) or non-dissective (non-penetrative).
Extends Geologic Structure, Morphologic Feature

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Bedding to Geologic Structure
⇦ Generalization from Bedding to Morphologic Feature

Contact

Class in package 'Geologic Structure'
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)]
Extends Geologic Structure, Relational Feature

OUTGOING STRUCTURAL RELATIONSHIPS
⇦ Generalization from Contact to Geologic Structure

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Contact to Relational Feature

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Sharp Contact to Contact
Generalization from StratigraphicPoint to Contact
Generalization from Gradational Contact to Contact

ATTRIBUTES
hasReference : Stratotype Multiplicity: ([0..1])
realizes : Geochronologic Boundary Multiplicity: ([0..1])
realizedBy : Rock Body Surface Multiplicity: ([2])
olderHost : Rock Body
youngerHost : Rock Body

Ductile Shear Zone

Class in package 'Geologic Structure'
Ductile Shear Zone (DSZ): a generally surface-like zone across which rock bodies have been displaces. Distinguished from fault by the absence of through-going fractures (material discontinuities) separating adjacent rock bodies.
Narrower than gsml:shearDisplacementStructure, which is broader because it includes faults.
Extends Geologic Structure, Relational Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Ductile Shear Zone to Geologic Structure
Generalization from Ductile Shear Zone to Relational Feature

ATTRIBUTES
Displacement : Displacement
participatesIn : Ductile Deformation

Fault

Class in package 'Geologic Structure'
Fault (FLT)
A surface across which there has been displacement of rock bodies, characterized by brittle deformation. This structure may have some mappable thickness (a deformation zone) and have an associated body of deformed rock.
Narrower than gsml:shearDisplacementStructure, which is broader, because it includes ductile shear zones.
Extends Fracture

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Fault to Fracture

ATTRIBUTES
Displacement : Displacement

Fold

Class in package 'Geologic Structure'
Fold (FLD):
Folds are a pattern in the shape of the rock body.
GeoSciML v3.2: One or more systematically curved layers, surfaces, or lines in a rock body. Fold denotes a structure formed by the deformation of a GeologicStructure to form a structure that may be described by the translation of an abstract line (the fold axis) parallel to itself along some curvilinear path (the fold profile). Folds have a hinge zone (zone of maximum curvature along the surface) and limbs (parts of the deformed surface not in the hinge zone). Folds are described by an axial surface, hinge line , profile geometry, the solid angle between the limbs, and the relationships between adjacent folded surfaces if the folded structure is a Layering fabric (similar, parallel).
FLD(x) <--> exists z, y [hosts(z,x) ^ partOf(y,z) ^ RB(y) ^ RB(z) --> not exists x1 [hosts(y,x1) ^ FLD(x1)]]
Extends Geologic Structure, Indissective Morphologic Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Fold to Geologic Structure
Generalization from Fold to Indissective Morphologic Feature

Foliation

Class in package 'Geologic Structure'
Foliation (FOL):
A pattern in the material of a rock body. The pattern shares matter with its hosts, so it is materially dependent on the host: FOL(x) --> exists y [(PO (y) v M(y)) ^ hosts (y,x) ^ mat-dep (x,y)]
GeoSciML v4.1: A foliation is a planar arrangement of textural or structural features in any type of rock. It includes any of a wide variety of penetrative planar geological structures that may be present in a rock. Examples include schistosity, mylonitic foliation, penetrative bedding structure (lamination), and cleavage. Following the proposed definition of gneiss by the NADM Science Language Technical Team, penetrative planar foliation defined by layers > 5 mm thick is considered Layering.
Extends Dissective Morphologic Feature , Geologic Structure

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Foliation to Geologic Structure
Generalization from Foliation to Dissective Morphologic Feature

Fracture

Class in package 'Geologic Structure'
Fracture (FR):
FR is a Geologic Structure:
- hosted by two or more rock bodies
- hosting a gap created by breaking rock
- not a part of any of the hosting rock bodies
Fractures are cracks in the Earth. If there is no displacement it is a joint. If there is displacement and associated deformation is brittle in nature, the fracture is a fault. Fractures are not contacts because the rock bodies that host a fracture do not touch; either some open space, vein-filling, or fault rock separates the two rock bodies, but the width of the fracture void or filling can be very small..
Extends Geologic Structure, Relational Feature

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Fracture to Relational Feature
Generalization from Fracture to Geologic Structure

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Fault to Fracture
Generalization from Joint to Fracture

ATTRIBUTES
displacement : Displacement Multiplicity: ([0..1])
participatesIn : Brittle Deformation

Gradational Contact

Class in package 'Geologic Structure'
Extends Contact

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Gradational Contact to Contact

ATTRIBUTES
boundaryThickness : Thickness Multiplicity: ([0..1])

Joint

Class in package 'Geologic Structure'
Joint (J): Fracture across which there is no displacement at the scale of interest.
Extends Fracture

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Joint to Fracture

ATTRIBUTES
Displacement : Displacement Multiplicity: ([0])

Lineation

Class in package 'Geologic Structure'
Geologic Structure defined by aligned elongate elements. Lineation connotes a pervasive (dissective) linear structure. Includes: flow lines, linear arrangements of elongate components in sediments, fold hinges (when abundant and closely spaced), elongate minerals, crinkles, and lines of intersection between penetrative planar structures. In a Geologic Surface: scratches, striae, slickenlines,
Class also includes discrete linear structures like boudin, channel axis, tool marks.
Extends Dissective Morphologic Feature , Geologic Structure

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Lineation to Dissective Morphologic Feature
Generalization from Lineation to Geologic Structure

Sharp Contact

Class in package 'Geologic Structure'
Extends Contact

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Sharp Contact to Contact

Geologic Time

GKO-Geologic Time diagram

Class diagram in package 'Geologic Time'

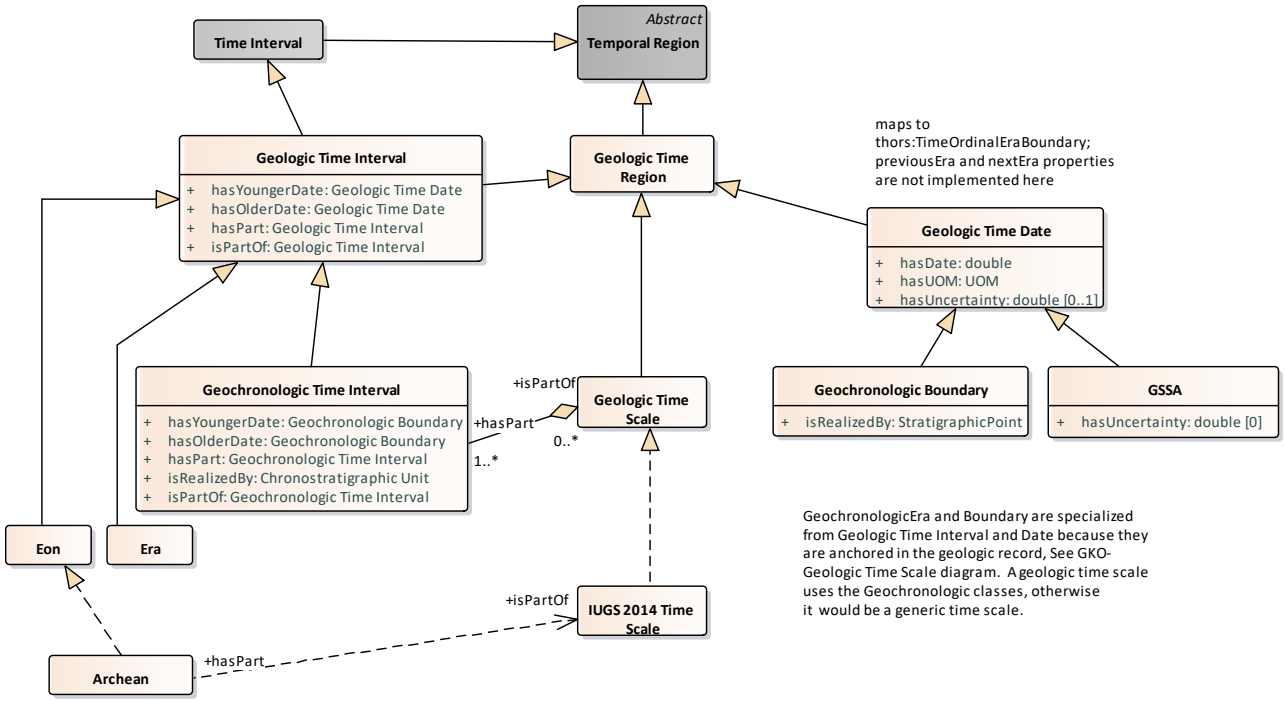


Figure 12: GKO-Geologic Time

GKO-Geologic Time Scale diagram

Class diagram in package 'Geologic Time'

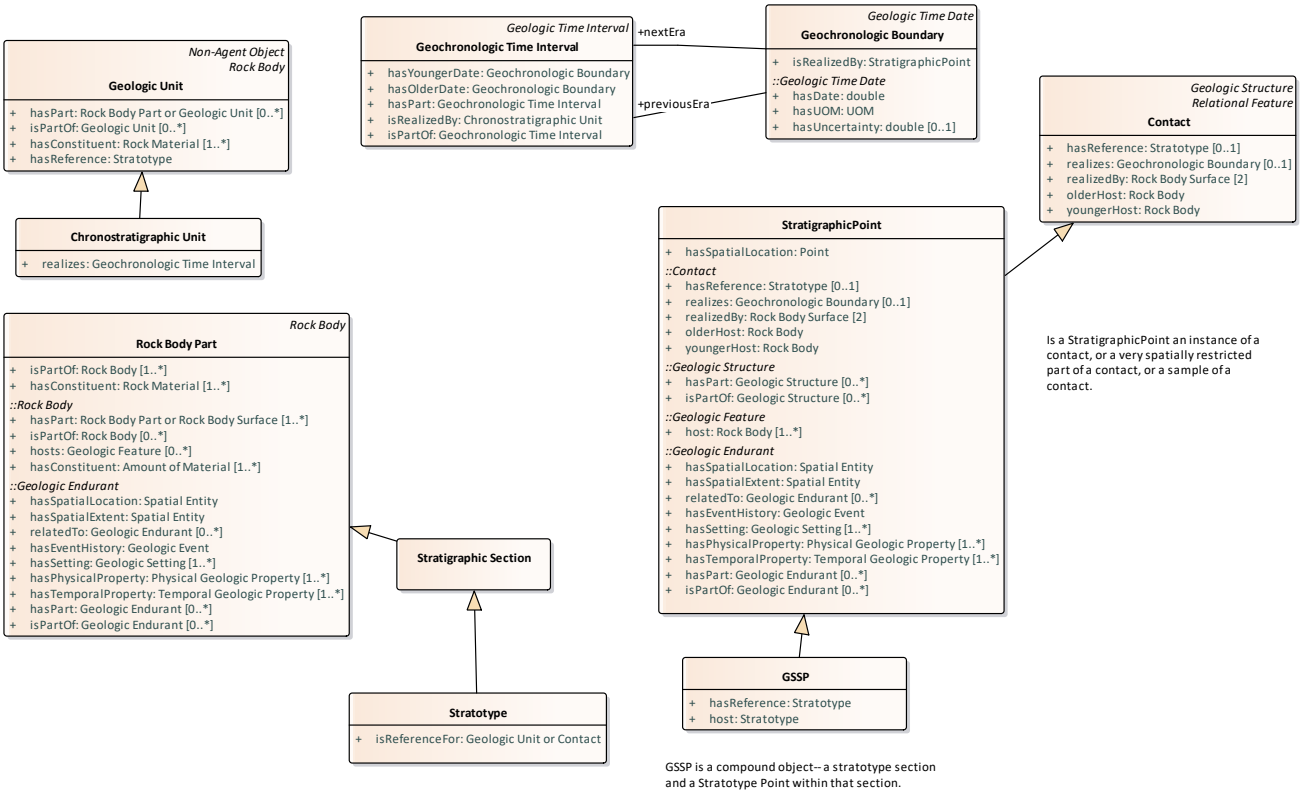


Figure 13: GKO-Geologic Time Scale

Classes

Archean

Class in package 'Geologic Time'
An instance of Eon, which is a subclass of Geochronologic Time Interval. Different Archaen Eon instances can be defined in different Geologic Time Scales; the instances are distinguished by having different hasYoungerData or hasOlderDate properties.

OUTGOING STRUCTURAL RELATIONSHIPS
Realization from Archean to Eon

CONNECTORS
Dependency Source -> Destination From:Archean : Class, hasPart To:IUGS 2014 Time Scale : Class, isPartOf

Archean Unit

Class in package 'Geologic Time'
An Instance of ChronostratigraphicUnit.Eonothem. Has instances that are rock body individuals that fall into the Archean age range. Thus Archean is a class, and its instances are rock body individuals.

OUTGOING STRUCTURAL RELATIONSHIPS
Realization from Archean Unit to Chronostratigraphic Unit
Realization from Archean Unit to Eonothem

Chronostratigraphic Unit

Class in package 'Geologic Time'
A geologic unit that was originated during a Geochronologic Time Interval, modeled as 'realizes' the time interval. A specific instance of Chronostratigrarphic Unit might be a reference that defines a time interval during which the unit was deposited.
Extends Geologic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Chronostratigraphic Unit to Geologic Unit
Realization from Chronostratigraphic Unit to IUGS Strat Guide Unit Type

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Archean Unit to Chronostratigraphic Unit
Generalization from Eonothem to Chronostratigraphic Unit

ATTRIBUTES
realizes : Geochronologic Time Interval

Eon

Class in package 'Geologic Time'
Extends Geologic Time Interval

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Eon to Geologic Time Interval

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Archean to Eon

Eonothem

Class in package 'Geologic Time'
Kind of Chronostratigraphic Unit
Extends Chronostratigraphic Unit

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Eonothem to Chronostratigraphic Unit

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Archean Unit to Eonothem

Era

Class in package 'Geologic Time'
Extends Geologic Time Interval

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Era to Geologic Time Interval

Geochronologic Boundary

Class in package 'Geologic Time'
A temporal position that is anchored to a specific location in a stratotype stratigraphic section. Serves as a temporal boundary between two Geochronologic Time Intervals.
Extends Geologic Time Date

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Boundary to Geologic Time Date

ATTRIBUTES
isRealizedBy : StratigraphicPoint this objectProperty links a Geochronologic Boundary, a temporal position == Geologic Time Date in this model to a Stratigraphic Point that is the mani

ASSOCIATIONS	
Association	
Source: Geochronologic Boundary	Target: nextEra Geochronologic Time Interval
Association	
Source: Geochronologic Boundary	Target: previousEra Geochronologic Time Interval

Geochronologic Time Interval

Class in package 'Geologic Time'
A time interval that is defined with reference to particular geologic feature in the Earth. Corresponds to GeochronologicEra of Cox and Richard (2014, DOI: 10.1007/s12145-014-0170-6) (gts). The isRealizedBy property corresponds to the manifestedBy property in gts (see http://resource.geosciml.org/vocabulary/timescale/isc2017 for implementation). gts models a stratotype property from GeochronologicEra (the time interval) directly to a Stratotype. In this model the association is indirect from era (time interval) to ChronostratigraphicUnit to Stratotype.
A Geochronologic Time Interval restricts a Geologic Time Interval by restricting the bounding dates to be Geochronologic Boundary.
Extends Geologic Time Interval

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Time Interval to Geologic Time Interval
Aggregation from Geochronologic Time Interval to Geologic Time Scale

ATTRIBUTES
hasYoungerDate : Geochronologic Boundary
hasOlderDate : Geochronologic Boundary

ATTRIBUTES
hasPart : Geochronologic Time Interval
isRealizedBy : Chronostratigraphic Unit
isPartOf : Geochronologic Time Interval

ASSOCIATIONS	
Association	
Source: Geochronologic Boundary	Target: nextEra Geochronologic Time Interval
Association	
Source: Geochronologic Boundary	Target: previousEra Geochronologic Time Interval

Geologic Age

Class in package 'Geologic Time'
A geologic Property used to specify the age date associated with some geologic entity. Can be quantified as a Chronostratigraphic Age, Geochronologic Age, or a Geochronologic Age Date.
Extends Temporal Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Age to Temporal Geologic Property

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Age to Geologic Age
Generalization from Geochronologic Age Date to Geologic Age
Generalization from Chronostratigraphic Age to Geologic Age

Geologic Time Date

Class in package 'Geologic Time'
A temporal coordinate value, specified by a numeric coordinate (generally MYPB, but definitiosn 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.
Extends Geologic Time Region

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Time Date to Geologic Time Region

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from GSSA to Geologic Time Date
Generalization from Geochronologic Boundary to Geologic Time Date

ATTRIBUTES
hasDate : double
hasUOM : UOM
hasUncertainty : double Multiplicity: ([0..1])

Geologic Time Interval

Class in package 'Geologic Time'
Extends Geologic Time Region, Time Interval

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Time Interval to Time Interval
Generalization from Geologic Time Interval to Geologic Time Region

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Time Interval to Geologic Time Interval
Generalization from Eon to Geologic Time Interval
Generalization from Era to Geologic Time Interval

ATTRIBUTES
hasYoungerDate : Geologic Time Date
hasOlderDate : Geologic Time Date
hasPart : Geologic Time Interval
isPartOf : Geologic Time Interval

Geologic Time Region

Class in package 'Geologic Time'
A position or interval located in a temporal reference system. The region can be defined using temporal coordinates, or as an ordinal era bounded by geochronologic boundaries.
Extends Temporal Region

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Time Region to Temporal Region

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Time Interval to Geologic Time Region
Generalization from Geologic Time Scale to Geologic Time Region
Generalization from Geologic Time Date to Geologic Time Region

Geologic Time Scale

Class in package 'Geologic Time'
A collection of hierarchical time intervals that cover some Geologic Time Region that is the scope of a Geologic Time Scale (see Cox and Richard, 2014).
Extends Geologic Time Region

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Time Scale to Geologic Time Region

INCOMING STRUCTURAL RELATIONSHIPS
Realization from IUGS 2014 Time Scale to Geologic Time Scale
Aggregation from Geochronologic Time Interval to Geologic Time Scale

GSSA

Class in package 'Geologic Time'
Global Standard Stratigraphic Age, abbreviated GSSA, is a temporal position defined by the International Stratigraphic Commission to define the boundary between Geochronologic Eras in cases where a GSSP (Global Stratigraphic Section and Point) can not be established as a reference for geochronologic boundaries. This is the case for Precambrian rocks older than Ediacaran, for which biostratigraphic evidence is not available and well preserved stratigraphic sections are rare.
Extends Geologic Time Date

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from GSSA to Geologic Time Date

ATTRIBUTES
hasUncertainty : double Multiplicity: ([0])

GSSP

Class in package 'Geologic Time'
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.
Extends StratigraphicPoint

OUTGOING STRUCTURAL RELATIONSHIPS

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from GSSP to StratigraphicPoint

ATTRIBUTES
hasReference : Stratotype
host : Stratotype

IUGS 2014 Time Scale

Class in package 'Geologic Time'

OUTGOING STRUCTURAL RELATIONSHIPS
Realization from IUGS 2014 Time Scale to Geologic Time Scale

CONNECTORS
Dependency Source -> Destination From:Archean : Class, hasPart To:IUGS 2014 Time Scale : Class, isPartOf

IUGS Strat Guide Unit Type

Class in package 'Geologic Time'
A geologic unit type that is defined based on criteria defined by the IUGS International Stratigraphic Guide (http://www.stratigraphy.org/index.php/ics-stratigraphicguide).
Extends Geologic Unit Type

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from IUGS Strat Guide Unit Type to Geologic Unit Type

INCOMING STRUCTURAL RELATIONSHIPS
Realization from Chronostratigraphic Unit to IUGS Strat Guide Unit Type
Realization from Lithostratigraphic Unit to IUGS Strat Guide Unit Type
Realization from Formation to IUGS Strat Guide Unit Type
Realization from Group to IUGS Strat Guide Unit Type

StratigraphicPoint

Class in package 'Geologic Time'
A spatially restricted part of a Contact feature, typically located by a point location. Could be thought of as an instance of a Contact, or a sample of a Contact.
Extends Contact

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from StratigraphicPoint to Contact

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from GSSP to StratigraphicPoint

ATTRIBUTES
hasSpatialLocation : Point

Properties

GKO-Abstract Property diagram

Class diagram in package 'Properties'

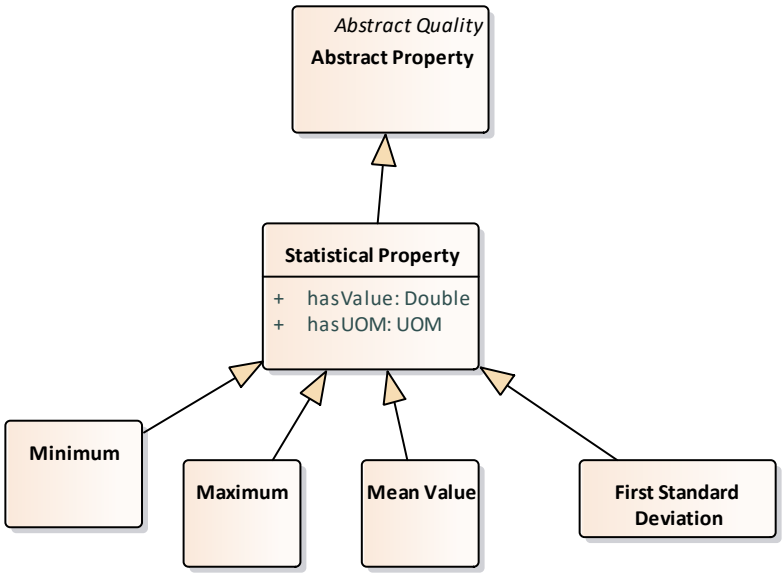


Figure 14: GKO-Abstract Property

GKO-Geologic Property diagram

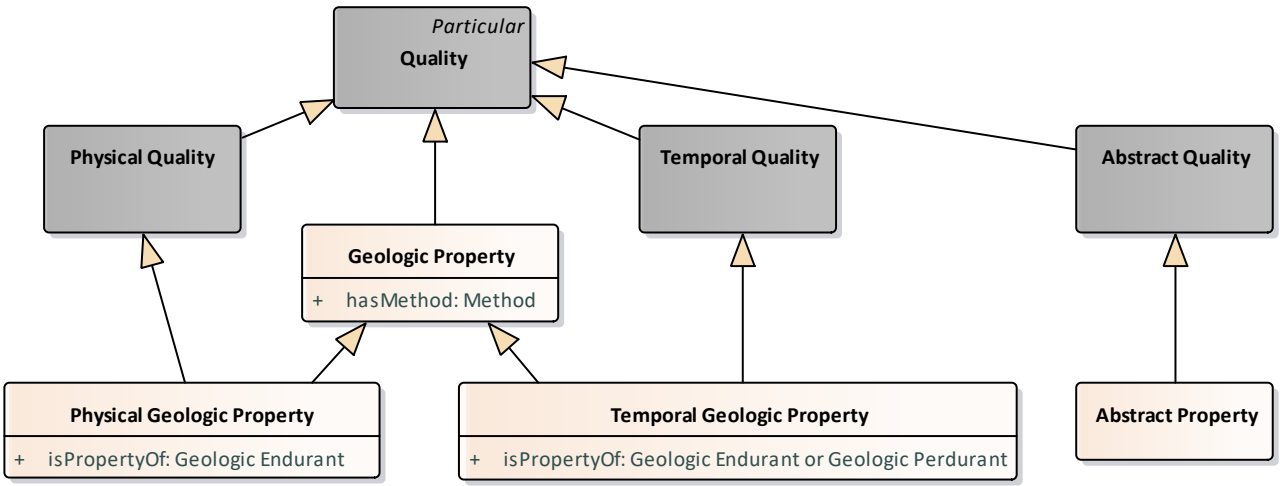


Figure 15: GKO-Geologic Property

GKO-Geologic Physical Property diagram

Class diagram in package 'Properties'

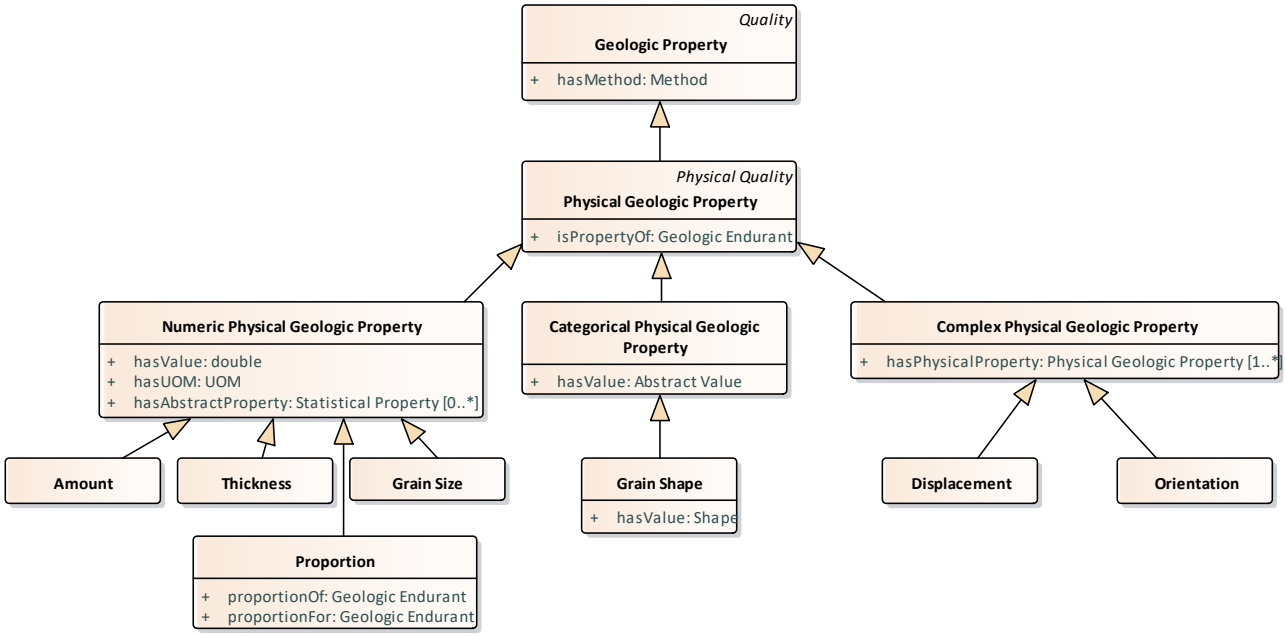


Figure 16: GKO-Geologic Physical Property

GKO-Geologic Temporal Property diagram

a property that specifies a Geologic Age using bounding (younger and older) Geologic Time Interval instances.

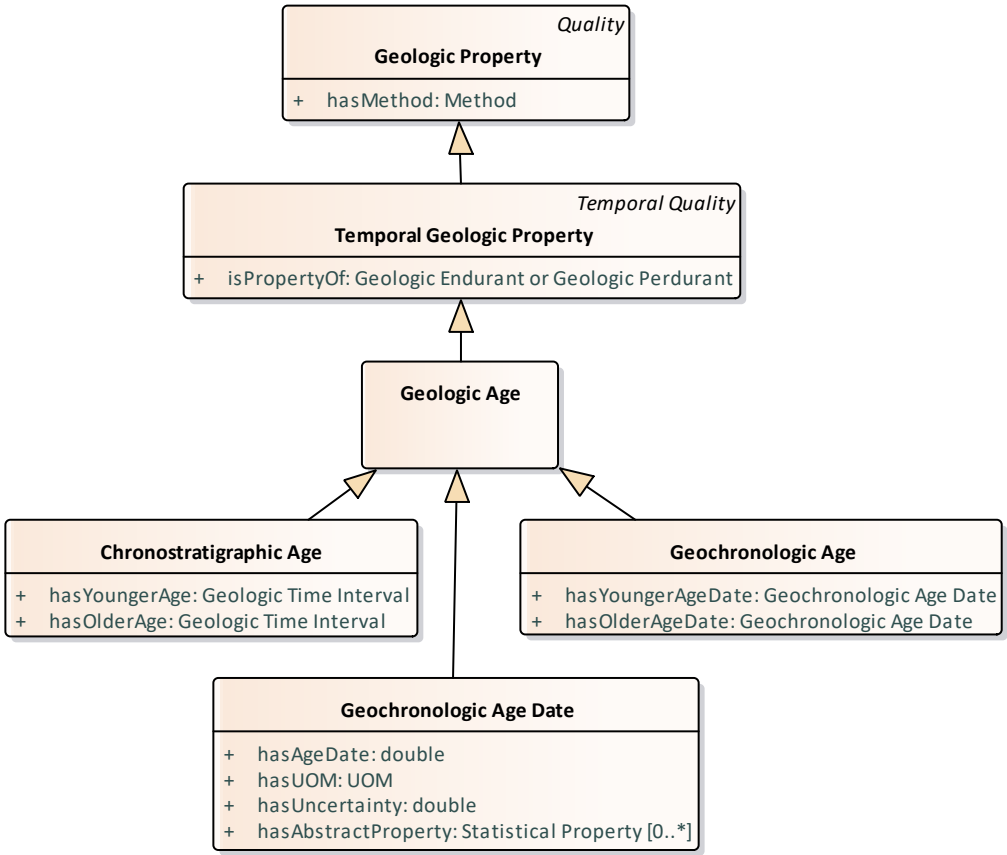


Figure 17: GKO-Geologic Temporal Property

Classes

Amount

Class in package 'Properties'
Extends Numeric Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Amount to Numeric Physical Geologic Property

Categorical Physical Geologic Property

Class in package 'Properties'
A physical property that is quantified by a category from a classification scheme.
Extends Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Categorical Physical Geologic Property to Physical Geologic Property

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Grain Shape to Categorical Physical Geologic Property

ATTRIBUTES
hasValue : Abstract Value

Chronostratigraphic Age

Class in package 'Properties'
A Geologic age that is specified with two bounding (younger and older) Geologic Time Interval instances.
Extends Geologic Age

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Chronostratigraphic Age to Geologic Age

ATTRIBUTES
hasYoungerAge : Geologic Time Interval
hasOlderAge : Geologic Time Interval

Complex Physical Geologic Property

Class in package 'Properties'
A geologic property specified by a data object that can be decomposed into separate components or dimensions. For example, the orientation of bedding is specified by a strike direction (in compass coordinates) and a dip magnitude in degrees.
Extends Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Complex Physical Geologic Property to Physical Geologic Property

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Orientation to Complex Physical Geologic Property
Generalization from Displacement to Complex Physical Geologic Property

ATTRIBUTES
hasPhysicalProperty : Physical Geologic Property Multiplicity: ([1..*])

Displacement

Class in package 'Properties'
Property that specifies the amount and direction of offset between rock bodies on opposite sides of a shear displacement structure. Most common approaches are to specify separation of a surface across the structure (separation), or the vector linking piercing points on opposite sides of the structure (slip).
Extends Complex Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Displacement to Complex Physical Geologic Property

First Standard Deviation

Class in package 'Properties'
An interval around a measurement result value that is asserted to include 68% of repeat measurement results for the same value.
Extends Statistical Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from First Standard Deviation to Statistical Property

Geochronologic Age

Class in package 'Properties'
A Geologic age that is specified with two bounding (younger and older) Geochronologic Age Date instances.
Extends Geologic Age

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Age to Geologic Age

ATTRIBUTES
hasYoungerAgeDate : Geochronologic Age Date
hasOlderAgeDate : Geochronologic Age Date

Geochronologic Age Date

Class in package 'Properties'
A Geologic age that is specified with a numeric temporal coordinate, including units of measure, uncertainty in value assignment, and other statistical properties associated with the measurement result.
Extends Geologic Age

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geochronologic Age Date to Geologic Age

ATTRIBUTES
hasAgeDate : double
hasUOM : UOM
hasUncertainty : double
hasAbstractProperty : Statistical Property Multiplicity: ([0..*])

Geologic Property

Class in package 'Properties'
A characteristic of a Geologic Endurant or Perdurant.
Extends Quality

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Property to Quality

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Physical Geologic Property to Geologic Property
Generalization from Temporal Geologic Property to Geologic Property

ATTRIBUTES
hasMethod : Method Specification of the measurement procedure used to assign a value to a property instance.

ASSOCIATIONS	
Association (direction: Destination -> Source) Source: Geologic Property Cardinality: [1..*]	Target: Geologic Endurant
Association (direction: Destination -> Source) Source: Geologic Property Cardinality: [1..*]	Target: Geologic Perdurant

Grain Shape

Class in package 'Properties'
Example categorical physical geologic property.
Extends Categorical Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Grain Shape to Categorical Physical Geologic Property

ATTRIBUTES
hasValue : Shape

Grain Size

Class in package 'Properties'
Example numeric physical geologic property.
Extends Numeric Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Grain Size to Numeric Physical Geologic Property

Maximum

Class in package 'Properties'
A statistical value used for property value assignment, represents the expected or measured maximum value for property
Extends Statistical Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Maximum to Statistical Property

Mean Value

Class in package 'Properties'
A statistical value used for property value assignment, represents the mean of multiple determination of the value for a property.
Extends Statistical Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Mean Value to Statistical Property

Minimum

Class in package 'Properties'
A statistical value used for property value assignment, represents the expected or measured minimum value for property
Extends Statistical Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Minimum to Statistical Property

Numeric Physical Geologic Property

Class in package 'Properties'
A physical property that is quantified by a measured numeric value.

Extends Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Numeric Physical Geologic Property to Physical Geologic Property

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Proportion to Numeric Physical Geologic Property
Generalization from Thickness to Numeric Physical Geologic Property
Generalization from Amount to Numeric Physical Geologic Property
Generalization from Grain Size to Numeric Physical Geologic Property

ATTRIBUTES
hasValue : double
hasUOM : UOM
hasAbstractProperty : Statistical Property Multiplicity: ([0..*])

Orientation

Class in package 'Properties'
Property that specifies the geometric disposition of a geologic structure relative to some spatial reference frame. The most common examples are strike and dip of bedding or a fault surface, or the trend and plunge of a linear structure.
Extends Complex Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Orientation to Complex Physical Geologic Property

percent

Class in package 'Properties'
a unit of measure that can be associated with a numeric property value
Extends UOM

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from percent to UOM

Proportion

Class in package 'Properties'
A numeric property value used to express the fraction of a whole that is composed of some part. Values will range from 0 to 1 (0 to 100%).
Extends Numeric Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Proportion to Numeric Physical Geologic Property

ATTRIBUTES
proportionOf : Geologic Endurant
proportionFor : Geologic Endurant

Statistical Property

Class in package 'Properties'
Specification of statistics associated with a measured value, e.g. minimum, maximum, mean, mode, standard deviation.
Extends Abstract Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Statistical Property to Abstract Property

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Mean Value to Statistical Property
Generalization from First Standard Deviation to Statistical Property
Generalization from Maximum to Statistical Property
Generalization from Minimum to Statistical Property

ATTRIBUTES
hasValue : Double
hasUOM : UOM

Subangular

Class in package 'Properties'
Example categorical value for Grain Shape property.
Extends Shape

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Subangular to Shape

Temporal Geologic Property

Class in package 'Properties'
property that assigns a geologic Age to a Geologic Endurant or Perdurant.
Extends Geologic Property, Temporal Quality

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Temporal Geologic Property to Geologic Property
Generalization from Temporal Geologic Property to Temporal Quality

INCOMING STRUCTURAL RELATIONSHIPS
Generalization from Geologic Age to Temporal Geologic Property

ATTRIBUTES
isPropertyOf : Geologic Endurant or Geologic Perdurant

Thickness

Class in package 'Properties'
Example Numeric Physical Geologic Property. Linear dimension across a unit; for stratigraphic units typically normal to bedding orientation; for dikes or other tabular bodies, normal to the boundaries of the body.
Extends Numeric Physical Geologic Property

OUTGOING STRUCTURAL RELATIONSHIPS
Generalization from Thickness to Numeric Physical Geologic Property

Top level ontology

This package includes Classes imported from DOLCE or other high-level ontologies. They are used to establish the conceptual framework for the geology ontology. Definitions are not in general included in this model, the user should refer to literature on DOLCE, e.g. S Borgo, C Masolo, 2009, Foundational choices in DOLCE, R. Poli et al. (eds.), Theory and Applications of Ontology: Computer Applications, DOI 10.1007/978-90-481-8847-5_13, Springer Science+Business Media B.V.

GKO-Abstract diagram

Class diagram in package 'Top'

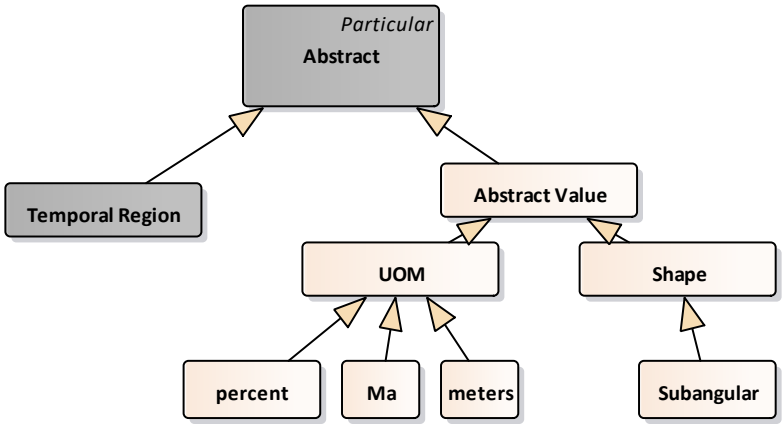


Figure 18: GKO-Abstract

GKO-Feature diagram

Class diagram in package 'Top'

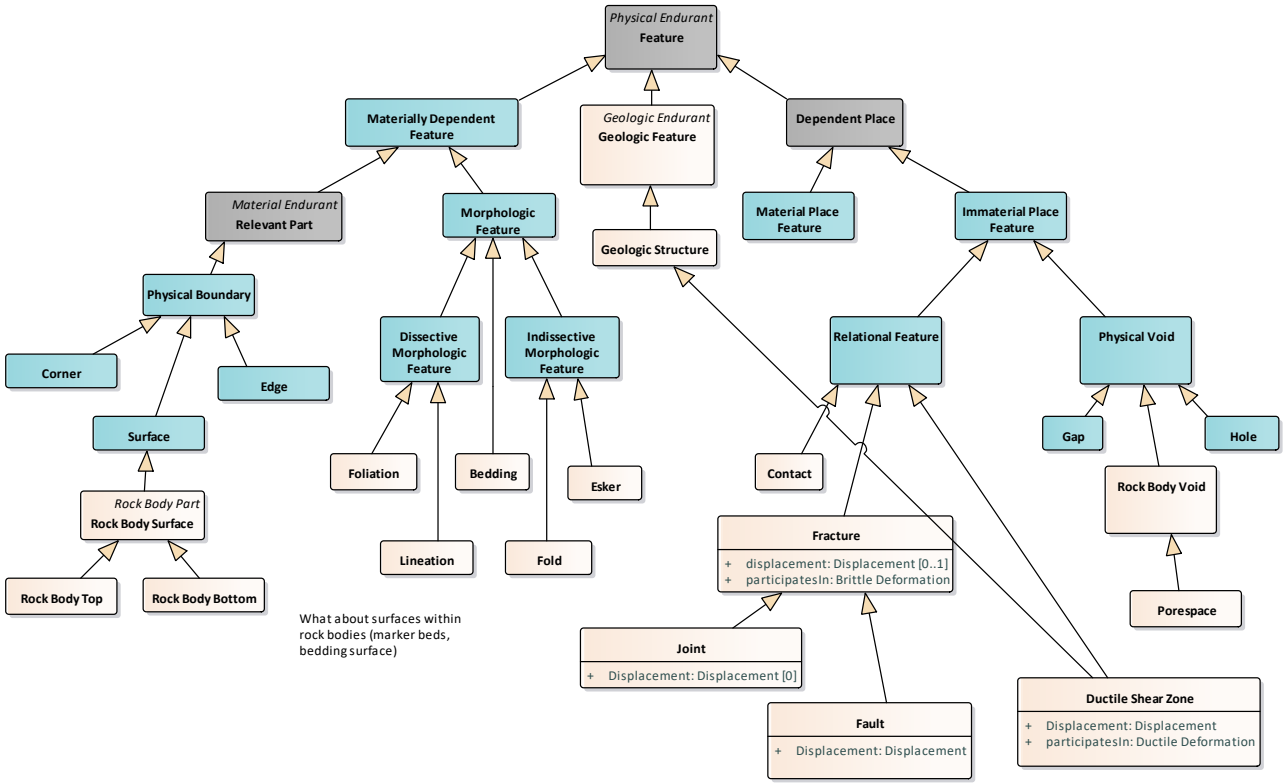


Figure 19: GKO-Feature

GKO-Top diagram

Class diagram in package 'Top'

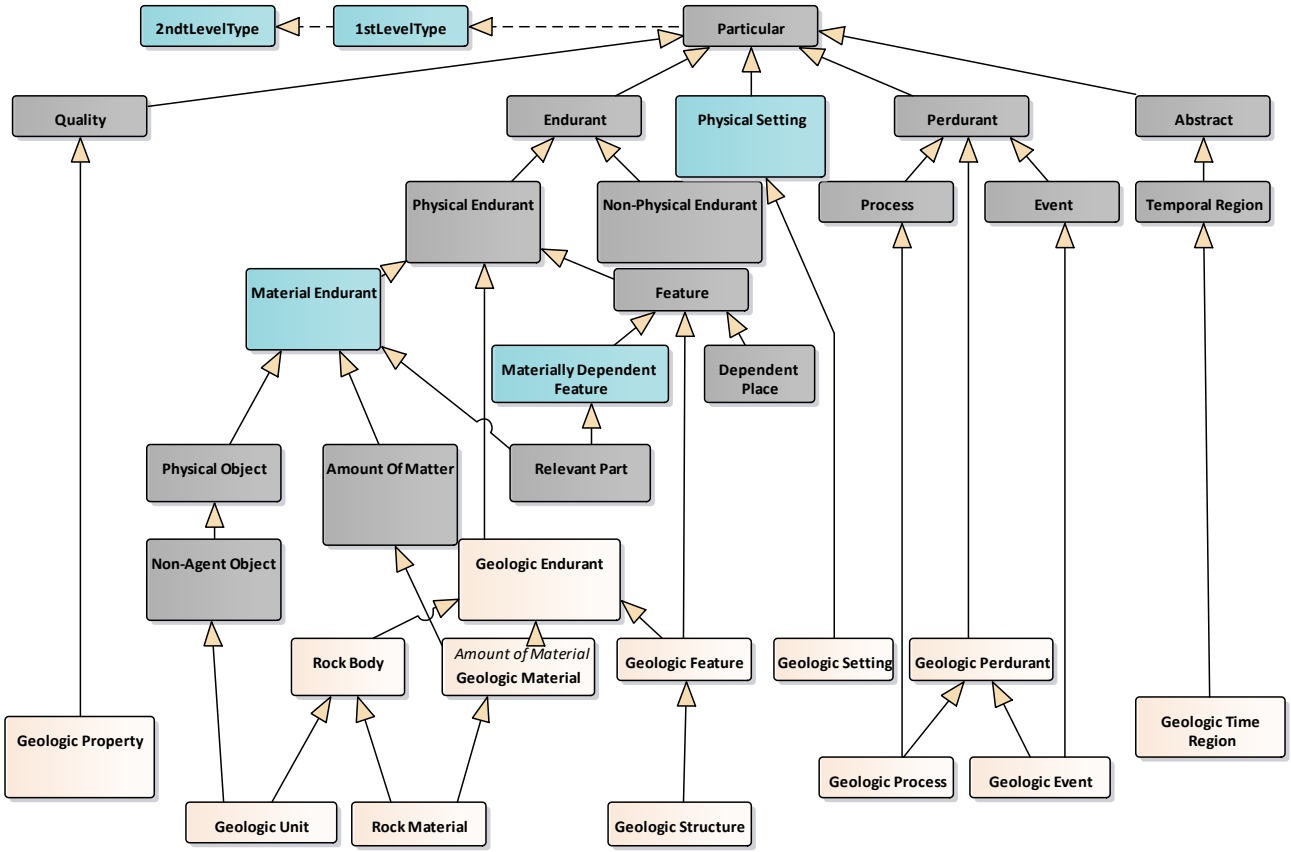


Figure 20: GKO-Top

Classes

1stLevelType

2ndLevelType

Abstract

Extends Particular

Abstract Property

Extends Abstract Quality

Abstract Quality

Extends Quality

Abstract Value

Extends Abstract

Amount of Material

Extends Amount Of Matter

CONNECTORS
Dependency Source -> Destination From:Amount of Material Type : Class, To: Amount of Material : Class, isPowerTypeOf

ATTRIBUTES
hasMaterialState : State of Material

ATTRIBUTES
hasPhysicalProperty : Physical Geologic Property Multiplicity: ([1..*])

Amount of Material Type

Extends Amount of Matter Type

CONNECTORS
Dependency Source -> Destination From:Amount of Material Type : Class, To: Amount of Material : Class, isPowerTypeOf

Amount Of Matter

The amount of matter type can be subdivided into [a volume] of (1) material (rock material), or (2) state of a material (solid, fluid), to enable designation of lumps of rock or lumps of fluid.
Extends Material Endurant, Particular

CONNECTORS
Dependency Source -> Destination From:Amount of Matter Type : Class, To: Amount Of Matter : Class, isPowerTypeOf

Amount of Matter Type

Type of amount of matter.
Subtype of amount of matter are classified by material (e.g. rock material) or by state (e.g. solid, fluid).
Extends 1stLevelType

CONNECTORS
Dependency Source -> Destination From:Amount of Matter Type : Class, To: Amount Of Matter : Class, isPowerTypeOf

Corner

Corner (CR):
A boundary in 3D space that is neither line nor area, but a point.
Extends Physical Boundary

Dependent Place

Dependent Place Feature (DPF):
Includes a variety of features, voids, shadows, frontyards. Also includes morphological arrangements, such as patterns in the landscape, patterns of holes, etc.
DPF(x) <--> F(x) ^ exists y [hosts(y,x) ^ not submaterial (x,y)]
Extends Feature

Dissective Morphologic Feature

Dissective Material Feature (DMF):
is homomerous (penetrative): all parts of an object host the same type of feature (the feature penetrates the host's material).
Includes:
--- grain / wood
--- honeycomb pattern / beehive
--- geological texture, fabric, foliation
DMF(x) <--> exists z forall y [hosts(z,x) ^ partOf(y,z) --> exists x1 [hosts(y,x1) ^ DMF(x1)]]
Extends Morphologic Feature

Edge

Edge (E):
A boundary in 3D space that is neither point nor area, but a line.
Extends Physical Boundary

Endurant

Extends Particular

Event

Extends Perdurant

Feature

Feature (F):
All features are specifically dependent on their hosts - that is, the hosts relation is a subrelation of specific dependence.
F(x) <--> exists y [hosts(y,x)]
Extends Physical Endurant

Gap

Gap (G):
A physical void with a scattered (disconnected) host, consisting of the spaces between the scattered parts of the host.
G(x) <--> exists y [hosts-v(y,x) ^ not ICon (y)]
ICon (x): x is interior connected (continuous, not scattered) Extends Physical Void

Hole

Hole (H):
A physical void with a self-connected (non-scattered) host, consisting of some depression or cavity within the host.
H(x) <--> exists y [hosts-v(y,x) ^ ICon (y)]
ICon (x): x is interior connected (continuous, not scattered). Extends Physical Void

Immaterial Place Feature

Material Place Feature (IPF):
A dependent place feature that is immaterial.
E.g. voids, shadows and relational features such as traffic intersections (meeting of roads).
MPF(x) <--> DPF(x) ^ not mat(x). Extends Dependent Place

Indissective Morphologic Feature

Non-Dissective Material Feature (NDMF):
Not homomerous (non-pentrative) entity: spatial subdivisions (parts) are not instances of this feature
Includes:
--- smile or frown / lips
--- strips / zebra
--- checkerboard / wood
--- ocean waves / ocean
--- geological fold
NDMF(x) <--> exists z, y [hosts(z,x) ^ partOf(y,z) --> not exists x1 [hosts(y,x1) ^ NDMF(x1)]] Extends Morphologic Feature

Ma

Unit of time, one million years.
Extends UOM

Material Endurant

Extends Physical Endurant

Material Place Feature

Material Place Feature (MPF): A dependent place feature that is material. E.g. my house's backyard, frontyard
MPF(x) <--> DPF(x) ^ mat(x). Extends Dependent Place

Materially Dependent Feature

Materially Dependent Feature (MDF):
A feature that is materially dependent on its host, because they share matter. Thus, host and feature are both material.
Includes boundaries (tabletop/table, edge of a hole), material patterns (grain/wood), morphological features (smile/lips).
MDF(x) <--> F(x) ^ mat(x) ^ exists y [hosts(y,x) ^ submaterial (x,y) ^ mat(y)]
Extends Feature

meters

Unit of length measure.
Extends UOM

Morphologic Feature

Materially-Dependent Morphological Feature (MF):
A feature that is not a part of its host, but characterized by the form or structure of the host:
Morphological features can have morphological properties e.g. orientation, thickness, fold profile, etc.
- smile or frown / lips
- mountain / planet surface (protrusion in the planet surface)
- graben and horst / planet surface (protrusion or depression in the planet surface caused by faulting)
- geological fold: rock body with a certain shape
MF(x) --> MDF (x) ^ exist y [hosts (y,x) ^ not partOf (x,y)]
Extends Materially Dependent Feature

Non-Agent Object

Extends Physical Object

Non-Physical Endurant

Extends Endurant

Particular

Particular Type

A metatype whose instances are localized types, i.e. types that exist in space and time and are dependent on an individual. For example, any geological formation typically has a finite existence in space and time, and is dependent on a formative process. Particular types are thus not universal, as they cannot be instantiated away from the individual on which they depend. So, various formations on Earth will not exist on Mars, because the actual processes (not types of processes) that created them will necessarily be different (have distinct identity) even if the processes are of the same type.

Perdurant

Extends Particular

Physical Boundary

Physical Boundary (PB):
A part of a physical object or amount of matter that touches the exterior in 3D space, either a point (e.g. table corner), a line (table edge), or a surface (e.g. table top)... possibly a volume.
PB(x) <--> RPF(x) ^ exists y,z [hosts(y,x) ^ partOf (x,y) ^ touches (x, complement(y))]
Extends Relevant Part

Physical Endurant

Extends Endurant

Physical Object

Extends Material Endurant

Physical Quality

A property that inheres in a Geologic Endurant. A property has a value space, but individual property instances do not exists separately from some entity that carries the property.
Extends Quality

Physical Setting

Extends Particular

ATTRIBUTES
isSettingFor : Physical Endurant or Perdurant Multiplicity: ([1..*])
hasConstituent : Physical Endurant or Perdurant Multiplicity: ([1..*])
hasPart : Physical Setting Multiplicity: ([0..*])
isPartOf : PhysicalSetting Multiplicity: ([0..*])

Quality

Extends Particular

Relational Feature

Relational Feature (RF):
A relational feature is an immaterial feature that has been reified from a relation between its hosts. It must therefore have at least two hosts (i.e. arise minimally from a binary relation). It is inherently immaterial (has no physical extents) because relations are immaterial. It exists in space and time only insofar as its hosts exist in space and time. If the relation is spatial or temporal the resulting feature can be seen as being a location in space or time, but these are immaterial. E.g. a traffic intersection (spatial location from the intersection of roads) or a scheduling conflict (temporal location from the intersection of two agendas).
- e.g. traffic intersection (meeting of roads)
- e.g. schedule conflict (intersection of two agenda)
RF(x) <--> IF(x) ^ exists y,z [hosts(y,x) ^ hosts(z,x) ^ related(y,z)]
- related(y,z) is topmost in the our relation hierarchy
Extends Immaterial Place Feature

Relevant Part

Relevant Part Feature (RPF)
A feature that is part of its host.
RPF(x) <--> MDF (x) ^ exist y [hosts (y,x) ^ partOf (x,y)]
Extends Material Endurant, Materially Dependent Feature

Shape

Extends Abstract Value

State of Material

Extends Amount Of Matter

ATTRIBUTES
isMaterialStateOf : Amount of Material
hasPhysicalPproperty : Physical Geologic Property Multiplicity: ([1..*])

State of Material Type

Extends Amount of Matter Type

Surface

Extends Physical Boundary

Temporal Quality

Extends Quality

Temporal Region

Extends Abstract

Time Interval

Extends Temporal Region

UOM

Unit of measurement
Extends Abstract Value

Appendix 1. Example test instances

This section uses a hypothetical cross section (Figure 1) that includes various geologic relationships and units for test implementation using an informal Turtle-like syntax.

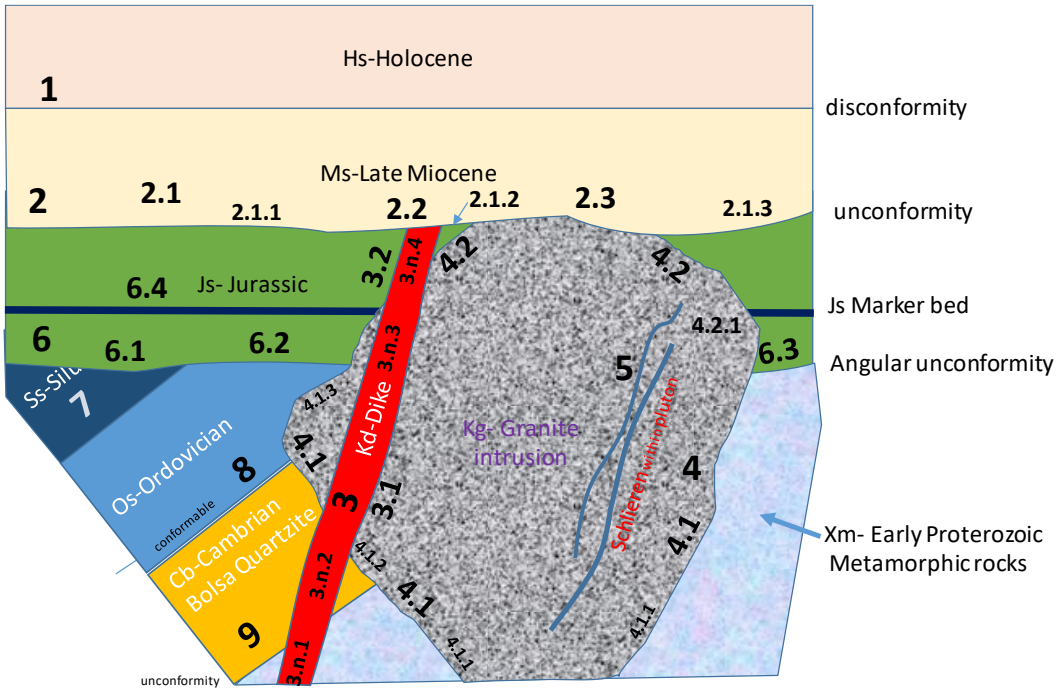


Figure 1. Schematic geologic Cross section.

Contacts are numbered; numbers are used in identifiers in the example RDF encoding. Top level numbers (e.g. N) are associated with boundaries at the base of lithostratigraphic units, or outer border of lithodemic units. Second and third level numbers (e.g. N.m, N.m.o) are associated with segments of contacts.

Geologic scenario:

Early Proterozoic metamorphic rocks are overlain unconformably by a Cambrian thru Silurian stratigraphic package; Sometime between Silurian and Jurassic, the sequence was tilted and eroded to a near flat surface, on which a Jurassic age sedimentary unit was deposited. That unit has a lower clastic part with an internal tuff marker bed, and an upper limestone part; these are not differentiated on the map, but are described as parts of the unit.

The Jurassic and older rocks are intruded by a Cretaceous granite, and by a Cretaceous diorite dike that also intrudes the Cretaceous granite. A contact metamorphic aureole formed around the Cretaceous granite. The pluton contains extensive internal schlieren surfaces with concentrations of mafic minerals. Another period of exumation and erosion removed the units that overlay the Jurassic sedimentary unit when the granite was intruded, producing an erosion surface on the Jurassic sedimentary unit and Cretaceous igneous rocks. Late Miocene sediment buried this surface, and after a period of non deposition in the Pliocene and Pleistocene, Holocene sediment blanketed the Miocene sediment.

Example 1. Geologic Material

```
Bolsa_Quartzite_Material
       rdfs:type    Rock_Material;
             rdfs:label  'Bolsa Quartzite, basal arkose';
        hasConstituent     Quartz_grains;
             hasConstituent      Feldspar_grains;
             hasConstituent      Clay_matrix;
        isConstituentOf    Bolsa_Quartzite_Formation;
        hasPhysicalProperty
```

```
                    [rdfs:type Proportion;
                          proportionOf Feldspar_grains;
                          proportionFor Bolsa_Quarzite_Material;
                          hasValue 50;
                          hasUOM [rdfs:type uom:percent]];

              hasPhysicalProperty       _:constituent_part2;
              hasPhysicalProperty       _:constituent_part3;
              hasPhysicalProperty
                    [rdfs:type color;
                          hasValue <http://colors.org/maroonbrown>].



Quartz_grains
              rdfs:type Granular_Material;
              hasConstituent Quartz_mineral;
              hasPhysicalProperty
                    [rdfs:type   GrainShape
                         hasValue       <http://geosciml.org/particleShape/subangular>];
              hasPhysicalProperty
                    [rdfs:type   GrainSizeMin
                         hasValue       .05
                         hasUOM  [rdfs:type mm]];
              hasPhysicalProperty
                    [rdfs:type   GrainSizeMax
                         hasValue       8
                         hasUOM  [rdfs:type mm]];
              hasPhysicalProperty
                    [rdfs:type   GrainSizeAverage
                          hasPart
                                [rdfs:type MeanValue
                                 hasValue 3;
                                 hasUOM [rdfs:type mm]];
                          hasPart
                                [rdfs:type StandardDeviation
                                hasValue .06;
                                hasUOM [rdfs:type mm]]].

Feldspar_grains
              rdfs:type Granular_Material;
              hasConstituent _:Feldspar_mineral;
              hasPhysicalProperty
                    [rdfs:type   GrainShape
                         hasValue       <http://geosciml.org/particleShape/subangular>];
              hasPhysicalProperty
                    [rdfs:type   GrainSizeMin
                         hasValue       .02
                         hasUOM  [rdfs:type mm]];
              hasPhysicalProperty
                    [rdfs:type   GrainSizeMax
                         hasValue       5
                         hasUOM  [rdfs:type mm]].

Clay_matrix
              rdfs:type Granular_Material;
              hasConstituent Clay_mineral;
              hasPhysicalProperty
                    [rdfs:type   GrainSizeMax
                         hasValue       .005
                         hasUOM  [rdfs:type mm]].


Quartz_mineral
              rdfs:type           Mineral;
```

```
            hasConstituent  Silicon_element;
            hasConstituent  Oxygen_element;
            sameAs <https://en.wikipedia.org/wiki/Quartz>.


Feldspar_mineral
            rdfs:type           Mineral;
            hasConstituent  Silicon_element;
            hasConstituent  Oxygen_element;
            hasConstituent  Sodium_element;
            hasConstituent  Calcium_element;
            hasConstituent  Potassium_element;
            sdo:seeAlso <https://en.wikipedia.org/wiki/Feldspar>.



constituent_part2
      rdfs:type Proportion;
      proportionOf Feldspar_grains;
      proportionFor Bolsa_Quarzite_Material;
      hasValue 50;
      hasUOM [rdfs:type uom:percent];

constituent_part3
      rdfs:type Proportion;
      proportionOf Clay_matrix;
      proportionFor Bolsa_Quarzite_Material;
      hasValue 5;
      hasUOM [rdfs:type uom:percent].
```

Example 2. Geologic Unit - Formation

```
rdfs:comment 'details of description of Js unit in Figure 1';
rdfs:comment 'Stephen M. Richard 2019-03-28';

JsFormation
      rdf:type Formation;
      rdfs:label 'Js Formation';
      rdfs:comment 'upper part is massive limestone with abundant ammonites';
      rdfs:comment 'lower part is fining-upward sequence from conglomeratic sandstone to fine
grained sandstone';
      rdfs:comment 'marker bed is a tuff in the upper part of the lower clastic interval';
      rdfs:comment 'clasts of Cb Quartzite are abundant in the lower part of the unit';

      hasTemporalProperty [
            rdf:type ChronostratigraphicAge
            hasYoungerAge <http://resource.geosciml.org/classifier/ics/ischart/Jurassic>;
            hasOlderAge <http://resource.geosciml.org/classifier/ics/ischart/Jurassic>.
      ];
      hasPart [
            JsFormation-lower
                  rdf:type Rock Body Part;
                  underlies _:JsFormation-upper;
                  rdfs:comment 'underlies, overlies, within are subproperty of relatedTo';
                  hasConstituent  [
                        lith_1
                              rdf:type Conglomeratic Sandstone;
                              rdfs:comment 'need to capture gradational fining upward
relationship';
                              underlies _:lith_2.
                  ];
                  hasConstituent  [
```

```
                        lith_2
                                rdf:type Sandstone;
                                hasPart [
                                        rdf:type Rock Body Bottom;
                                        participatesIn [
                                                rdf:type Deposition.
                                                ].
                                        ];
                                underlies _:lith_3;
                                overlies _:lith_1
                        ];
                        hasConstituent  [
                                lith_3
                                 rdf:type Fine-grained Sandstone
                                 hasPart [
                                        rdf:type Rock Body Bottom;
                                        participatesIn [
                                                rdf:type Deposition.
                                                ]
                                        ];
                                 overlies _:lith_2.
                        ];
                        hasPart [
                                JsFormationMarker-6.4
                                        rdf:type Bed;
                                        rdfs:comment 'Bed is viewed as a degenerate volume,
considered a surface that has a hasConstiuent property, and hasPart that represents contacts
of the bed';
                                        hasConstituent  <http:\\uri.org\Ballyloghlin_tuff>;
                                        hasPart [
                                                rdf:type Rock Body Top.

                                                ];
                                        hasPart [
                                                rdf:type Rock Body Bottom;
                                                participatesIn Deposition.

                                                ];
                                        within _:lith_3.
                                ]
                        hasPart _:baseJs-6.
                ];
        hasPart [
                JsFormation-upper
                        rdf:type Rock Body Part;
                        hasConstituent  [
                                lith_4
                                        rdf:type Limestone.
                        ];
                        overlies _:JsFormation-lower
                        hasPart [
                                rdf:type Rock Body Bottom;
                                participatesIn [
                                        rdf:type Deposition
                                ]
                        ];
                        hasPart _:topJs-2.
                ];
        hasPart _:baseJs-6;
        hasPart _:topJs-2;
        rdfs:comment 'the following parts are not elucidated in this example, but are referenced
in the Contact instances below. These surfaces would participate in intrusion and also ?contact
metamorphism? processes';
        hasPart _:KdInJsDikeContact-3.2.4;
        hasPart _:KdInJsDikeContact-3.1.4;
```

```
	hasPart _:KgInJsIntrusiveContact-4.2.

contactJs-lith_1-lith_2
	rdf:type Gradational Contact;
	rdfs:label 'internal gradational contact ';
	boundaryThickness [
		rdf:type Thickness;
		hasValue 10;
		hasUOM meter
	];
	youngerHost _:lith_2;
	olderHost _:lith_1.

contactJs-lith_2-lith_3
	rdf:type Gradational Contact;
	rdfs:label 'internal gradational contact ';
	boundaryThickness [
		rdf:type Thickness;
		hasValue 4;
		hasUOM meter
	];
	youngerHost _:lith_3;
	olderHost _:lith_2.

baseJs-6
	rdf:type Rock Body Bottom, Depositional Surface;
	hasPart [
		baseJs-6.1
			rdf:type Rock Body Bottom;
			rdfs:comment 'Js on Ss surface';
			participatesIn [
				rdf:type Deposition]
		];
	hasPart [
		baseJs-6.2
			rdf:type Rock Body Bottom;
			rdfs:comment 'Js on Os surface';
			participatesIn [
				rdf:type  Deposition]
		];
	hasPart [
		baseJs-6.3
			rdf:type Rock Body Bottom;
			rdfs:comment 'Js on Xm surface';
			participatesIn [
				rdf:type  Deposition]
		].

topJs-2.1
	rdf:type Rock Body Top;
	participatesIn [
		rdf:type Erosion
	].
```

Example 3. Simple Contact

```
rdfs:comment 'this example references Figure 1';
HsFormation
	rdf:type Formation;
	rdfs:label 'Hs Formation';
	rdfs:comment 'Gravelly sand, mud, some gravel, deposited in alluvial fans';
	hasConstituent  [
		rdf:type Rock Material
```

```
            ];
      hasPart _:baseHs-1.


MsFormation
      rdf:type Formation;
      rdfs:label 'Ms Formation';
      rdfs:comment 'fine-grained sandstone, minor marl, some coquina';
      hasConstituent  [
            rdf:type Rock Material
            ];
      hasPart _:baseMs-2;
      hasPart _:topMs.


baseHs-1
      rdf:type Rock Body Bottom, Depositional Surface;

      rdfs:comment 'base of Hs formation';
      rdfs:label  'Base Hs';
      rdfs:comment 'This is a simple disconformable contact';

      host _:HsFormation.

topMs-1
      rdf:type Rock Body Top, Depositional Surface;

      rdfs:comment 'top of Ms formation';
      rdfs:label  'Top Ms';
      rdfs:comment 'This is a simple disconformable contact';

      host _:MsFormation.

contact_Hs_on_Ms
      rdf:type Contact;
      rdfs:label 'relational feature, Hs formation overlies Ms formation';
      host _topMs-1, baseHs-1;
      youngerHost HsFormation;
      olderHost MsFormation.
```

Example 4. Complex contact

```
rdfs:comment 'this example references Figure 1';
rdfs:comment 'Focus is Js and its contacts.';

MsFormation
      rdf:type Formation;
      rdfs:label 'Ms Formation';
      rdfs:comment 'fine-grained sandstone, minor marl, some coquina';

      hasConstituent  [
            rdf:type Rock Material;
            rdfs:comment 'TBD'.
            ];
      hasPart _:baseMs-2;
      hasPart _:topMs-1.

topMs-1
      rdf:type Rock Body Top;
      rdfs:comment 'top of Ms formation';
      rdfs:label  'Top Ms';
      rdfs:comment 'This is a simple disconformable contact';
      host _:MsFormation.
```

```
baseMs-2
	rdf:type Rock Body Bottom;
	rdfs:comment 'base of Ms formation';
	rdfs:label  'Base Ms';
	rdfs:comment 'This is an unconformity; Ms overlies Jurassic sediment, Cretaceous dike
and granite';
	participatesIn [
		rdf:type Deposition.
	];
	host _:MsFormation;
	hasPart [
		baseMs-2.1
			rdf:type Rock Body Bottom;
			rdfs:label 'surface at base of Ms where overlies Js';
			rdfs:comment 'surface separating Ms on top of Js'
		];
	hasPart [
		baseMs-2.2
			rdf:type Rock Body Bottom;
			rdfs:label 'surface at base of MS where overlies Kd dike';
			rdfs:comment 'surface separating Ms on top of Kd'
		];
	hasPart [
		baseMs-2.3
			rdf:type Rock Body Bottom;
			rdfs:label 'surface at base of Ms where overlies Kg';
			rdfs:comment 'surface separating Ms on top of Kg'
		].

JsFormation
	rdf:type Formation;
	rdfs:label 'Js Formation';
	rdfs:comment 'details of unit description are in Example 2-Formation';
	hasTemporalProperty [
		rdf:type ChronostratigraphicAge;
		hasYoungerAge <http://resource.geosciml.org/classifier/ics/ischart/Jurassic>;
		hasOlderAge <http://resource.geosciml.org/classifier/ics/ischart/Jurassic>
	];

	hasPart _:baseJs-6;
	hasPart _:topJs-2;
	rdfs:comment 'the following parts are not elucidated in this example, but are referenced
in the Contact instances below. These surfaces would participate in intrusion and also contact
metamorphism processes';
	hasPart _:KdInJsDikeContact-3.2.4;
	hasPart _:KdInJsDikeContact-3.1.4;
	hasPart _:KgInJsIntrusiveContact-4.2.



baseJs-6
	rdf:type Rock Body Bottom, Depositional Surface;
	hasPart [
		baseJs-6.1
			rdf:type Rock Body Bottom;
			rdfs:comment 'Js on Ss surface';
			participatesIn [
				rdf:type Deposition]
		];
	hasPart [
		baseJs-6.2
			rdf:type Rock Body Bottom;
			rdfs:comment 'Js on Os surface';
```

```
                participatesIn [
                        rdf:type  Deposition]
        ];
    hasPart [
        baseJs-6.3
                rdf:type Rock Body Bottom;
                rdfs:comment 'Js on Xm surface';
                participatesIn [
                        rdf:type  Deposition]
        ].

topJs-2.1
    rdf:type Rock Body Top;
    participatesIn [
        rdf:type Erosion
    ].


KdDike
    rdf:type Rock Body;
    intrudes KgGranite, JsFormation, CbFormation, XmRockBody;
    rdfs:comment 'intrudes is subproperty of relatedTo';
    rdfs:comment 'dike has lots of intrusive contacts, on the hanging wall (up) and footwall
(down) side of the dike, each contact is with a different unit.';
    hasConstituent  [
                rdf:type Diorite;
                hasPhysicalProperty  [
                        rdfs:type    GrainSizeAverage;
                        hasValue     .05 ;
                        hasUOM [rdfs:type mm]
                        ]
                ];
    haspart [
        upSideKd-3.2
                rdf:type Rock Body Surface;
                rdfs:comment 'upper side of dike';
                participatesIn [
                        rdf:type Intrusion
                ];
                hasPart [
                        upSideKd-3.2.1
                                rdfs:comment 'dike intrudes Xm'
                        ];
                hasPart [
                        upSideKd-3.2.2
                                rdfs:comment 'dike intrudes Cb'
                        ];
                hasPart [
                        upSideKd-3.2.3
                                rdfs:comment 'dike intrudes Kg'
                        ];
                hasPart [
                        upSideKd-3.2.4
                                rdfs:comment 'dike intrudes Js'
                        ]
                ];
    hasPart [
        downSideKd-3.1
                rdf:type Rock Body Surface;
                rdfs:comment 'lower side of dike';
                participatesIn [
                        rdf:type Intrusion
                        ];
                haspart [
                        downSideKd-3.1.1
```

```
                                rdf:type Rock Body Surface;
                                rdfs:comment 'could have more properties describing contact
effectw sith Xm here'
                        ];
                haspart [
                        downSideKd-3.1.2
                                rdf:type Rock Body Surface
                        ];
                haspart [
                        downSideKd-3.1.3
                                rdf:type Rock Body Surface
                        ];
                haspart [
                        downSideKd-3.1.4
                                rdf:type Rock Body Surface;
                                rdfs:comment 'dike intrudes Js'
                        ].
        ];
    hasPart [
        KdUnderMs
                rdf:type Rock Body Surface;
                rdfs:comment 'Eroded surface under Ms';
                participatesIn [
                        rdf:type Erosion
                ]
        ].

KgGranite
    rdf:type Rock Body;
    intrudes XmRockBody, CbFormation, OsFormation, JsFormation;
    rdfs:comment 'intrudes is subproperty of relatedTo';
    rdfs:comment 'intrusion has lots of intrusive contacts, each contact is with a different
unit, also an erosion surface at the top, overlain by Ms.';
    hasConstituent  [
                rdf:type Granitoid;
                hasPhysicalProperty  [
                        rdfs:type    GrainSizeAverage
                                hasValue    5
                                hasUOM      [rdfs:type mm]]
        ];
    rdfs:comment 'contacts are complicated! Here are the parts:';
    hasPart [
        KgIntrusiveBoundary-4.1
                rdf:type Rock Body Surface;
                rdfs:comment 'Kg intruding the tilted Xm-Cb-Os-Ss sequence';
                participatesIn Intrusion;
                hasPart      [
                        KgIntrusiveBoundary-4.1.1
                                rdf:type Rock Body Surface;
                                rdfs:comment 'Kg intruding the tilted Xm'
                        ];
                hasPart      [
                        KgIntrusiveBoundary-4.1.2
                                rdf:type Rock Body Surface;
                                rdfs:comment 'Kg intruding tilted Cb'
                        ];
                hasPart      [
                        KgIntrusiveBoundary-4.1.3
                                rdf:type Rock Body Surface;
                                rdfs:comment 'Kg intruding tilted Os'
                        ]
                ];
    hasPart [
        KgIntrusiveBoundary-3.1.3
                rdfs:comment 'Kg in footwall wall of Kd contacts';
```

```
                rdf:type Rock Body Surface;
                participatesIn Intrusion
        ];
    hasPart [
        KgIntrusiveBoundary-3.2.3
                rdfs:comment 'Kg in Hanging wall of Kd';
                rdf:type Rock Body Surface;
                participatesIn Intrusion
        ];
    hasPart [
        KgIntrusiveBoundary-4.2
                rdfs:comment 'Kg intruding Js';
                rdf:type Rock Body Surface;
                participatesIn Intrusion
        ];
    hasPart [
        KgErosionSurface-2.3
                rdfs:comment 'Kg erosion surface overlain by Ms';
                rdf:type Rock Body Surface;
                participatesIn Erosion
        ].

contact_Ms_on_Js
    rdf:type Contact;
    rdfs:label 'relational feature, Ms formation overlies Js formation';
    realizedBy _:topJs-2.1, _:baseMs-2.1;
    youngerHost _:MsFormation;
    olderHost _:JsFormation.

contact_Ms_on_Kg
    rdf:type Contact;
    rdfs:label 'relational feature, Ms formation overlies Kg Granite on erosion surface';
    realizedBy _:KgErosionSurface-2.3, _:baseMs-2.3;
    youngerHost _:MsFormation;
    olderHost _:KgGranite.

contact_Kd_in_Js
    rdf:type Contact;
    rdfs:label 'relational feature, Kd dike intrudes Js formation';
    realizedBy _:upSideKd-3.2.4, _:KdInJsDikeContact-3.2.4, _:KdInJsDikeContact-3.1.4,
_:downSideKd-3.1.4;
    youngerHost _:KdDike;
    olderHost _:JsFormation.

contact_Kg_in_Js
    rdf:type Contact;
    rdfs:label 'relational feature, Kg granite intrudes Js formation';
    realizedBy _:KgIntrusiveBoundary-4.2, _:KgInJsIntrusiveContact-4.2;
    youngerHost _:KgGranite;
    olderHost _:JsFormation.

rdfs:comment 'Xm, Cb, Os, and Ss and their boundary surfaces not elucidated here';

contact_Js_on_Xm
    rdf:type Contact;
    rdfs:label 'relational feature, Js formation overlies Xm Rock Body';
    host _:baseJs-6.3, _:XmBoundary-6.3;
    youngerHost _:JsFormation;
    olderHost _:XmFormation.

contact_Js_on_Os
    rdf:type Contact;
    rdfs:label 'relational feature, Js formation overlies Os Formation';
    rdfs:comment 'OsBoundary-6.2 is Erosional Surface';
    realizedBy _:baseJs-6.2, _:OsBoundary-6.2;
```

```
	youngerHost _:JsFormation;
	olderHost _:OsFormation.

contact_Js_on_Ss
	rdf:type Contact;
	rdfs:label 'relational feature, Js formation overlies Ss Formation';
	rdfs:comment 'SsBoundary-6.1 is Erosional Surface';
	realizedBy _:baseJs-6.1, _:SsBoundary-6.1;
	youngerHost _:JsFormation;
	olderHost _:SsFormation.
```

Example 5. Geologic time-Epoch

```
Lower_Jurassic_Epoch
	rdf:type Epoch;
	rdfs:comment 'Epoch is a subclass of Geochronologic Era';
	rdfs:label  'Lower Jurassic time interval';
	rdfs:comment 'This is a temporal interval';
	isPartOf  <http://resource.geosciml.org/vocabulary/timescale/isc2017>;
	hasYoungerDate
		[rdfs:type Geochronologic Boundary;
			hasDate	174.1 ;
			hasUncertainty 1.0;
			hasUOM [rdfs:type uom:MillionYearsBP];
			isRealizedBy
	<http://resource.geosciml.org/classifier/ics/ischart/BaseMiddleJurassic>;
			rdfs:comment 'the Base Middle Jurassic class represents all rock body
	surfaces correlated with the surface at the Global Stratotype Point';
			stratotype
	<http://resource.geosciml.org/classifier/ics/ischart/BaseMiddleJurassicSP>
		];
	hasOlderDate
		[rdfs:type Geochronologic Boundary;
			hasDate 201.3 ;
			hasUncertainty 0.2;
			hasUOM [rdfs:type uom:MillionYearsBP];
			isRealizedBy
	<http://resource.geosciml.org/classifier/ics/ischart/BaseJurassic>;
			stratotype
	<http://resource.geosciml.org/classifier/ics/ischart/BaseJurassicSP>
		].

Lower_Jurassic_Chronostrat_Unit
	rdf:type Series;
	realizes Lower_Jurassic_Epoch;
	rdfs:label 'Lower Jurassic rocks';
	rdfs:comment 'see Table 3 in http://www.stratigraphy.org/upload/bak/chron.htm for
hierarchy of chronostrat and geochron unit names';
	rdfs:comment 'ISC2017 time scale does not define stratotypes for the Geochronologic Eras
it defines'.
```

Appendix 2. Alphabetic index of classes