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# Conceptual Model for Multiscale Geological Data in 2&3D v1

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| Abbreviations | |
|---|---|
| CGI | IUGS Commission for the Management and Application of Geoscience Information |
| GeoSciML | Geoscience Markup Language<br>[a data model and data transfer standard for geological data] |
| GSE | Geological Service of Europe |
| GSML | Namespace prefix for GeoSciML components |
| ICS | IUGS International Commission on Stratigraphy |
| INSPIRE | Infrastructure for Spatial Information in Europe |
| IUGS | International Union of Geological Sciences |
| LTL | Lithotectonic limit |
| LTU | Lithotectonic unit |
| OGC | Open Geospatial Consortium |
| RDF | Resource Description Framework<br>[a standard model for data interchange on the Web] |
| SKOS | Simple Knowledge Organization System<br>[a common data model for sharing and linking knowledge organization systems via the Web] |
| UML | Unified Modeling Language<br>[a general-purpose visual modelling language intended to provide a standard way to visualise the design of a system] |
| URI | Uniform Resource Identifier<br>[a unique sequence of characters that identifies a logical or physical resource used by web technologies] |
| WP | Work Package |

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# 1. Introduction

This working document serves as a technical note to the Unified Modeling Language (UML) scheme of the Conceptual Data Model developed in WP6/Task 6.2.1.

The objective of Task 6.2.1 is to develop a Conceptual Data Model that:

- supports the activities of WP6 and allows at the same time integration of (thematic) data from WPs 2-5
- provides a framework for high-quality information about Europe's subsurface, including cross-border regional 2D and 3D data
- covers both on- and offshore terrain at multiscale level
- is future-proof, i.e. with the ambition to become a lasting core-EGDI product and the ability to accommodate future community-driven transitions towards semantic models.

Other tasks within WP6 directly relating to the data model are Task 6.2 (with subtasks for the creation of vocabularies/thesauri for lithology, anthropogenic deposits and lithotectonic concepts) and Task 6.4 (cross-thematic multi-scale pilot). Potential users/applications beyond GSEU are related to activities of the future GSE (Geological Service of Europe) or by the national geological surveys.

The Conceptual Data Model is primarily based on GeoSciML (Geoscience Markup Language), version 4.1. GeoSciML is a model of geological features commonly described and portrayed in geological maps, cross sections, geological reports and databases. The model was developed by the Commission for the Management and Application of Geoscience Information of the International Union of Geological Sciences (IUGS-CGI) and version 4.1 is the first version officially submitted as standard to the Open Geospatial Consortium (OGC 2016).

In addition, some elements of the data model are based on the Geology Package of the INSPIRE (Infrastructure for Spatial Information in Europe) Consolidated UML Model, itself largely an implementation of an earlier GeoSciML version 3.0 (INSPIRE 2012). Since the available data models do not fulfil all functional requirements of the task, it was necessary to develop some further extensions to the model.

The GeoSciML Basic schema specifies a set of feature types describing core geoscience information, including geologic units, structures, earth materials, relations between geologic features, and spatial geometries that represent geologic features on maps (see Figure 1). GeoSciML Extension allows the accommodation of additional feature properties and feature type classes. The proposed extensions for the GSEU Data Model are customized following rules outlined in the GeoSciML standard (OGC 2016). The position of the extensions proposed here (WP6/Task 6.2.1) within the GeoSciML Basic schema is roughly indicated in Figure 2. As a matter of good practice, the extensions will not change any of the functionality or definitions of original GeoSciML elements and schemas, so that a smooth exchange with other platforms can be assured.

### Reading guide

In this technical note, short general descriptions of each data element are based on GeoSciML documentation (OGC 2016), with additional definitions according to the INSPIRE (2012) data model. Notes on and discussion of proposed conceptual extensions include alternative options (as indicated in the UML scheme) and requests for input from the WP6 or WP7 teams (see Table 1 for annotation guide). All required input is summarized below, with cross-reference to the relevant sections and the UML scheme. Finally, each feature type is illustrated with real-world examples.

**Table 1. Annotation guide of this technical note.**

| | |
|---|---|
| **GeologicFeature** | Data element, with short general description primarily based on GeoSciML standard documentation (OGC 2016) |
| [GeoSciML Basic] | Data element is defined in GeoSciML Basic |
| [GeoSciML Extension] | Data element is defined in GeoSciML Extension |
| *INSPIRE properties* | Additional or different definition according to INSPIRE data model |
| GSEU implementation | Notes on and discussion of proposed conceptual extensions to GeoSciML and INSPIRE data models |
| Option X | Proposed alternative option for extension (indicated in UML scheme) |
| WP6/Task 6.2.X | Input required from the WP6 team or one of its subtasks |
| WP7 | Input required from the WP7 team |

## Required input

Input/advise is required from WP6 on the following topics:

- Lithology vocabulary to be developed by Task 6.2.2 (p. 20)
- Anthropogenic materials vocabulary and implementation to be developed by Task 6.2.3 (p. 20)
- Lithotectonic vocabularies to be developed by Task 6.2.4 (p. 18 and p. 24)
- Orogenic cycles vocabulary (XD labels) to be developed by Task 6.2.4 (p. 29)
- Q4, Task 6.2.2: properties role and proportion required for material description (p. 19)
- Choice Task 6.2.3: implementation of anthropogenic materials, Option 5A or 5B (see UML scheme and p. 20), 5C (UML and p. 22) and 5D (UML and p. 26)
- Q6, Tasks 6.2.2 and 6.2.4: requirement of AlterationDescription (p. 21)
- Q7, Task 6.2.4: requirement of additional properties for ShearDisplacementStructures (p. 23)
- Q8, Task 6.2.4: association of orogenic cycle events (XD labels) with LTLs or LTUs (p. 29).

Input/advise is required from WP7 on the following topics:

- Q1: clarification of difference between classifier and “type-of” property, both relating to terminology in a controlled vocabulary (p. 13)
- Choice: implementation of lithotectonic units (LTUs), Option 1A or 1B (see UML scheme and p. 17)
- Choice: implementation of hierarchies: Option 4A or 4B (see UML scheme, p. 19, p. 26 and p. 32)
- Q2: implications of choice for hierarchical relations (p. 19)
- Q3: querying hierarchical relations in thesauri (p. 19)
- Q5: implementation of lithology property conform GeoSciML or INSPIRE (p. 19 and p. 20)
- Choice: implementation of lithotectonic limits (LTLs), Option 2A or 2B (see UML scheme and p. 24)
- Choice: implementation of orogenic (Wilson) cycle, Option 3A or 3B (see UML scheme and p. 29)
- Q9: use GeologicCollection as container for metadata, including for feature concepts (p. 31)
- Provide guidance on the functional implications of the choices between options.

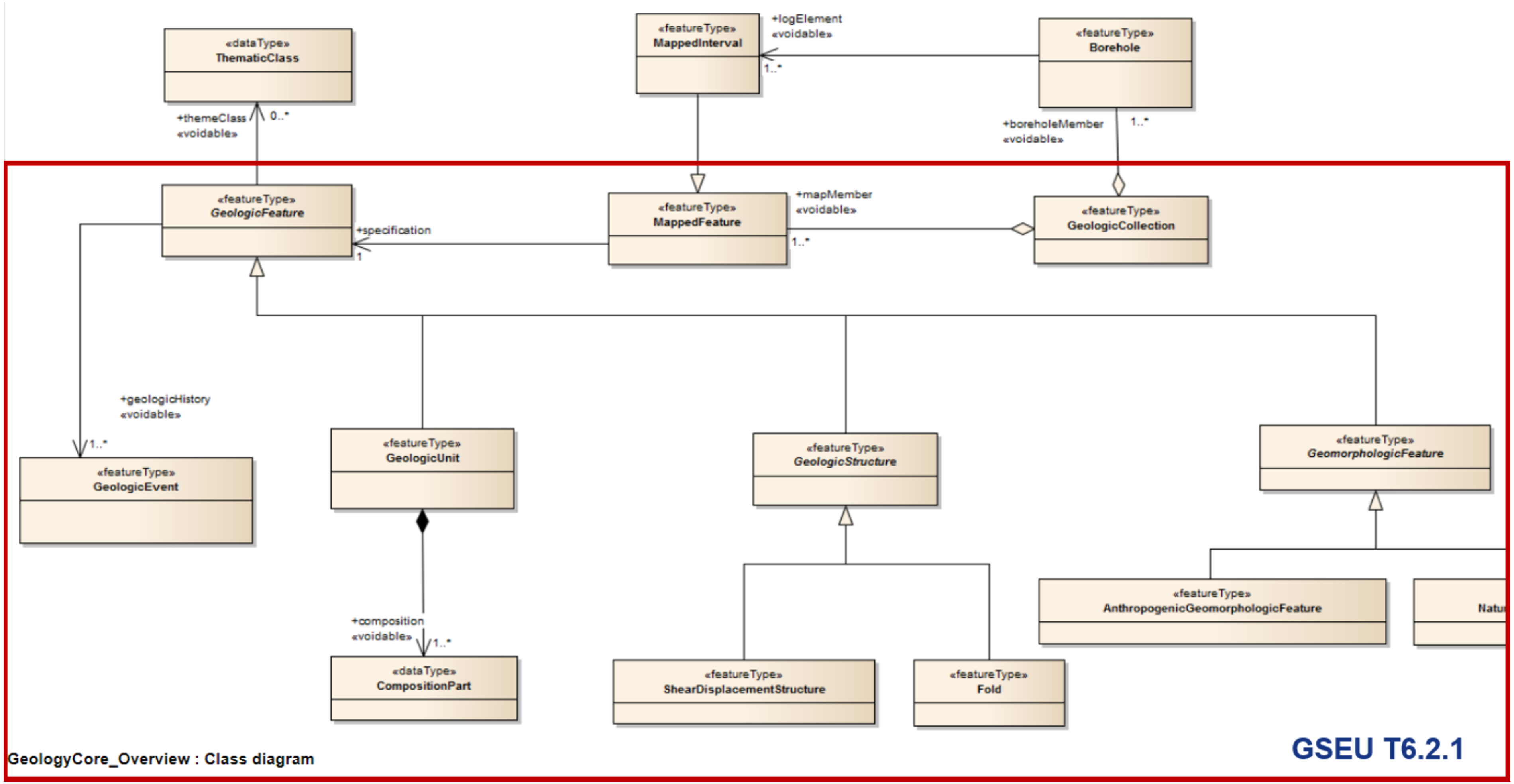


**Figure 1. High-level model of the core features in INSPIRE Geology Package, which is largely based on an implementation of GeoSciML-Core 3.0**

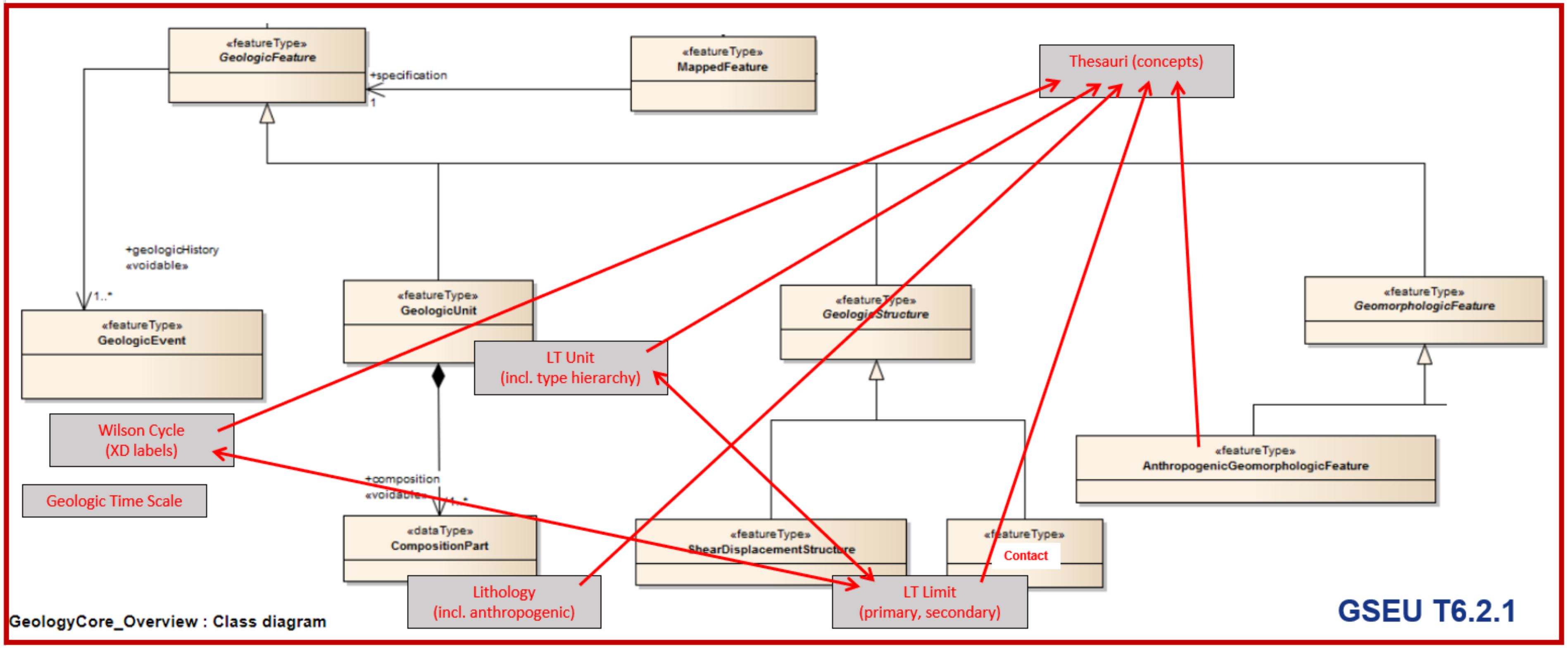


**Figure 2. High-level model of the core features in INSPIRE Geology Package, with indication of the main extensions proposed for implementation in the GSEU data model**

# 2. «Leaf» GeologicFeature

## GeologicFeature

The abstract GeologicFeature class [GeoSciML Basic] represents a conceptual feature that is hypothesized to exist coherently in the world. It corresponds with a “legend item” from a traditional geologic map and its instance acts as the “description package”. A GeologicFeature appearing on a map is considered as an “instance”. GeologicFeature can be used outside the context of a map, for example when describing typical or defining norms.

*INSPIRE definition: A conceptual geological feature that is hypothesized to exist coherently in the world.*

Properties:

- observationMethod (Category, voidable) specifies the approach to acquiring the collection of attribute values that constitute an individual feature
- purpose (Term, voidable) specifies the intended purpose/level of abstraction for a given feature or object instance. Possible values are: instance, typicalNorm, and definingNorm
- classifier (Category, voidable) contains a standard description or definition of the feature typ.
- occurrence (voidable) is an association that links a notional geologic feature with any number of mapped features
- geologicHistory (voidable) is an association that relates one or more GeologicEvents to a GeologicFeature to describe its age or geologic history
- relatedFeature (voidable) is a general structure used to define relationships between any features or objects within GeoSciML. This is a stub association with subtypes defined in GeoSciML Extension.

*INSPIRE properties:*

- *inspireId (Identifier, required) refers to an external object identifier of the spatial object*
- *name (CharacterString, voidable) specifies the name of the geologic feature*
- *geologicHistory (as above)*
- *themeClass (voidable) is an association that relates the geologic feature to one or more thematic schemas.*

*Note: In INSPIRE the association between GeologicFeature and MappedFeature is only defined from perspective of the MappedFeature, using the specification property.*

GSEU implementation: Properties included in the GSEU data model are underlined above.

Q1 to WP7: In GeoSciML a classifier is “an abstract UML metaclass which describes (classifies) a set of instances having common features … (Classes, Interfaces, Association, and Types are kinds of classifier)”. If the classifier property is inherited by all geologic feature types, then what is the difference or relation between classifier and, e.g., geologicUnitType in the case of GeologicUnits? Both seem pointing to terms in a controlled vocabulary; however, in the Vocabulary package [GeoSciML 3.0] the property classifier provides the association-link to a description or definition of the feature type in the ControlledConcept schema. Some clarification would be welcome.

## MappedFeature

A MappedFeature [GeoSciML Basic] is part of a geological interpretation. It provides a link between a notional feature (description package) and one spatial representation of it, or part of it. MappedFeatures are the elements that compose a map, a cross-section, a 3D model, or any other representation.

*INSPIRE definition: A spatial representation of a geologic feature.*

Properties:

- observationMethod (Category, voidable) is a category from a controlled vocabulary describing how the spatial extent of the mapped feature was determined
- positionalAccuracy (Quantity, voidable) provides a quantitative value defining the radius of an uncertainty buffer around a MappedFeature
- resolutionRepresentativeFraction (Integer, voidable) is an integer value representing the denominator of the representative scale of the spatial feature*
- mappingFrame (Term, voidable) provides a term from a vocabulary indicating the geometric frame on which the MappedFeature is projected (e.g., topographic surface, base of Quaternary, bedrock surface)
- exposure (Term, voidable) provides a term for the nature of the expression of the mapped feature at the Earth's surface (e.g., exposed, concealed)
- shape (GM_Object, voidable) contains the geometry delimiting the mapped feature. Note that while in most cases the geometry will be a 2D polygon, it is not restricted to any dimension
- specification (voidable) is an association that links an instance of MappedFeature to the GeologicFeature being mapped.

*INSPIRE properties: shape, mappingFrame, specification (as above). Note that according to INSPIRE the specification association is required, while in GeoSciML it is voidable.*

GSEU implementation: Properties included in the GSEU data model are underlined above; specification is required.

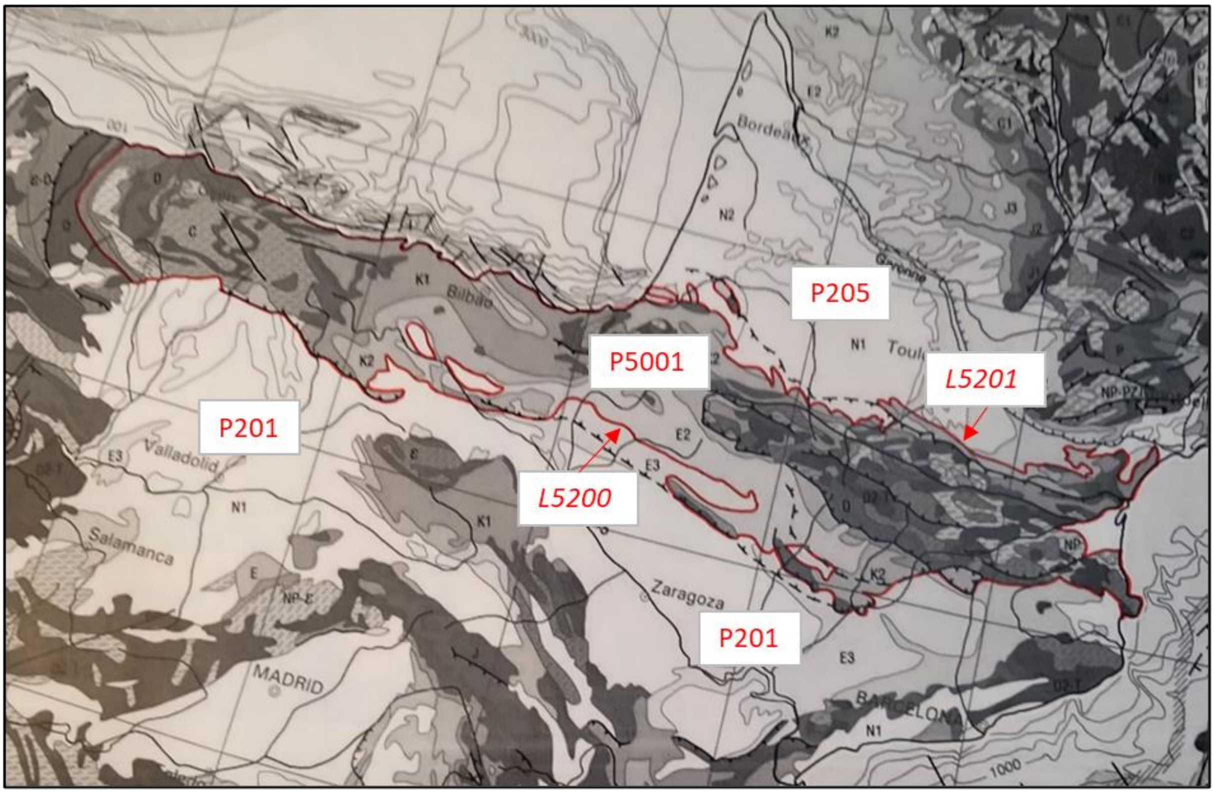


**Figure 3. Example of MappedFeatures related to the Cantabrian-Pyrenean orogenic belt. The orogenic belt is represented by polygon P5001; linear features L5200 and L5201 represent the primary limits of adjacent basins (Duero-Ebro and Aquitaine foreland basins, P201 and P205), acting as secondary limits to the orogenic belt. Reference surface (mappingFrame) of this map view is the base of Quaternary. Excerpt map modified from IGME 5000 (Asch 2005)**

| «FeatureType» **MappedFeature** | |
|---|---|
| shapeID | P5001 |
| resolutionRepresentativeFraction | 5000000 |
| mappingFrame | base of Quaternary |
| specification | LTU1 |

Cantabrian-Pyrenean orogenic belt [GeologicUnit]

**Figure 4. Instance example of a MappedFeature representing the Cantabrian-Pyrenean orogenic belt LTU (see map view, Figure 3)**

| «FeatureType» **MappedFeature** | |
|---|---|
| shapeID | L5200 |
| resolutionRepresentativeFraction | 5000000 |
| mappingFrame | base of Quaternary |
| specification | LTL201 |

Duero-Ebro unconformity [GeologicStructure: LithotectonicLimit]

**Figure 5. Instance example of a MappedFeature representing the Duero-Ebro unconformity LTL (see map view, Figure 3)**

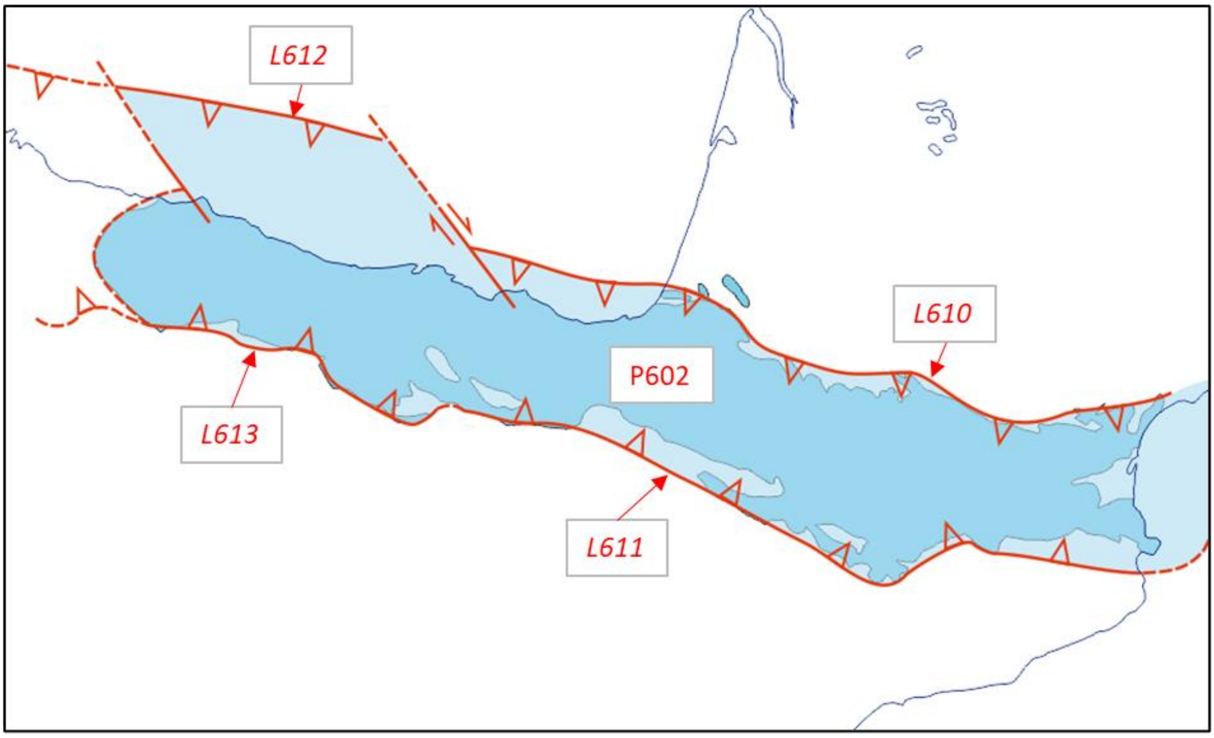


**Figure 6. Example representation of MappedFeatures related to the Cantabrian-Pyrenean orogenic belt. The orogenic belt is represented by polygon P602; linear features L610-L613 represent its primary limits, which are generally obscured by recent (Miocene-Quaternary) sedimentation. Reference surface (mappingFrame) of this map view is the top of basement. Map features modified after Teixell et al. (2018) and Lloret et al. (2021)**

| «FeatureType»<br>**MappedFeature** | |
|---|---|
| shapeID<br>resolutionRepresentativeFraction<br>mappingFrame | P602<br>5000000<br>top of basement |
| specification | LTU1 |

Cantabrian-Pyrenean orogenic belt
[GeologicUnit]

**Figure 7. Instance example of a MappedFeature representing the Cantabrian-Pyrenean orogenic belt LTU (see map view, Figure 6)**

| «FeatureType»<br>**MappedFeature** | |
|---|---|
| shapeID<br>resolutionRepresentativeFraction<br>mappingFrame | L610<br>5000000<br>top of basement |
| specification | LTL1 |

North-Pyrenean frontal thrust
[GeologicStructure: LithotectonicLimit]

**Figure 8. Instance example of a MappedFeature representing the North-Pyrenean frontal thrust LTL (see map view, Figure 8)**

# 3. «Leaf» GeologicUnit

## GeologicUnit

Conceptually, a GeologicUnit [GeoSciML Basic] may represent a body of material in the Earth whose complete and precise extent is inferred to exist, a stratigraphic unit or a classifier used to characterize parts of the Earth. It includes formal units (i.e. formally adopted and named in an official lexicon), informal units (i.e. named but not promoted to a lexicon) and unnamed units (i.e., recognizable, described and delineable in the field but not otherwise formalised).

*INSPIRE definition: A volume of rock with distinct characteristics.*

Operationally, a GeologicUnit is a container used to associate geologic properties with some mapped occurrence (through the occurrence-specification link), or with a geologic unit via a vocabulary (through the classifier property).

Properties:

- observationMethod, purpose, classifier (all inherited from GeologicFeature, voidable)
- geologicUnitType (Term, voidable) is a term from a controlled vocabulary defining the type of geologic unit. Logical constraints and valid property cardinalities should be contained in the definition
- rank (Term, voidable) contains a term that classifies the geologic unit in a generalization hierarchy from most local/smallest volume to most regional/largest.
- hierarchyLink (voidable) is an association that links a GeologicUnit with a GeologicUnitHierarchy to represent containment of a part GeologicUnit within another GeologicUnit. It indicates a subsidiary unit with its role and proportion with respect to the container unit
- composition (voidable) is an association that links a GeologicUnit with one or more CompositionParts to describe its material composition
- gbMaterialDescription (voidable) is a placeholder that provides detailed material description. This is a stub property with subtypes defined in GeoSciML Extension
- gbUnitDescription (voidable) is a placeholder that provides detailed unit feature description. This is a stub property with subtypes defined in GeoSciML Extension [required for option 1B only].

*INSPIRE properties: geologicUnitType, composition (as above).*

GSEU implementation: Properties included in the GSEU data model are underlined above.

The GSEU data model requires to distinguish lithotectonic units (LTUs) with a specialized vocabulary as (sub)type of GeologicUnit. We propose two options for implementation (following the rules for GeoSciML Extension), on which WP7 is asked to decide which one is the technically most viable solution:

Option 1A. Introduce a new feature type LithotectonicUnit as subclass of GeologicUnit with additional properties:

- lithotectonicUnitType (Term, voidable) is a term from a controlled vocabulary describing the type of LTU
- lithotectonicUnitRank (Term, voidable) contains a term that classifies the LTU in a generalization (part-whole) hierarchy.

Option 1B. Constrain GeologicUnitTypeTerm to LTU, using its definition from the CGI Geologic Unit Type vocabulary (CGI, 2020),,and introduce extended properties via the placeholder gbUnitDescription:

- lithotectonicUnitType (Term, voidable) is a term from a controlled vocabulary describing the type of LTU
- lithotectonicUnitRank (Term, voidable) contains a term that classifies the LTU in a generalization (part-whole) hierarchy.

The LTU vocabulary/thesaurus will be developed in WP6/Task 6.2.4.

| «FeatureType» GeologicUnit | | |
|---|---|---|
| geologicUnitID | LTU1 | concept from instantiated LTU vocabulary |
| name | Cantabrian-Pyrenean orogenic belt | |
| geologicUnitType | lithotectonic unit | class of GeologicUnit |
| lithotectonicUnitType | orogenic belt | term from LTU type vocabulary |
| liithotectonicUnitRank | system | term from LTU rank vocabulary |
| occurrence | P5001 | polygon feature from IGME5000 |
| occurrence | P602 | polygon feature from map layer X |
| composition: hasCompositionPart | LTU1-CP1 | granitic rocks |
| composition: hasCompositionPart | LTU1-CP2 | metamorphic rocks |
| relatedFeature: hasLithotectonicChild | LTU2 | Cantabrian orogenic belt |
| relatedFeature: hasLithotectonicChild | LTU3 | Pyrenean orogenic belt |
| relatedFeature: isLithotectonicChildOf | … | |
| relatedFeature: hasPrimaryLimit | LTL1 | North-Pyrenean frontal thrust |
| relatedFeature: hasPrimaryLimit | LTL2 | South-Pyrenean frontal thrust |
| relatedFeature: hasSecondaryLimit | LTL21 | Duero-Ebro unconformity |

**Figure 9. Instance example of an LTU concept, describing the Cantabrian-Pyrenean orogenic belt system and its relation to other features. In this example, the orogenic belt is associated with two occurrences (two alternative map representations) and includes two LTU elements of lower hierarchical level (the Cantabrian orogenic belt and the Pyrenean orogenic belt). In addition, its lithological composition is described by two components (associated via CompositionParts) and its limits are defined by primary and secondary limits (via customized relatedFeatures)**

### GeologicUnitHierarchy

GeologicUnitHierarchy [GeoSciML Basic] associates a GeologicUnit with another GeologicUnit that is a proper part of that unit. Parts may be formal or notional. Formal parts refer to a specific body of rock, as in formal stratigraphic members. Notional parts refer to assemblages of particular EarthMaterials with particular internal structure within a unit.

*Not available in INSPIRE.*

Properties:

- role (Term, voidable) provides a term describing the nature of the parts
- proportion (QuantityRange, voidable) provides a quantity that represents the fraction of the geologic unit formed by the part
- targetUnit (voidable) is an association that specifies exactly one GeologicUnit that is a proper part of the source unit.

GSEU implementation: The GSEU data model includes hierarchical relations, but the solution offered in GeoSciML Basic does not fully cover our needs: it only relates to GeologicUnits and only to part-whole relationships. We propose two options to implement (additional) hierarchies, on which WP7 is asked to decide which one is the technically most viable solution:

Option 4A. Introduce new, additional types of hierarchical relationships using GeologicRelation (following the rules for GeoSciML Extension):

- Introducing part-of hierarchical relations also between GeologicStructure features, in particular LithotectonicLimits
- Introducing more strict IsLithoTectonicChildOf relationships (fundamentally defined as belongs-to as opposed to spatially lies-within)

Note that «Leaf» GeologicRelation also provides other custom relations (section 7).

Option 4B. Implement these different types of hierarchical relationships in controlled thesauri (using the Application Schema Vocabulary, included as concept in GeoSciML 3.0).

Q2 to WP7: can option 4A cover all hierarchical relations that are possible in option 4B?

Q3 to WP7: can hierarchical relations contained in thesauri be accessed through a map interface for visualizing and querying?

### CompositionPart

CompositionPart [GeoSciML Basic] represents the composition of a geologic unit in terms of earth material constituents (via CompoundMaterial). It decomposes the material making of the unit into parts having distinct roles and proportions.

*INSPIRE definition: The composition of a geologic unit in terms of lithological constituents.*

Properties:

- role (Term, voidable) defines the relationship of the CompoundMaterial constituent in the geologic unit
- proportion (QuantityRange, voidable) specifies the fraction of the geologic unit composed of the compound material
- material (voidable) is an association that links the material description of CompoundMaterial with the composing part.

*INSPIRE properties:*

- *role (as above, but required), proportion (as above)*
- *material (Term, required) is a term from a controlled vocabulary identifying the lithology class (i.e., lithology property of RockMaterial is directly integrated in CompositionPart).*

GSEU implementation: Properties included in the GSEU data model are underlined above.

Notes:

- The properties' role and proportion are required if a GeologicUnit or LTU may contain several types of different lithologies/compound descriptions. [Q4: to be decided by WP6/Task 6.2.2]
- If only rock-type materials are considered, the lithology property can be integrated here (following INSPIRE practice). [Q5: to be decided by WP7]
- Additional material properties can be added through a placeholder in EarthMaterial (see below).

| «DataType» CompositionPart | | |
|---|---|---|
| compositionPartID | LTU1-C2 | |
| material | methamorphic rocks | term from Lithology vocabulary |
| role | dominant constituent | |
| proportion | … | |

**Figure 10. Instance example of a CompositionPart, describing the lithology of an associated LTU using terminology from the Lithology vocabulary**

## CompoundMaterial

A CompoundMaterial [GeoSciML basic] is composed of particles made of EarthMaterials, possibly including other CompoundMaterials. In the context of GeoSciML RockMaterial should be used to describe geological units.

This abstract class is provided primarily as an extensibility point for related domain models. Material types that are compound but are not rock or rock-like material can be defined and introduced here.

*Not available in INSPIRE.*

## RockMaterial

RockMaterial [GeoSciML Basic] is a specialized CompoundMaterial that includes consolidated and unconsolidated materials, as well as mixtures. In GeoSciML Basic, Rock Material is essentially a link to a controlled vocabulary (lithology property) and colour (inherited from EarthMaterial). Specific material properties (and CompoundMaterial nesting) are available in GeoSciML Extension.

Properties:

- lithology (Term, voidable) is a term from a controlled vocabulary identifying the lithology class. *INSPIRE: this property is integrated in CompositionPart.*

GSEU implementation: Properties included in the GSEU data model are underlined above.

Notes:

- The Lithology vocabulary/thesaurus will be developed in WP6/Task 6.2.2.
- If only rock-type materials are considered, the lithology property can be integrated directly in CompositionPart (following INSPIRE practice). [Q5: to be decided by WP7]
- Anthropogenic materials may be included in the Lithology vocabulary [Option 5A]. However, if considered as non-rock-type materials, they should be introduced as a new subtype of CompoundMaterial [Option 5B, to be decided by WP6/Task 6.2.3]. More options for describing anthropogenic deposits are included in sections 4 [Option 5C: AnthropogenicDescription] and 6 [Option 5D: AnthropogenicGeomorphologicFeature]. Vocabulary/thesaurus for anthropogenic materials will be developed in WP6/Task 6.2.3.

## EarthMaterial

The EarthMaterial [GeoSciML Basic] class holds a description of a naturally occurring substance in the Earth. Ideally, EarthMaterials are defined strictly based on physical properties, but because of standard geological usage, genetic interpretations enter into the description as well.

Properties:

- purpose (Term, required) provides a specification of the intended purpose or level of abstraction for the given EarthMaterial. Possible values are: instance, typicalNorm, and definingNorm.
- color (Category, voidable) is a term from a controlled vocabulary specifying the colour of the earth material.
- gbEarthMaterialDescription (voidable) is a placeholder that provides a detailed earth material description. This is a stub property with subtypes defined in GeoSciML Extension.

*Not available in INSPIRE.*

GSEU implementation: Properties included in the GSEU data model are underlined above. Extensions via EarthMaterialAbstractDescriptions are included to describe additional Alteration, Metamorphic and Anthropogenic properties (section 4, see below).

# 4. «Leaf» EarthMaterial

## EarthMaterialAbstractDescription

EarthMaterialDescription abstract class [GeoSciML Extended] materialises into a series of concrete classes to address various aspects of EarthMaterial descriptions:

- ChemicalCompositionDescription: not applicable
- FabricDescription: not applicable
- RockMaterialDescription: not applicable
- AlterationDescription: see below
- MetamorphicDescription: see below
- PhysicalDescription: not applicable
- CompoundMaterialDescription: not applicable.

*Not available in INSPIRE.*

## AlterationDescription

AlterationDescription describes aspects of a geologic unit or earth material that are the result of bulk chemical, mineralogical or physical changes related to changes in the physical or chemical environment. It includes weathering, supergene alteration, hydrothermal alteration and metasomatic effects not considered metamorphic. The property alterationEvent provides a link to the GeologicEvent that describes the age, environment and process associated with the alteration.

Q6 to WP6: Is this class required in the GSEU data model?

## MetamorphicDescription

MetamorphicDescription describes the character of metamorphism applied to a CompoundMaterial or GeologicUnit using one or more properties including estimated intensity (grade), characteristic metamorphic mineral assemblages (facies), peak P-T estimates, and protolith material if known. The property metamorphicEvent provides a link to the GeologicEvent that describes the age, environment and process associated with the metamorphic assemblage.

GSEU implementation: Is included in the GSEU data model to characterize metamorphic materials contained in a GeologicUnit or LTU and associate it with a specific metamorphicEvent and/or a specific geologic age.

### AnthropogenicDescription

GSEU implementation: The GSEU data model may include AnthropogenicDescription as an additional EarthMaterialDescription class, to describe the character of anthropogenic earth materials. The property anthropogenicEvent provides a link to the GeologicEvent that describes the age, environment and process associated with the anthropogenic deposit. [Option 5C, to be decided by WP6/Task 6.2.3]

# 5. «Leaf» GeologicStructure

### GeologicStructure

A GeologicStructure [GeoSciML Basic] is a configuration of matter in the Earth based on describable inhomogeneity, pattern, or fracture in an earth material. The identity of a GeologicStructure is independent of the material that is the substrate for the structure.

*INSPIRE definition: A configuration of matter in the Earth based on describable inhomogeneity, pattern, or fracture in an earth material.*

GeoSciML Basic only provides a limited set of core structures (Contact, Fold, ShearDisplacementStructure and Foliation) with a single property to categorise them. Other geologic structure features available in GeoSciML Extension include: Fracture, Joint, FoldSystem, Lineation, Layering, NonDirectionalStructure.

*INSPIRE only includes the feature types ShearDisplacementStructure and Fold.*

The general GeologicFeatureRelation [GeoSciML Extension] is used to associate penetrative GeologicStructures with GeologicUnits.

Note for GSEU implementation: Contacts and ShearDisplacementStructures are relevant feature types for the GSEU data model, as they may correspond to lithotectonic limits (LTLs) (wholly or partially). LTLs are not explicitly defined in GeoSciML, so their implementation requires extensions (Options 2A and 2B, see below).

**Contact**

A contact [GeoSciML Basic] is a general concept representing any kind of surface separating two geologic units, including primary boundaries such as depositional contacts, all kinds of unconformities, intrusive contacts, and gradational contacts, as well as faults that separate geologic units.

*Not available in INSPIRE.*

Properties:

- observationMethod, purpose, classifier (all inherited from GeologicFeature, voidable)
- contactType (Term, voidable) is a term from a controlled vocabulary classifying the contact (e.g. intrusive, unconformity, bedding surface, lithologic boundary, phase boundary)
- stContactDescription (voidable) is a placeholder that provides a detailed contact description. This is a stub property with subtypes defined in GeoSciML Extension.

ContactDescription [GeoSciML Extension] provides extended descriptive properties for Contact:

- contactCharacter (Category, voidable) is a term from a controlled vocabulary describing the character of the boundary (e.g. abrupt, gradational)
- Orientation (GSML/GeoSciML DataType, voidable) reports the general orientation of the contact surface

- correlatesWith (voidable) is an association that links the ContactDescription to a geochronologic boundary (only if the contact type is ChronostratigraphicBoundary).

GSEU implementation: Properties underlined above are minimum requirements for the GSEU data model – that is, if decided to make use of this feature type (in case of Option 2B, see below).

### ShearDisplacementStructure

A shear displacement structure [GeoSciML Basic] includes all brittle to ductile style structures along which displacement has occurred, from a simple, single 'planar' brittle or ductile surface to a fault system comprised of tens of strands of both brittle and ductile nature.

*INSPIRE definition: Brittle to ductile style structures along which displacement has occurred.*

Properties:

- observationMethod, purpose, classifier (all inherited from GeologicFeature, voidable)
- faultType (Term, voidable) contains a term from a controlled vocabulary describing the type of shear displacement structure (e.g., thrust fault, normal fault or wrench fault)
- stStructureDescription (voidable) is a placeholder that provides a detailed geologic structure description. This is a stub property with subtypes defined in GeoSciML Extension.

*INSPIRE properties: faultType (see above).*

The structure may have some significant thickness (a deformation zone) and have an associated body of deformed rock that may be considered a deformation unit that can be associated to the ShearDisplacementStructure using GeologicFeatureRelation from GeoSciML Extension.

ShearDisplacementStructureDescription [GeoSciML Extension] provides extended descriptive properties for a ShearDisplacementStructure:

- deformationStyle (Term) is a term from a vocabulary describing the style of deformation
- planeOrientation (GSML/GeoSciML DataType, voidable) reports the orientation of the structure's planar surface
- stPhysicalProperty refers to values of generic physical properties (not specified).

DisplacementValue [GeoSciML Extension] expresses the displacement on a fault with respect to a planar surface. It includes several properties describing the direction, type and amount of displacement. The property displacementEvent is an association between a Displacement and a GeologicEvent that contains a description of its age, environment and process.

GSEU implementation: Properties underlined above are minimum requirements for the GSEU data model – that is, if decided to make use this feature type (in case of option 2B, see below). Additional properties may be considered, including the attribution of individual displacement events of ShearDisplacementStructures to GeologicEvents [Q7: to be decided by WP6/Task 6.2.4].

### LithotectonicLimit

LTL is a general concept representing any kind of surface limiting a geologic unit [or more specifically an LTU], both in space and time (after Piessens et al. submitted). Primary limits are linked to events defining the start and finalization of a LTU (example: orogenic frontal thrust), while Secondary limits are posterior created bounding surfaces, not conceptually defining the unit (example: erosive surface).

(LTLs are not explicitly defined in GeoSciML and INSPIRE. They may coincide with Contacts, but are fundamentally differently defined, as they primarily relate to a single LTU (or even none), instead of to two geologic units. As a result, an LTL may correspond to one or several Contacts. LTLs may also coincide with ShearDisplacementStructures. Not all Contacts and ShearDisplacement-Structures are LTLs and not all LTLs can be classified as Contacts or ShearDisplacementStructures.

GSEU implementation: Considering the above, we propose two options for implementation (following the rules for GeoSciML Extension), on which WP7 is asked to decide which one is the technically most viable solution:

Option 2A. Introduce a new feature type LithotectonicLimit as subclass of GeologicStructure with additional properties:

- lithotectonicLimitType (Term, voidable) is a term from a controlled vocabulary describing the type of LTL
- lithotectonicLimitRank (Term, voidable) contains a term that classifies the LTL in a generalization (part-whole) hierarchy.

Option 2B. Introduce additional properties via the placeholders stContactAbstractDescription and stShearDisplacementAbstractDescription to characterize Contacts and ShearDisplacementStructures as LTLs:

- lithotectonicLimitType (Term, voidable) is a term from a controlled vocabulary describing the type of LTL
- lithotectonicLimitRank (Term, voidable) contains a term that classifies the LTL in a generalization (part-whole) hierarchy.

Option 2A may result in duplication of map features, because map features can be attributed to only one geologic feature (e.g., if a linear feature representing a Contact is redefined as LTL, each concept requires a separate mapped instance); however, definitions of both feature classes remain intact and unambiguous. Option 2B prevents multiplication of map features, but the original definitions of feature classes may be challenged (e.g., how to accommodate LTLs that are not Contacts or ShearDisplacementStructures?) and LTLs may become fragmented (e.g., a single LTL may be composed of several linear features representing numerous Contacts or ShearDisplacementStructures).

The LTL vocabulary/thesaurus will be developed in WP6/Task 6.2.4.

| «FeatureType» **GeologicStructure: LithotectonicLimit** | | |
|---|---|---|
| geologicStructureID | LTL1 | concept from instantiated LTL vocabulary |
| name | North-Pyrenean frontal thrust | |
| lithotectonicLimitType | thrust fault | term from LTL type vocabulary |
| liithotectonicLimitRank | system | term from LTL rank vocabulary |
| occurrence | L610 | line feature from map layer X |
| relatedFeature: hasLithotectonicChild | … | |
| relatedFeature: isLithotectonicChildOf | … | |
| relatedFeature: isPrimaryLimitOf | LTU1 | Cantabrian-Pyrenean orogenic belt |
| relatedFeature: isPrimaryLimitOf | LTU3 | Pyrenean orogenic belt |
| relatedFeature: isSecondaryLimitOf | … | |
| geologicHistory | E98 | Pyrenean orogenic phase ApD1 |
| geologicHistory | E99 | Pyrenean orogenic phase AnD2 |

**Figure 11. Instance example of an LTL concept describing the North-Pyrenean frontal thrust system and its relation to other features. In this example, the frontal thrust is associated with**

one occurrence (map representation) and two formative events (orogenic phases linked via geologicHistory). In addition, it serves as a primary limit of two LTUs (the Cantabrian-Pyrenean orogenic belt and its hierarchical child, the Pyrenean orogenic belt).**

| «FeatureType» GeologicStructure: LithotectonicLimit | | |
|---|---|---|
| geologicStructureID | LTL21 | concept from instantiated LTL vocabulary |
| name | Duero-Ebro unconformity | |
| lithotectonicLimitType | unconformity | term from LTL type vocabulary |
| liithotectonicLimitRank | element | term from LTL rank vocabulary |
| occurrence | L5200 | line feature from IGME5000 |
| relatedFeature: hasLithotectonicChild | LTL22 | Duero unconformity |
| relatedFeature: hasLithotectonicChild | LTL23 | Ebro unconformity |
| relatedFeature: isLithotectonicChildOf | … | |
| relatedFeature: isPrimaryLimitOf | LTU201 | Duero-Ebro foreland basin |
| relatedFeature: isSecondaryLimitOf | LTU1 | Cantabrian-Pyrenean orogenic belt |
| relatedFeature: isSecondaryLimitOf | LTU4 | Pyrenean orogenic belt |
| geologicHistory | E102 | Duero-Ebro transgression |

**Figure 12. Instance example of an LTL concept describing the Duero-Ebro unconformity and its relation to other features. In this example, the unconformity is associated with one occurrence (map representation), a formative event (transgression phase linked via geologicHistory) and includes two LTL elements of lower hierarchical level (the Duero and Ebro unconformities). In addition, it serves as primary and secondary limits of several LTUs (primary limit of the Duero-Ebro foreland basin and secondary limit of the Cantabrian-Pyrenean orogenic belt).**

# 6. «Leaf» Geomorphology

### GeomorphologicFeature

A GeomorphologicFeature [GeoSciML Basic] describes the shape and nature of the Earth's land surface. Landforms may be created by natural Earth processes (e.g., river channel, beach, moraine or mountain) or through human (anthropogenic) activity (e.g., dredged channel, reclaimed land, mine waste dumps).

*INSPIRE definition: An abstract spatial object type describing the shape and nature of the Earth's land surface (i.e., a landform).*

Properties:

- unitDescription (voidable) is an association that links the geomorphologic feature to a geologic unit that composes the form (e.g., related stratigraphic units and earth materials).\
- gmFeatureDescription is a placeholder that provides a detailed morphologic description. This is a stub property with subtypes defined in GeoSciML Extension.

*INSPIRE properties: none.*

### NaturalGeomorphologicFeature

A natural geomorphologic feature [GeoSciML Basic] is a geomorphologic feature (i.e., landform) that has been created by natural Earth processes.

GSEU implementation: Not applicable.

### AnthropogenicGeomorphologicFeature

An anthropogenic geomorphologic feature [GeoSciML Basic] is a geomorphologic feature (i.e., landform) that has been created by human activity.

*INSPIRE definition: A geomorphologic feature (i.e., landform) which has been created by human activity.*

Properties:

- anthropogenicGeomorphologicFeatureType (Term, voidable) is a term from a controlled vocabulary describing the type of geomorphologic feature.

*INSPIRE properties: anthropogenicGeomorphologicFeatureType (as above).*

GSEU implementation: Applicability in the context of the GSEU data model depends on whether the vocabulary for anthropogenic deposits will include geomorphologic descriptors. [Option 5D, to be decided by WP6/Task 6.2.3]

# 7. «Leaf» GeologicRelation

The GeologicFeatureRelation class [GeoSciML Extension] defines the general structure used to define relationships between any GeoSciML feature types. Relationships are always binary and directional. There is always a single source and a single target. The relationship is always defined from the perspective of the Source and is generally an active verb.

*Not available in INSPIRE.*

Properties:

- relationship (Term, voidable) is a term from a controlled vocabulary describing the geologic relationship (e.g., stratigraphic relation, structural relation, intrusive relation)
- sourceRole (Term, voidable) is a term from a controlled vocabulary describing the role played by the source geologic feature or object (e.g., overlying unit, underlying unit)
- targetRole (Term, voidable) is a term from a controlled vocabulary describing the role played by the target geologic feature or object. (e.g., overlying unit, underlying unit).

Notes:

- MaterialRelation [GeoSciML Extension] is a specialized GeologicFeatureRelation class describing the relationships between constituent parts within an EarthMaterial
- An association between GeologicFeature and GeologicEvent, for the purpose of describing geologic history, and therefore geologic age, shall use the geologicHistory property [GeoSciML Basic]
- A hierarchical part-of-relation between units can the described by using the hierarchyLink property [GeoSciML Basic] that links a GeologicUnit with a GeologicUnitHierarchy.

GSEU implementation: The GSEU data model includes definitions of additional GeologicFeatureRelations:

- Introducing additional, alternative types of hierarchical relationships: the more strict LithotectonicChildRelation (belongs-to as opposed to lies-within) and the more general PartOfRelation (applicable to all feature types, not exclusively to GeologicUnits). [Option 4A: section 3, GeologicUnitHierarchy]

- Introducing the LithotectonicLimitRelation to associate LTUs with their limits. The role of a LTL can be further specified as either Primary (linked to a defining event of the LTU) or Secondary (a posterior created bounding surface of the LTU).

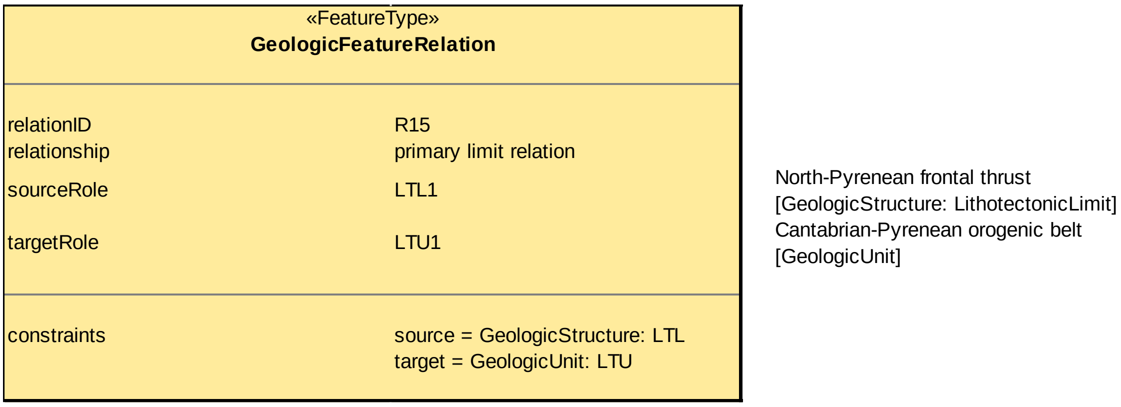


**Figure 13. Instance example of a customized GeologicFeatureRelation. It describes the association between an LTU (the Cantabrian-Pyrenean orogenic belt) and one of its primary limits (the North-Pyrenean frontal thrust LTL).**

# 8. «Leaf» GeologicEvent

A GeologicEvent [GeoSciML Basic] is an identifiable event during which one or more geological processes act to modify geological entities. It may have a specified geologic age (numeric or geochronologic age) and it may have specified environments and processes.

*INSPIRE definition: An identifiable event during which one or more geological processes act to modify geological entities.*

Properties:

- eventProcess (Term, voidable) provides a term from a controlled vocabulary specifying the process or processes that occurred during the event
- numericAge (DataType, voidable) reports an age range in absolute years before present (BP).
- olderNamedAge (Term, voidable) defines the older age boundary of the event expressed using a geochronologic era as defined according to a geologic time scale (e.g., the Geologic-Time schema, based on the chronostratigraphic chart published by the International Commission on Stratigraphy, the IUGS-ICS)
- youngerNamedAge (Term, voidable) defines the younger age boundary of the event expressed using a geochronologic era as defined according to a geologic time scale (e.g., the GeologicTime schema, based on the IUGS-ICS chart)
- eventEnvironment (Category, voidable) is a category from a controlled vocabulary identifying the physical setting within which a GeologicEvent takes place. It includes physical settings on the Earth surface specified by climate, tectonics, physiography or geography, and settings in the Earth's interior specified by pressure, temperature, chemical environment, or tectonics
- geEventDescription (voidable) is a placeholder that provides a detailed event description. This is a stub property with subtypes defined in GeoSciML Extension.

*INSPIRE properties:*

- *name (CharacterString, voidable) specifies the name of the geologic event*
- *eventEnvironment, eventProcess, olderNamedAge, youngerNamedAge (as above).*

*In GeoSciML, GeologicEvent is defined as a class of GeologicFeature (which can be associated to any other type of GeologicFeature), whereas according to INSPIRE it is a distinct feature type (only by association related to any type of GeologicFeature).*

Notes:

- A geologic event must at least have one age representation, either numerical or named. *INSPIRE: this constraint is not included*
- Because associated processes are incompatible, a single event cannot be shared between DisplacementEvent, AlterationDescription of MetamorphicDescription.

GSEU implementation: Properties included in the GSEU data model are underlined above; olderNamedAge and youngerNamedAge are redundant when implementing the GeoSciML Geologic Time Scale package (section 9, see below). If AnthropogenicDescriptions are to be associated with GeologicEvents [Option 5C: section 4], EventProcess terms should be extended to include anthropogenic processes. OrogenicCycleEvent may be introduced as a specialized class of GeologicEvent [Option 3A: section 10, Wilson Extension].

| «FeatureType» **GeologicEvent** | | |
|---|---|---|
| geologicEventID | E102 | concept from instantiated Geologic Event vocabulary |
| name | Duero-Ebro transgression | |
| eventProcess | deposition | term from Event Process vocabulary |
| eventProcess | subsidence | term from Event Process vocabulary |
| eventEnvironment | … | term from Event Environment vocabulary |
| olderGeochronologicEra | Upper Cretaceous | term from GTS ontology |
| youngerGeochronologicEra | Early Miocene | term from GTS ontology |

**Figure 14. Instance example of a GeologicEvent. It describes the age and process associated with the Duero-Ebro unconformity LTL (see Figure 12).**

# 9. «Leaf» Geologic Time Scale

## GeologicEventDescription

GeologicEventDescription [GeoSciML Extension] provides extended descriptions of geologic events through links to GeochronologicEras in the GeologicTimescale model. GeoSciML Basic provides terms (from a controlled vocabulary) whereas GeoSciML Extension provides a fuller ontology to describe geochronology.

*Not available in INSPIRE.*

Properties:

- olderGeochronologicEra is an association with a GeochronologicEra that corresponds to the older estimated age of the geologic feature
- youngerGeochronologicEra is an association with a GeochronologicEra that corresponds to the younger estimated age of the geologic feature.

GeochronologicEra refers to entries in the Geologic Time Scale model, an extension developed by Cox & Richard (2005).

GSEU implementation: Properties included in the GSEU data model are underlined above. In addition, implementation of the GeoSciML Geologic Time package is required.

# 10. Wilson Extension

### OrogenicCycleEvent

The OrogenicCycleEvent feature refers to an individual phase of the orogenic (Wilson) cycle, as defined within the concept of plate tectonics. Each phase (represented by a unique XD label) is characterized by its specific tectonic position and associated sedimentary or metamorphic processes (cf. Németh 2021).

GSEU implementation: The GSEU data model distinguishes OrogenicCycleEvents with a specialized vocabulary (containing definitions of the XD labels) as (sub)type of GeologicEvent. We propose two options for implementation (following the rules for GeoSciML Extension), on which WP7 is asked to decide which one is the technically most viable solution:

Option 3A. Introduce a new feature type OrogenicCycleEvent as subclass of GeologicEvent with additional properties:

- orogenicCycle (Term, voidable) is a term from a controlled vocabulary specifying the orogenic cycle
- orogenicPhase (Term, voidable) is a term from a controlled vocabulary that specifies the phase within the orogenic cycle.

Option 3B. In case EventProcessTerm = OrogenicCycle (a constraint is added), introduce extended properties via the placeholder geEventDescripton:

- orogenicCycle (Term, voidable) is a term from a controlled vocabulary specifying the orogenic cycle
- orogenicPhase (Term, voidable) is a term from a controlled vocabulary that specifies the phase within the orogenic cycle.

Material properties of geologic units can be associated to OrogenicCycleEvents via the available extended EarthMaterial descriptions (i.e., AlterationDescription and MetamorphicDescription, see section 4).

According to the data model, orogenicCycleEvents can be associated with any GeologicFeature, i.e. units [LTUs] as well as structures [LTLs]. However, for consistency it is advisable to constrain this association to either one or the other. Because LTLs are by definition linked to events, it seems logical to associate orogenicCycleEvents with their corresponding Primary limits. The consequence is that LTUs are only indirectly associated with orogenicCycleEvents (via their related limits); a sequence of overprinting events can be deduced from its position within successive LTLs. [Q8: to be decided by WP6/Task 6.2.4]

The XD vocabulary/thesaurus will be developed in WP6/Task 6.2.4.

| «FeatureType» GeologicEvent: OrogenicCycleEvent | | |
|---|---|---|
| geologicEventID | E98 | concept from instantiated Geologic Event vocabulary |
| name | Pyrenean orogenic phase ApD1 | |
| eventProcess | continental collision | term from Event Process vocabulary |
| eventEnvironment | collisional setting | term from Event Environment vocabulary |
| olderGeochronologicEra | Upper Cretaceous | term from GTS ontology |
| youngerGeochronologicEra | Lower Paleocene (?) | term from GTS ontology |
| orogenicCycle | Ap | term from Orogenic Cycle vocabulary [XD label for Paleo-Alpine orogenic cycle] |
| orogenicPhase | D1 | term from Orogenic Cycle vocabulary [XD label for convergent phase] |

**Figure 15. Instance example of an OrogenicCycleEvent, defined as subclass of GeologicEvent. It describes the age and process associated with the North-Pyrenean frontal thrust system, using terminology from the Orogenic Cycle vocabulary (XD labels relating to the Wilson Cycle).**

# 11. «Leaf» GeologicCollection

## Collection

In GeoSciML [Basic] a collection is a convenience class to manage sets of features or type instances. A collection can be made of heterogeneous items. Practically, it is a collection container for items to be bundled in WFS response documents and other applications.

Properties:

- collectionType (Term, required) is a term from a controlled vocabulary describing the type of collection, thus providing context or purpose (e.g., geological maps, sets of boreholes)
- member (required?) is an association that links instances to features and objects to be included as members of the collection.

*INSPIRE definition: A collection of geological or geophysical objects.*

*INSPIRE properties:*

- *<u>inspireId</u> (identifier, required) is an external object identifier of the spatial object*
- *<u>name</u> (CharacterString, required) is the name of the collection*
- *<u>collectionType</u> (Terms, required) is a term from a controlled vocabulary describing the type of the collection*
- *<u>reference</u> (CharacterString, voidable) is a reference for the collection*
- *<u>beginLifespanVersion</u> (DateTime, voidable) contains date and time at which this version of the spatial object was inserted or changed in the spatial data set*
- *<u>endLifespanVersion</u> (DateTime, voidable) contains date and time at which this version of the spatial object was superseded or retired in the spatial data set*
- *geophObjectMember, geophObjectSet, boreholeMember (voidable) are associations with geophysical entities, sets of geophysical object and boreholes, respectively, to be included as members in a GML Collection*
- *<u>mappedMember</u> (voidable) is an association with a mappedFeature object to be included as member in a GML Collection.*

<u>GSEU implementation:</u> Properties included in the GSEU data model are <u>underlined</u> above.

The INSPIRE approach to GeologicCollection seems more suitable for implementation in the GSEU data model. It practically is a collection container for referencing and versioning, hence suited for storing metadata. However, as implemented in INSPIRE it only relates to MappedFeatures, geophysical objects and boreholes, not to GeologicFeature instances (which may be defined independently of their mapped occurrences). [Q9: to be decided by WP7 if this can/needs to be expanded]

# 12. «Application Schema» Vocabulary

The GeoSciML Vocabulary package [GeoSciML 3.0] contains classes to support definitions and classifications.

This package is in concept only and is implemented using Simple Knowledge Organization System and Resource Description Framework (SKOS-RDF) encoded vocabularies, and Uniform Resource Identifiers (URIs) to link by reference to controlled concepts which define classifiers.

*Not available in INSPIRE.*

### ControlledConcept

A ControlledConcept [GeoSciML 3.0] is an element to represent a defined concept. It is a relationship class that associates GeologicFeature instances with concept instances in a GeologicVocabulary. The GeologicConcept instance must have an associated definition, which may be text for human interpretation, or a formal description in the form of a geologic entity. A ControlledConcept must have only one preferred Name.

Properties:

- LocalizedGenericName (CharacterString, required) is a localized term that acts as a human-readable label for the concept
- Vocabulary (required) associates the ControlledConcept to the vocabulary it belongs to
- Prototype (voidable) associates the ControlledConcept to a GeologicFeature instance which exemplifies the concept.

### GeologicVocabulary

A collection of terms (ControlledConcepts) and their associated definitions and relationships between the terms, usually organized in some logical fashion such as in a hierarchy. An instance of a Geologic-Concept may occur only once in a particular GeologicVocabulary.

### VocabRelation

VocabRelation specifies relationships between ControlledConcepts, which in the most common case are parent-child relationships establishing a concept hierarchy and synonymy establishing equivalent terms. Other Thesaurus type term relationships (e.g., Broader, Narrower, Equivalent and Related Terms) can also be implemented.

GSEU implementation: The GSEU data model includes thesauri for:

- Lithology [cf. WP6/Task 6.2.2]
- Anthropogenic deposits [cf. WP6/Task 6.2.3].
- Lithotectonic Units (LTUs) and Lithotectonic Limits (LTLs) [cf. WP6/Task 6.2.4]
- Orogenic cycles and phases (XD labels) [cf. WP6/Task 6.2.4]

We propose using the Application Schema Vocabulary (included as concept in GeoSciML 3.0) to implement such controlled thesauri, which should be able to accommodate customized hierarchical and other (geologic) relationships. [Option 4B, to be decided by WP7 if this is a technically viable solution].

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# 14. Annexes

**Annex 1: WP6-D44-Conceptual-data-model_v31Oct2023 (.pdf, 360 KB)**

## Annex 2: Consortium Partners

| Consortium partners | | | |
|---|---|---|---|
| | **Partner Name** | **Acronym** | **Country** |
| 1 | EuroGeoSurveys | EGS | Belgium |
| 2 | Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek | TNO | Netherlands |
| 3 | Sherbimi Gjeologjik Shqiptar | AGS | Albania |
| 4 | Vlaamse Gewest | VLO | Belgium |
| 5 | Bureau de Recherches Géologiques et Minières | BRGM | France |
| 6 | Ministry for Finance and Employment | MFE | Malta |
| 7 | Hrvatski Geološki Institut | HGI-CGS | Croatia |
| 8 | Institut Royal des Sciences Naturelles de Belgique | RBINS-GSB | Belgium |
| 9 | Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy | PGI-NRI | Poland |
| 10 | Institut Cartogràfic i Geològic de Catalunya | ICGC | Spain |
| 11 | Česká Geologická Služba | CGS | Czechia |
| 12 | Department of Environment, Climate and Communications - Geological Survey Ireland | GSI | Ireland |
| 13 | Agencia Estatal Consejo Superior de Investigaciones Cientificas | CSIC-IGME | Spain |
| 14 | Bundesanstalt für Geowissenschaften und Rohstoffe | BGR | Germany |
| 15 | Geološki zavod Slovenije | GeoZS | Slovenia |
| 16 | Federalni Zavod za Geologiju Sarajevo | FZZG | Bosnia and Herzegovina |
| 17 | Istituto Superiore per la Protezione e la Ricerca Ambientale | ISPRA | Italy |
| 18 | Regione Umbria | - | Italy |
| 19 | State Research and Development Enterprise State Information Geological Fund of Ukraine | GIU | Ukraine |
| 20 | Institute of Geological Sciences National Academy of Sciences of Ukraine | IGS | Ukraine |

| | | | |
|---|---|---|---|
| 21 | M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine | IGMOF | Ukraine |
| 22 | Ukrainian Association of Geologists | UAG | Ukraine |
| 23 | Geologian Tutkimuskeskus | GTK | Finland |
| 24 | Geological Survey of Serbia | GZS | Serbia |
| 25 | Ministry of Agriculture, Rural Development and Environment of Cyprus | GSD | Cyprus |
| 26 | Norges Geologiske Undersøkelse | NGU | Norway |
| 27 | Latvijas Vides, ģeoloģijas un meteoroloģijas centrs SIA | LVGMC | Latvia |
| 28 | Sveriges Geologiska Undersökning | SGU | Sweden |
| 29 | Geological Survey of Denmark and Greenland | GEUS | Denmark |
| 30 | Institutul Geologic al României | IGR | Romania |
| 31 | Szabályozott Tevékenységek Felügyeleti Hatósága | SZTFH | Hungary |
| 32 | Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport | VBS (DDPS) | Switzerland |
| 33 | Elliniki Archi Geologikon kai Metalleftikon Erevnon | HSGME | Greece |
| 34 | Laboratório Nacional de Energia e Geología I.P. | LNEG | Portugal |
| 35 | Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos | LGT | Lithuania |
| 36 | GeoSphere Austria | - | Austria |
| 37 | Service Géologique de Luxembourg | SGL | Luxembourg |
| 38 | Eesti Geoloogiateenistus | EGT | Estonia |
| 39 | Štátny Geologický ústav Dionýza Štúra | SGUDS | Slovakia |
| 40 | Íslenskar Orkurannsóknir | ISOR | Iceland |
| 41 | Instituto Português do Mar e da Atmosfera | IPMA | Portugal |
| 42 | Jarðfeingi | Jardfeingi | Faroe Islands |
| 43 | Regierungspräsidium Freiburg | LGRB | Germany |

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| 44 | Geologischer Dienst Nordrhein-Westfalen | GD NRW | Germany |
| 45 | Landesamt für Geologie und Bergwesen Sachsen-Anhalt | LfU | Germany |
| 46 | Vlaamse Milieumaatschappij | VMM | Belgium |
| 47 | Norwegian Petroleum Directorate | NPD | Norway |
| 48 | United Kingdom Research and Innovation - British Geological Survey | UKRI-BGS | UK |