Implementation of INSPIRE Directive in Digital Geological Map Production in Portugal*

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Abstract

This work deals with the implementation of the INSPIRE Geology data model (INSPIRE GE) in digital geological map production in the Portuguese Laboratory of Energy and Geology (LNEG), and its extension to comply with the Portuguese geology requirements. The process of harmonising geological mapping data involves the restructuring of the LNEG's data model to the extended INSPIRE GE which aim at building a more efficient, inter-operable and harmonised management data structure for geological mapping, across the European Community. The methodology was applied to the Rosario Antiform, a geological structure that belongs to the Portuguese part of the Iberian Pyrite Belt. Three maps concerning the Antiform were produced, namely: (i) The lithostratigraphic map representing the geological units organized according to their spatial distribution and age; (ii) The age map which represents the lower age of the geological units; and (iii) The lithological map where the most important rock types are represented. This study shows that the INSPIRE GE implementation is feasible in the geological mapping production at LNEG and it constitutes a first step towards data harmonisation and inter-operability. The structuring of geological data allows the implementation of geoprocessing operations in the production of geological and other thematic maps (e.g. lithologic map, age map).

Keywords: LNEG, INSPIRE, geological mapping, data harmonisation, inter-operability, GIS, SDI.

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1. INTRODUCTION

We live in an “Information Society” where the availability of tools such as the Google Earth implies an increasing demand for geoscience spatial data (Jakson, 2007). Nowadays, users want to access and interact with geologic maps and other spatial data freely and without any type of restriction. Under these circumstances the Geological Surveys have started to develop efforts to improve the interaction between data providers and users. This is the case of the model/schema North American Data Model (NADM) (NADM Steering Committee, 2004) used for implementing the National Geologic Map Database (NGMDB) project (Soller and Berg, 2005), with the aim of promoting the interoperability of the geological datasets from the United States.

In Europe, the Commission for the Management and Application of Geoscience Information (CGI) from the International Union of Geological Sciences (IUGS), has been working for the development of a common geoscience conceptual model (Asch et al., 2004) which is the basis for the deployment of the Geoscience Markup Language (GeoSciML) (Sen and Duffy, 2005) - an interchange standard for sharing geoscience spatial data through the internet. CGI has also contributed to the development of several controlled vocabularies that are intended to be as widely applicable across the geoscientific domain as possible. More recently, the OneGeology-Europe (1G-E) project has enabled the online decentralized exchange of the digital geological map of Europe at a 1:1 Million scale. LNEG has participated in this project, together with 20 European Geological Surveys. In order to achieve the objectives of the project from the Portuguese part, it was necessary to adjust the database of the Geological Map of Portugal to the adopted data model. The map services were made available in harmony with the other European countries. This successful project promoted the LNEG`s acquirement of new working methodologies and contributed to the implementation of the INSPIRE Directive in the institution. It also called the attention for the need of a new standardized and harmonised structure for geologic mapping.

The European Commission, having in mind the growing importance of spatial information for society and the existing constraints in terms of availability, quality, organization, accessibility, and sharing of spatial information across the various levels of public authority, approved on March, 14th the 2007/CE Directive, known as INSPIRE (INfrastructure for SPatial InfoRmation in Europe), which was transposed to the Portuguese law by decree 180/2008, August 7th. This decree also proceeds to the revision of the Portuguese National Geographic Information Infrastructure (SNIG). The entry into force of the INSPIRE Directive marks a key step towards the inter-operability of the European spatial datasets and services implying the establishment of an Infrastructure for Spatial Information in the European Community. This Directive aims to provide the users with an integrated network of spatial information services that allow any user to identify and access harmonised spatial data, from a wide range of sources, in an open way and for a variety of uses. The INSPIRE Directive lays down the principles and rules to be adopted by the Member States in terms of metadata, sharing and interoperability of spatial datasets and services, network services, coordination and measures for monitoring and reporting. In its Annexes I, II, and III are listed by priority 34 themes related to spatial datasets held by or on behalf of public authorities of the Member States. Out of these themes, the one related to Geology and described in Annex II will be the subject of the present work.

The INSPIRE Committee has approved the ongoing Implementing Rules (IR) in preparation which, together with Technical Guidance (TG) documents, allow the application of the Directive. Once adopted, the IR become European legislative acts and national law in 27 Member States (Open Geospatial Consortium, 2012). The TG documents are not legally binding documents but provide the necessary implementation details aiming to help the public authorities to accomplish the INSPIRE requirements, recommendations and IR. Each IR approval is preceded by the elaboration of data specifications for each spatial data theme made by Thematic Working Groups (TWG). The resulting draft documents are then submitted for Spatial Data Interest Communities (SDIC) and Legally Mandated Organizations (LMO) consultation, and also for public view. The Geology TWG integrate experts in geosciences, GIS, spatial databases, etc. from several European Geological Surveys, public and private outstanding enterprises. This group has been drafting the geologic data specification documents and the corresponding data models in Unified Modeling Language (UML) which are available in the INSPIRE website. For now only the draft versions are available.

LNEG is the Portuguese public institution acting in the fields of energy and geology. Besides a central administrative department, LNEG also incorporates the Laboratory of Energy and the Laboratory of Geology and Mines. The latter acts as the Portuguese Geological Survey which is the national institution made responsible for the production, management and publication of the official geological mapping covering the country. Geological maps are fundamental tools for mining exploration, environment and land management.

In LNEG, the geological mapping data is presently stored in distinct departments, a situation that raises difficulties in their shared access. Each geological map has its own Geodatabase and whenever the stored data is needed for application in other projects it is copied, normally in shapefile format. This can be time consuming and causes constraints in the data completeness and security, compromising the development of reliable information systems. Furthermore, the existing data model structure shows inconsistencies with respect to several attributes, particularly map units, lithologies and ages. This work aims to implement the INSPIRE GE in LNEG digital geological map production, in order to minimize the existing problems and improve the accessibility and reuse of geological map data. This data model must be supported in those features that are used in geological mapping such as MappedUnit, GeologicUnit, GeologicAge, RockMaterial and GeologicStructure. In addition, this structure must also be flexible in such a way that the integration of other themes such as Mineral Resources, Paleontology, etc. can be added. Furthermore, it should also support the GIS used to produce geological maps in LNEG which is based on ArcGIS software. Several advantages are thus expected, namely:

- An adequate structure and harmonisation of the national geological map data compliant with INSPIRE data specifications contributing to the desired interoperability among the European countries;
- A better consistency of shared data;
- The easiest purchase of geological maps through GeoWebServices;
- Simplification of operations that imply spatial analysis on age, lithology and structure of mapped rock units;
- The easiest production of applied maps such as lithological maps, age maps, tectonic maps, etc. required by thematic users.

2. INSPIRE DIRECTIVE IN LNEG ACTIVITIES

Just like the other European Geological Surveys, LNEG is forced to follow the rules of the INSPIRE Directive. Its implementation follows a step-wise approach consistent with the INSPIRE model scheme reference (Architecture and Standards Working Group, 2002). The first step focused on documenting the existing spatial datasets and services according to the INSPIRE metadata implementing rules (European Commission, 2008). LNEG has used the software "Geographic Information Metadata Creator" (MIG) which is available on the SNIG website (http://snig.igeo.pt/portal/, accessed on March 10th, 2012). In parallel, LNEG has developed a geo-portal (http://geoportal.lneg.pt, accessed on March 25th, 2013) which provides a range of network services for discovery, view and download of spatial datasets and metadata. In the near future, after the IR adoption, in what regards geology data specification, LNEG must provide their digital geological maps, within two years for the new recently collected data, and seven years for the remainder. At the same time, LNEG should gradually proceed to harmonise geological map data in order to make it interoperable with that of the European countries. Concerning this action, the present work represents an added value for the INSPIRE implementation in LNEG, being a first contribution for the design of the geological map database to adopt hereafter.

According to INSPIRE, inter-operability is defined as the "possibility of the spatial data sets to be combined and the services to interact, without repetitive manual intervention, in such a way that the result is coherent and the added value of the datasets and services is enhanced" (European Parliament and Council, 2007).This definition changes the focus from the systems to data level of inter-operability (Tóth et al., 2012).

Data inter-operability depends on data harmonisation, which may be achieved in two ways:

1. Restructuring the source schemas according to the INSPIRE data model;
2. Creating schema transformation services that apply to data providers who want to publish their data “as is” (Open Geospatial Consortium, 2012).

Concerning the second option, data is transformed by specific software which maps between the source and the INSPIRE DB schemas. Although the transformation services have the advantage of preserving the original structure of data, thus fulfilling the user requirements for which it has been created, there are some cases where it is easier to adopt the INSPIRE model for the production of new data and to migrate the remainder data for such structure.

In LNEG, the implementation of transformation services may not be the best choice, due to the following reasons:

- The existing data model for geological mapping does not conform to INSPIRE data specifications, being necessary to add tables, attributes and new relationships;
- The way the data is structured constrains the automatism that is required with the transformation services;
- Until recently, the existing data model for geological mapping was mainly intended for the publication of printing maps, so that there is no need to keep it for other purposes;
- In the institution there is no specialized know-how for the development and implementation of the transformation services, so it is easier to adopt the INSPIRE GE data model and extend it to suit the Portuguese geological mapping specifications.

Due to the reasons pointed out, the harmonisation of the geological map data requires changes in the underlying data structures to conform to INSPIRE data specifications. It is also required the mapping between geological terms used in the Portuguese geologic maps and the ones included in INSPIRE code lists.

To fulfill such goals, the INSPIRE directive also highlights the need of using international specifications and standards (de-jure and de-facto) which are being developed jointly by several standards organizations, such as the Technical Committee 211 (TC 211) of the International Organization for Standardization (ISO), the Open Geospatial Consortium (OGC) and the Technical Committee 287 (TC 287) of the European Committee for Standardization (CEN). The linkage between OGC and ISO is particularly strong as OGC standards are often approved as ISO standards. For example: Web Feature Service (WFS), Web Mapping Service (WMS) and Geographic Markup Language (GML) are also ISO 19142, ISO 19128 and ISO 19136. TC 287 has an important role in the approval and adoption of some of the ISO 19100-series standards. Once a standard is adopted in Europe an EN prefix is put before the ISO number, e.g. EN ISO 19142 (Open Geospatial Consortium, 2012).

In order to harmonise the symbology used for cartographic portrayal (map symbols, text fonts, line styles, map colours and patterns), LNEG is developing an informal standard for digital geologic map production (Cunha, 2008). Despite these efforts, the international standards are not always followed. This procedure is common in almost all the European Geological Surveys since they have developed, over the years, their own conventions that apply to geologic map production. To overcome this situation, INSPIRE advises that the symbology used for cartographic portrayal should be that already harmonised by standard organizations (Drafting Team Data Specifications, 2008).

3. IMPLEMENTATION OF INSPIRE GE MODEL TO DIGITAL GEOLOGICAL MAP PRODUCTION

3.1. INSPIRE GE UML model

INSPIRE GE model has been downloaded from the INSPIRE website (http://inspire.jrc.ec.europa.eu/index.cfm/pageid/2/list/1, accessed on March 24th, 2012), in the EAP format and imported in Enterprise Architect which is the UML modelling tool from Sparx Systems.

INSPIRE application schemas for each individual theme (as defined in the Annexes I, II and III of the Directive) are modelled using a common language, and are maintained in the Consolidated INSPIRE UML Model. The adopted language is based on INSPIRE UML Profile that specifies the stereotypes and basic types to be used in application schemas (Drafting Team Data Specifications, 2013). The Geology TWG has developed a core data model (INSPIRE GE) composed of three application schemas: Geology, Hydrogeology and Geophysics. From these, only the Geology application schema was analyzed, since it contains the main types of geologic features needed for geological map production, namely: GeologicUnit, GeologicStructure, CompositionPart (Lithology) and GeologicEvent (Age). The data model also enables a description of the landforms (geomorphologic features), that are not usually represented on Portuguese geologic maps. The domains are a special kind of classes whose names have the suffix *Value* added.

3.2. Methodology of implementation

ArcGIS Desktop, version 10.1 is currently the GIS software used in LNEG for geologic map production. The DB format is the Geodatabase from ESRI. The transposition from the INSPIRE GE model to the Geodatabase is not straightforward. Therefore, it was necessary to design a Geodatabase based on the mapping between the UML notation and the ArcGIS concepts. To achieve this goal the software Enterprise Architect 9.3 was used along with its Profile for ArcGIS. This technology allows the ArcGIS schema generation as a workspace XML (eXtensible Markup Language) file, which is directly imported into ArcCatalog. It also enables the reverse engineering of legacy geodatabases into a visual UML model (Sparx Systems, 2012).

3.2.1. UML Geodatabase Modelling

The Enterprise Architect uses a package structure, which supports the UML Geodatabase design for ArcGIS. When a new project is generated a top-level ArcGIS stereotyped package is created along with the following three packages:

- Features;
- Domains;
- Spatial References.

Within the “Features” package (a Feature Dataset stereotyped package), the Topology and Subtypes sub-packages were modelled. The former sub-package is used to store all the feature classes that take part in topology and the latter to store all of the subtypes. Coded Value and Range Domains were defined in the "Domains" package, while the Object Classes were created outside the Feature Dataset. In the “Spatial References” package the ETRS_1989_Portugal_TM06 coordinate system was defined, in line with the requirement from Annex II (1.3) of the Commission Regulation (EU) Nº1089/2010, in what regards inter-operability of spatial datasets and services (European Commission, 2010). This spatial reference system was assigned to the “Features” package in order to geographically refer all feature classes.

The UML Geodatabase design has included the modelling of the classes from the GeologyCore application schema, except Borehole, GeologicCollection, MappedInterval and ThematicClass. The Borehole class was not modeled since a work concerning this class is in progress in LNEG. The other outlined classes were not modeled because they were not available on INSPIRE website when this study began. Additionally other classes which are essential in geological mapping production have been modeled. The documents that served as a basis to model the Geodatabase were:

- Geology application schema from INSPIRE GE model and data specification documents (Inspire Thematic Working Group Geology, 2012);
- GeoSciML model from CGI (http://www.geosciml.org/, accessed on March 24th, 2012);
- Portuguese geologic mapping data specification.

The Geodatabase schema model contains five Packages, seven Abstract Classes, nine Feature Classes, twelve Subtypes, eighteen Object Classes, two Association Classes and fifty Domains. The main model key points are described and illustrated in class diagrams shown in Figures 1 to 8.

Figure 1 shows the top level hierarchy between the *GeologicFeature* and their subclasses. The lithology is now part of the *EarthMaterial* class. The geologic resources have been added to the model. The contacts and other geologic structures (e.g. lineation, bedding, foliation) usually shown in a geological map were added as subclasses of the *GeologicStructure* class. The geologic age was individualized. The geologic unit was divided into two components: the MappedUnit to hold the spatial properties of the geologic units and the GeologicUnit to store the alphanumerical information.

Figure 1: UML class diagram for the *GeologicFeature*. Abstract classes are in italic. The added classes are outlined in brown.

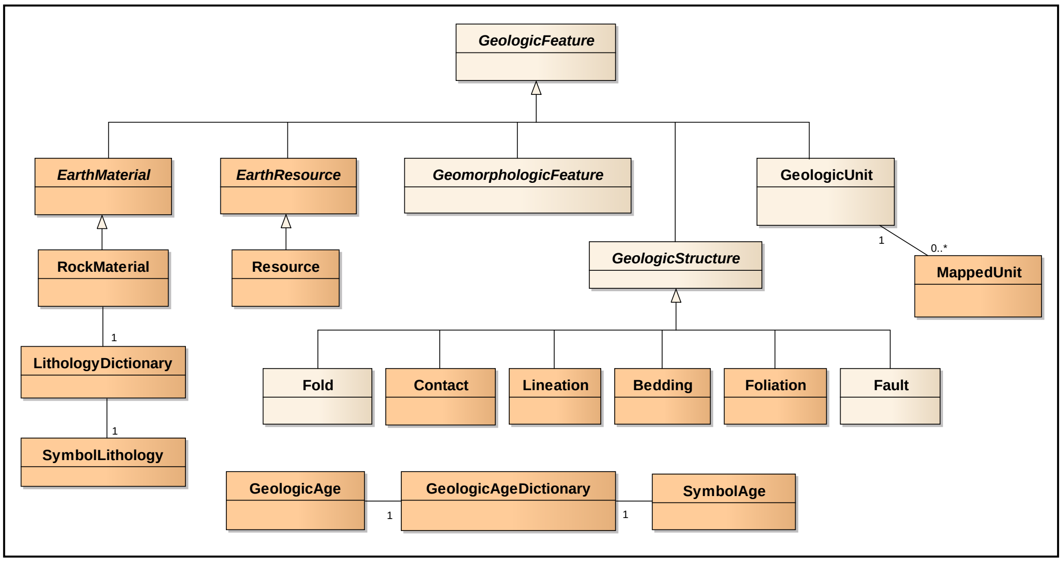


Figure 2 shows the top level hierarchy between the *MappedFeature* and their subclasses. Each feature class has its own stereotype that indicates the type of geometry: point, line and polygon. Subtypes are also shown. The *MappedFeature* defines fields which are shared by all the inherited spatial data classes. The *MappedFeature* is always associated with a “mappingFrame” attribute which in the case of this study is the map surface. The “observationMethod” attribute enables the storage of the distinct methodologies for its recording. For example, a MappedFeature might be obtained through field observation (mapping) or it may have been obtained by compilation of published works.

Figure 2: UML class diagram for the *MappedFeature*. The added classes are outlined in brown.

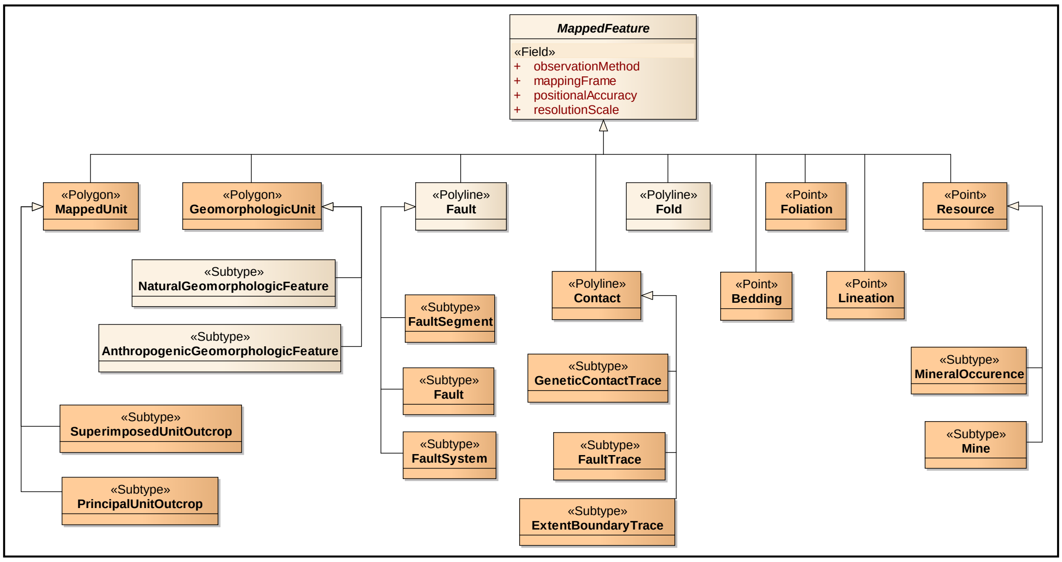


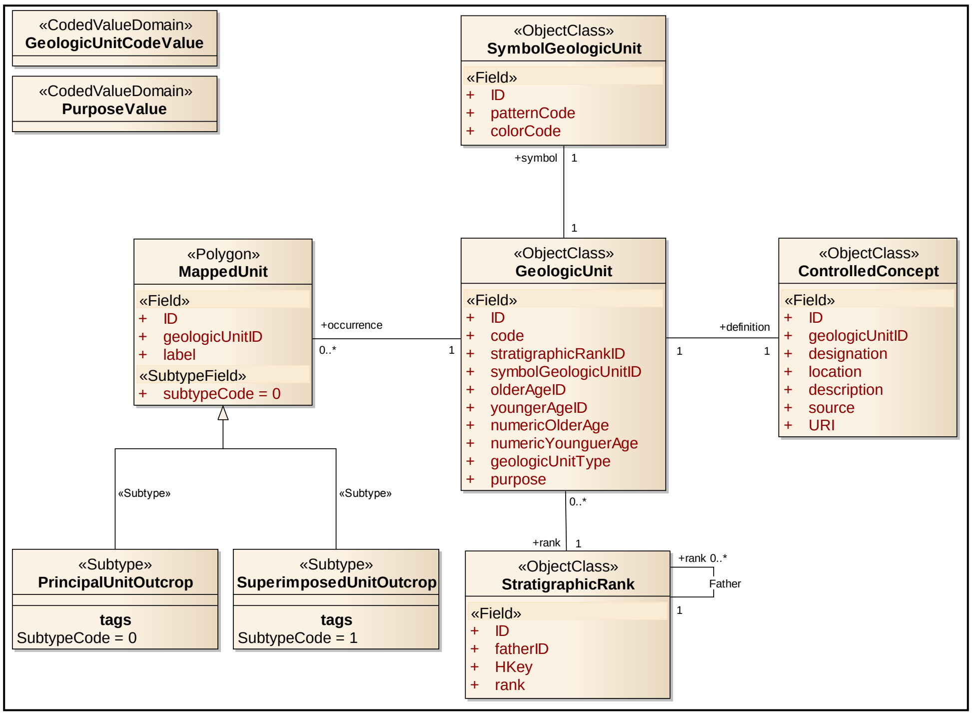
Figure 3 shows the following classes:

- **MappedUnit**, characterized by the different polygons that comprise a geologic map, the geologic unit identifier (geologicUnitID) and a label. This class was divided into two subtypes used to differentiate the main mapping units (PrincipalUnitOutcrop) from the ones which are superimposed to them (SuperimposedUnitOutcrop);
- **GeologicUnit**, identified by a code, a stratigraphic rank identifier (stratigraphicRankID), a cartographic representation identifier (symbolGeologicUnitID), the chronostratigraphic age identifiers (olderAgeID, youngerAgeID), the numerical age in million years (numericOlderAge, numericYoungerAge), the geologic unit type (geologicUnitType) and the “purpose” which states whether the geologic unit is an instance or normative description. The “code” values are listed in the GeologicUnitCodeValue domain. The “purpose” allowed values that are listed in the PurposeValue enumeration: definingNorm for geological units officially formalized,

typicalNorm for geologic units informally formalized or instance for geologic units that weren't yet formalized;

- **StratigraphicRank**, used to classify the geologic units in Members, Formations, SubGroups, Groups, Supergroups, etc. depending on their hierarchical level. The "Father" association that links the StratigraphicRank class with itself is used to identify the hierarchy between each rank;
- **ControlledConcept**, describes the geologic units in terms of designation, location where it was defined, natural description, source where it is referred and an URI to unequivocally identify each geologic unit;
- **SymbolGeologicUnit**, defines the colours and the patterns to portray geologic units on maps.

Figure 3: UML class diagram: GeologicUnit, MappedUnit, StratigraphicRank, ControlledConcept, SymbolGeologicUnit.



The association between the GeologicUnit and the MappedUnit is a "one-to-many" type relationship because a given geologic unit can have several map units occurrences. This linkage is defined by the geologic unit identifier (geologicUnitID). The "Father" association in the StratigraphicRank class yields the implementation of two attributes: the fatherID, a numeric field that holds the top hierarchical level of each rank instance and its corresponding hierarchical key (HKey). For example, the "Formation" fatherID identifies the "Subgroup", which has its own fatherID, the “Group”, which in turn has its own fatherID, the “Supergroup”. This hierarchical structure is essential to perform queries based on these attributes.

Figure 4 shows the following classes:

- **GeologicUnit**;
- **RockMaterial**, described by the lithology identifier term (lithologyDictionaryID) drawn from the lithology dictionary (LithologyDictionary). The “Father” association that links the RockMaterial class with itself is used to identify the hierarchy between the lithologies instances;
- **GeologicAge**, described by the age identifier term (ageDictionaryID) drawn from the geologic age dictionary (GeologicAgeDictionary). The “Father” association that links the GeologicAge class with itself is used to identify the hierarchy between each age term;
- **GeochronologicRank**, classifies the geologic age in terms of its geochronologic rank (e.g. Eon, Era, Period, Epoch and Age). The “Father” association that links the GeochronologicRank class with itself is used to identify the hierarchy between each rank;
- **LithologyDictionary**, stores the lithology terms in portuguese (lithologyPT) and in english (lithologyEN), the URI and the hierarchical key (HKey) of each lithologic term;
- **GeologicAgeDictionary**, stores the geologic age terms provided by the IUGS International Stratigraphic Chart (IUGS, 2009), in portuguese (agePT) and in english (ageEN). Each term has an URI, a hierarchical key (HKey), an older and a younger boundary (olderBoundary, youngerBoundary) attributes in million years before present;
- **SymbolLithology** and **SymbolAge**, defines the colours to portray lithologies and ages on maps.

The lithological composition of a geologic unit is described using a “many-to-many” type association between RockMaterial and GeologicUnit. A geologic unit can have single or multiple lithologies and a given lithology may be part of other geologic units. This relationship implies the creation of a new class (GeologicUnitLithology), which holds the role and the proportion attributes of each lithology in a given geologic unit. The role describes the relationship among the lithologies within the context of the geologic unit (e.g. unique, partial, marker bed, interbedded constituent). The proportion refers to the amount of each lithology within the context of the geologic unit (e.g. total, dominant, subordinate). This data structure allows querying the DB in order to identify which lithologies make up a geologic unit and even check their role and proportion.

The “Father” association between each lithology term enables to query a rock type and all rocks related to it. For example, if “sedimentary rock” is queried, “sandstone” is also returned.

To define the lower and upper age boundary of each geologic unit, two associations of “one-to-many” type relationship between the GeologicAge and the GeologicUnit classes were established.

The “Father” association between each age term enables the querying of, for example Mesozoic geologic units and all their subdivisions.

Figure 4: UML class diagram: GeologicUnit, RockMaterial, LithologyDictionary, SymbolLithology, GeologicAge, GeochronologicRank, GeologicAgeDictionary and SymbolAge.

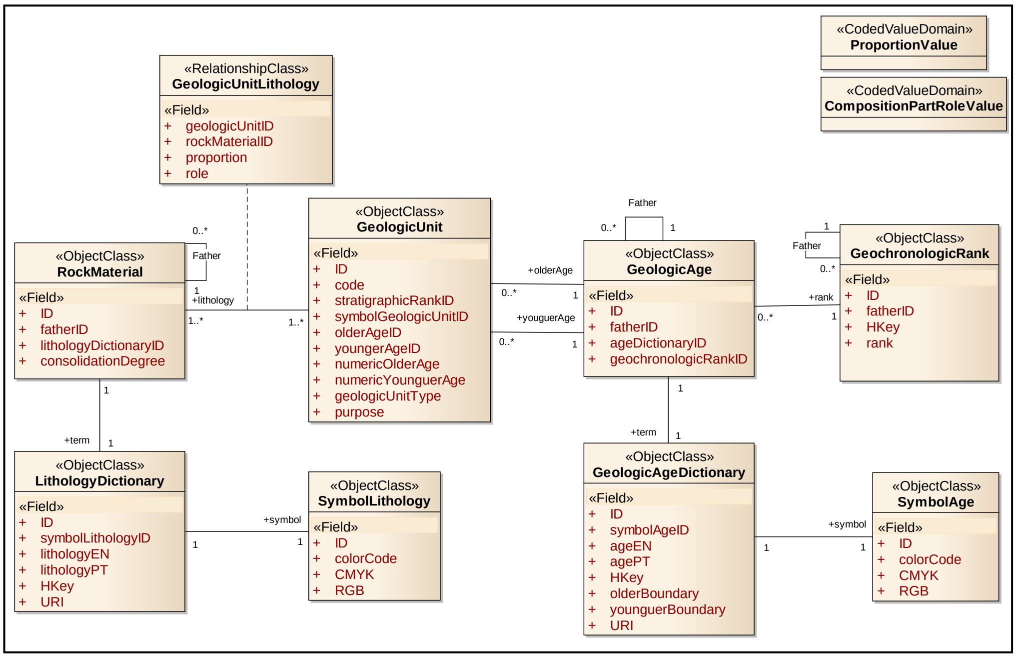


Figure 5 shows the following classes:

- **GeologicUnitEvent**, characterizes all the events that affected the geological units over the geologic time;
- **Alteration**, defines the alteration processes that affected the geologic units, in terms of type, grade, distribution and product of alteration;

- **Metamorphism**, identifies the metamorphic processes that affected the geologic units, in terms of type, grade, facies, peak P-T estimates and protolith material if known.

To define the lower and upper age of a geologic event, two associations of “one-to-many” type relationship between GeologicAge and GeologicUnitEvent classes were established.

Figure 5: UML class diagram: GeologicUnit, GeologicUnitEvent, GeologicAge, Alteration and Metamorphism.

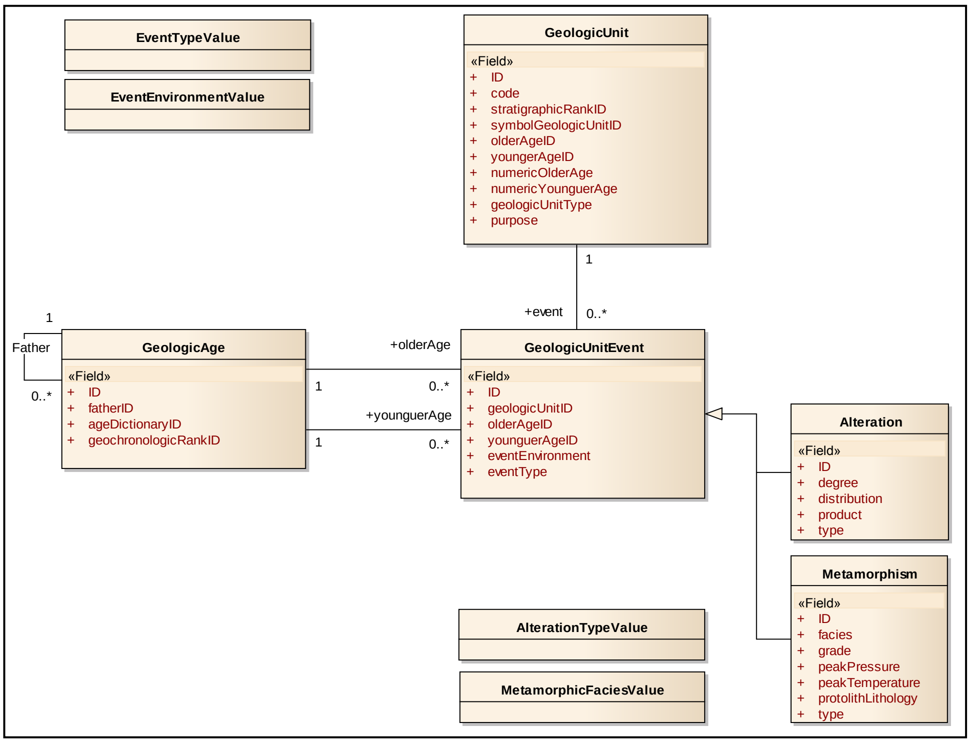


Figure 6 shows the following classes:

- **Fault**, a type of geologic structure which is represented by lines on geologic maps. These lines have distinct portrayal styles depending on the fault type (type) and its level of certainty (character). Faults are also characterized by length, azimuth and dip. The Fault class was divided into three subtypes in order to distinguish fault segments from faults (one fault is made of several fault segments) and fault systems (a fault system is made of several faults);
- **Displacement**, characterizes the tectonic activity of a fault, namely the type and sense of movement, its estimated maximum displacement, etc..

The “Father” association that links the Fault class with itself allows the definition of the “Father” segment (fatherID) for each fault trace.

Figure 6: UML class diagram: Fault, Displacement.

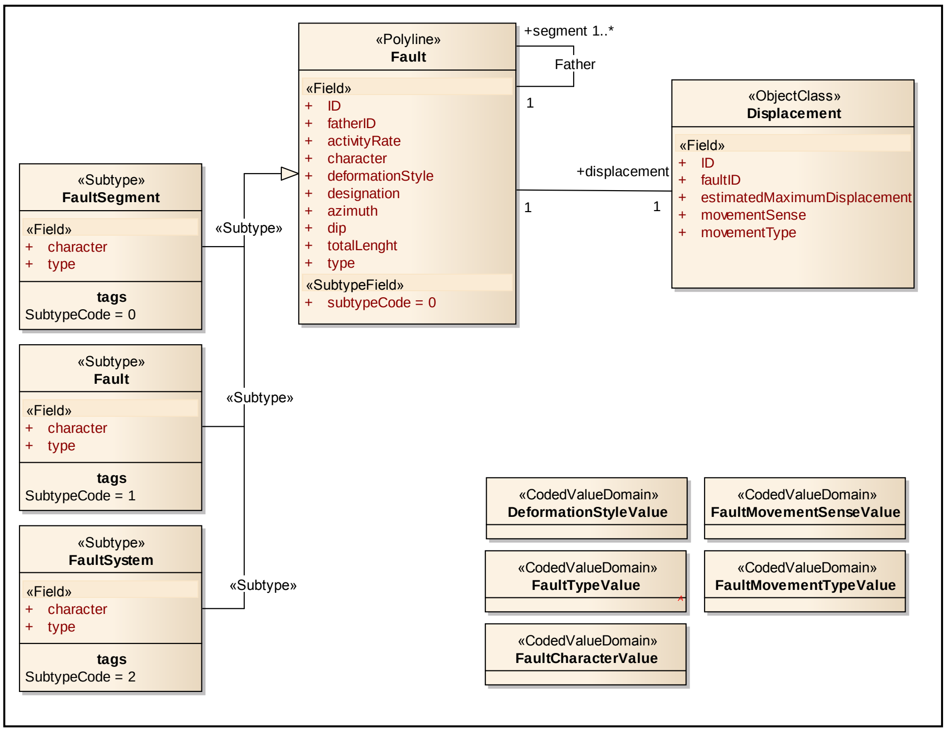


Figure 7 shows the **Contact** class used to store the boundaries between mapped units. Contact is a type of geological structure represented by lines. These lines have distinct styles depending on the contact type (type) and its level of certainty (character). This class was subdivided into three subtypes, as listed hereafter:

- **GeneticContactTrace**, such as depositional, intrusive, gravitational, etc.;
- **FaultTrace**;
- **ExtentBoundaryTrace** (e.g. river boundaries, coast line, map limit extent).

Figure 7: UML class diagram: Contact.

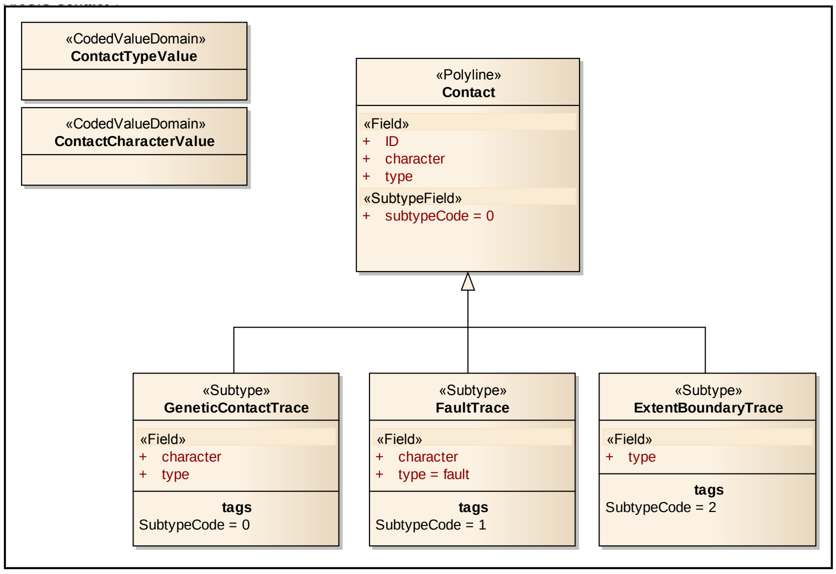
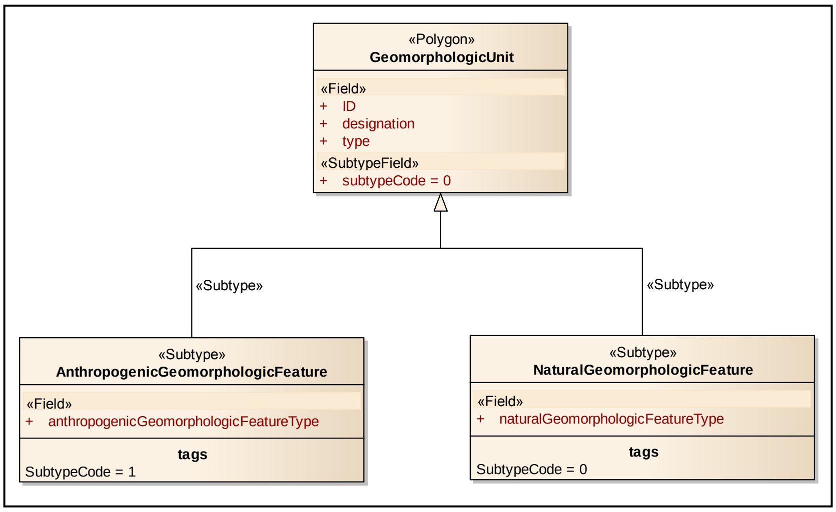


Figure 8 shows the **GeomorphologicUnit** class which has a polygon geometry type. This class was divided into two subtypes: NaturalGeomorphologicFeature and the AnthropogenicGeomorphologicFeature. Many other geomorphologic features are commonly represented by points and lines, which were not modelled at the present work but can be in the future.

Figure 8: UML class diagram: GeomorphologicUnit.



3.2.2. Geodatabase Implementation

The first step to implement the UML model in ArcGIS was to build an enterprise SDE Geodatabase, which was connected to the SQL Server 2008 (the LNEG's DB management system). The next step was the import of the workspace XML file into the ArcCatalog from which the resultant Geodatabase schema was generated. The "Features" package originated the Feature Dataset "Geology". Feature Classes were created within the Feature Dataset. Tables were inherited from the Object Classes, while the Domain Classes were stored in the Geodatabase as Domains. Each attribute class was mapped as a field on the Table or Feature Class. Associations between classes were transposed as Relationship Classes. Attributed Relationships Classes were created from the Association Classes. Abstract classes were not implemented but their attributes were included as fields of the inherited classes.

Topology has been created within the Feature Dataset using the following topology rules:

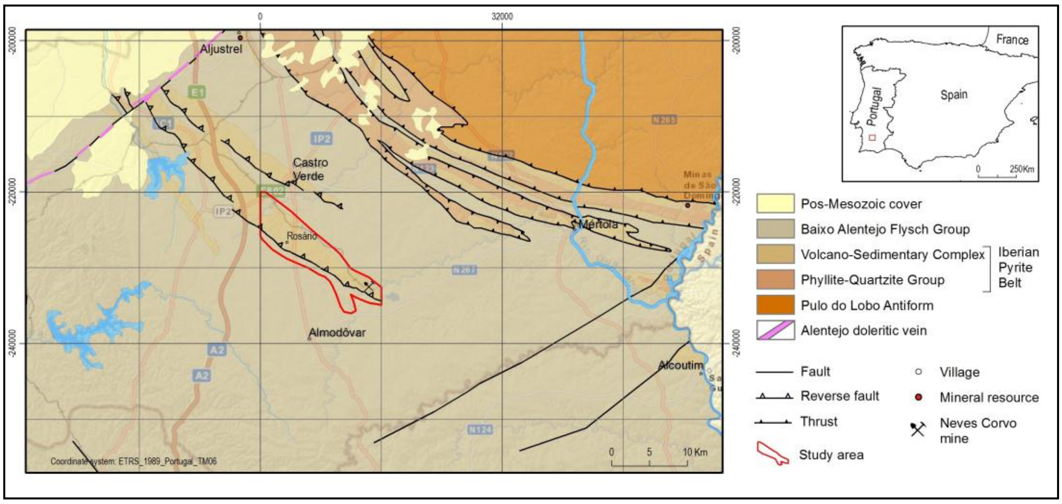
1. MappedUnit: geologic unit polygons must not overlap, must not have gaps and must be bounded by contacts;
2. Fault: dangles are allowed, self intersections are forbiden as well as intersections with other fault or genetic contact trace (one or the other must be younger and break the older surface trace);
3. Contact: must connect to other genetic contacts or to faults, must self connect to form closed loop, fault trace boundaries must be coincident with Fault.

4. CASE STUDY: ROSARIO ANTIFORM, IBERIAN PYRITE BELT

In order to assess the DB efficiency in geological map production, it was necessary to populate it and then perform the required geoprocessing operations to produce the geologic maps. The case study was developed with data from the geological map of the Rosario Antiform, a geological structure that belongs to the Portuguese part of the Iberian Pyrite Belt located in the municipality of Castro Verde, Alentejo (Figure 9 and Oliveira et al., 2013). This option was due to three main reasons:

- The region covered by this map is well studied because of its potential in base metals. At the southeast termination of this geological structure is situated the famous Neves Corvo mine, a major copper producing mine in Europe;
- From the existing knowledge, a large amount of information resulted, much of it already in digital format, thereby creating suitable conditions for the implementation of INSPIRE Directive;
- Support from geologists working in the area.

Figure 9: Geological map with location of the Rosario Antiform, outlined in red. Inset shows the location of the study area in South Portugal.



Source: Geologic Map of Portugal scale 1:1 Million, LNEG, 2010.

The main purpose of this case study was the achievement of three distinct but complementary maps concerning the Antiform, namely:

- The lithostratigraphic map that represents the geological units organized according to their age;
- The age map which represents the lower age of the geological units;
- The lithological map where the most important rock types are represented.

Besides the maps production it has constituted a test bed regarding INSPIRE Directive implementation concerning data harmonisation.

4.1. Methodologies

4.1.1. Used data and their harmonisation

The geological data used is contained in map sheets 556 and 554 at 1:25,000 scale, in vector format (shapefile) and also in the VolcRosário project report produced for Lundin Mining (Rosa et al., 2011).The data preparation phase was preceded by the analysis of the information collected, which allowed its organization in themes outlined in Table 1. In this table, the themes marked with an asterisk were not used but may be implemented in the future. From the used themes the layers and the corresponding attributes outlined in Table 2 were obtained.

Table 1: Available themes and metadata of the Rosario Antiform. The themes marked with a * were not considered in the development of the case study.

Theme	Model	Format	Spatial Reference System	Source	Scale	Year
Stratigraphy	Vector	Shapefile	Lisboa- Hayford-Gauss-IgeoE	LNEG	1:25 000	2010
Palinostratigraphy*	Table	XLS	-	LNEG	-	2011
Geochemistry*	Table	XLS	-	LNEG	-	2011
Geocronology*	Table	XLS	-	LNEG	-	2011
Contact	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Fault	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Fold	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Bedding	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Foliation	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Sample*	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Borehole*	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Resource	Vector	Shapefile	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	2010
Photography*	Digital	JPG	-	LNEG	-	2010
Field map*	Raster	JPG	Lisboa- Hayford-Gauss- IgeoE	LNEG	1:25 000	1998

Table 2: Layers and related attributes.

Layer	Attribute
Mapped unit	Identifier, geologic unit code, observation method, positional accuracy, resolution scale, label.
Geologic unit	Identifier, geologic unit code, designation, purpose, source, location, URI, thickness, stratigraphic rank, geologic unit type, representation rule.
Geologic age	Identifier, geologic unit code, numerical older and younger age, older and younger chronostratigraphic age, URI, representation rule.
Lithology	Identifier, geologic unit code, lithotypes, URI, proportion, role, composition category, genetic category, consolidation degree, representation rule.
Alteration	Identifier, geologic unit code, alteration type, alteration degree, alteration distribution, alteration product.
Metamorphism	Identifier, geologic unit code, metamorphic facies, metamorphic degree, peak pressure, peak temperature, protolith.
Contact	Identifier, contact type, contact character, observation method, positional accuracy, resolution scale, representation rule.

Layer	Attribute
Fault	Identifier, fault type, fault character, deformation style, total length, azimuth, dip, activity rate, estimated maximum displacement, movement type, movement sense, observation method, positional accuracy, resolution scale, representation rule.
Fold	Identifier, profile type, observation method, positional accuracy, resolution scale, representation rule.
Bedding	Identifier, bedding type, observation method, determination method, positional accuracy, resolution scale, azimuth, dip, polarity, label, representation rule.
Foliation	Identifier, foliation type, observation method, determination method, positional accuracy, resolution scale, azimuth, dip, label, representation rule.
Resource	Identifier, designation, resource type, substance, observation method, positional accuracy, resolution scale, label, representation rule.
Geomorphologic unit	Identifier, geomorphologic unit type, designation, observation method, positional accuracy, resolution scale, representation rule.

The coded values attributes were obtained from the CGI vocabularies which are available in the CGI website (https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG, accessed on March 24th, 2012), except for the Lithology and Age terms which were obtained from the 1G-E dictionaries instead (Asch et al., 2010).

The information concerning the lithologies in the pre-existing structure of data was grouped in the same field of the attribute table related to the theme stratigraphy. In the new structure the lithologies were individualized in the Rock Material table that is linked to each geologic unit. With regard to the age, each geologic unit was related to an attribute describing its base and top age. In the new structure that attribute has been replaced by two fields which identify the base and top age of the unit.

Regarding semantics, a correspondence was established between the Portuguese and English geological terms defined in the CGI and 1G-E vocabularies. This process was more or less straightforward, with the exception for those terms that are not included in the dictionary of lithologies used. For example, jasper and chert, two rock types that occur in the area, were classified as "non clastic siliceous sedimentary rock" because there are no corresponding terms in the dictionary of lithologies used. Some fields could not be populated since they have not yet been defined, e.g. the URI of geological units.

The fault traces had to be aggregated into fault segments and for each of these fault segments the type and sense of movement was inferred.

4.1.2. Data processing

The data processing was carried out using the tools provided by ArcToolbox with the following operations being used:

- Projection of the original themes from the coordinate system Lisbon_Hayford_Gaus_IgeoE to the ETRS_1989_Portugal_TM06 system, with the Project tool using the Bursa-Wolf transformation method;
- Populating the coded values domains with the Table to Domain tool;
- Loading the feature classes and tables with the Append tool;
- Calculation of the foreign keys with the Join and Calculate Field tools;
- Loading the relationship tables with the Table To Relationship Class tool.

The cartographic representation rules used to display lithologies and ages on lithologic and age maps were created based on the symbology portrayal schema of the 1G-E project (Asch et al., 2010). The symbols (color and / or pattern) and cartographic representation rules used to display the geologic units on lithostratigraphic map were defined based on the following documents in order of priority:

- ISO 710-2 and ISO 710-3 (ISO, 1974a, b);
- 1G-E Work Package 3 data specification (Asch et al., 2010);
- Standard for Digital Geologic Map Production in LNEG (Cunha, 2008).

The cartographic representation rules were stored as primary keys (ID) of the tables SymbolGeologicUnit, SymbolLithology and SymbolAge. These ID's were later associated to the tables: GeologicUnit, LithologyDictionary and GeologicAgeDictionary as foreign keys. This data structure was essential for the implementation of the geoprocessing operations in the calculation of cartographic representation rules as illustrated in Figures 10, 11 and 12. The models shown were created with the Model Builder tool. These models served as the basis to the production of the lithostratigraphic, lithologic and age maps, shown in Figures 13, 14 and 15. The implemented processes consisted in the following operations:

- Adding the cartographic representations with the Add Representation tool, opting for importing the *lyr* file which contains the rules of representation previously created. This operation was performed three times in order to add to the MappedUnit the cartographic representations concerning the themes lithostratigraphy, lithology and age;
- Calculation of the cartographic representation rules concerning the theme lithostratigraphy through the operations Add Join and Calculate Field shown in Figure 10;
- Calculation of the representation rules concerning the theme lithology through the operations Add Join, Make Query Table to create a table with the most

important lithologies (totals, dominants, predominants and principals) and Calculate Field represented in Figure 11;

- Calculation of the representation rules concerning the theme age through the operations Add Join and Calculate Field represented in Figure 12.

Figure 10: Implemented processes used to calculate the cartographic representation rules needed for the production of the litostratigraphic map. Model obtained in Model Builder, ArcGIS Desktop®.

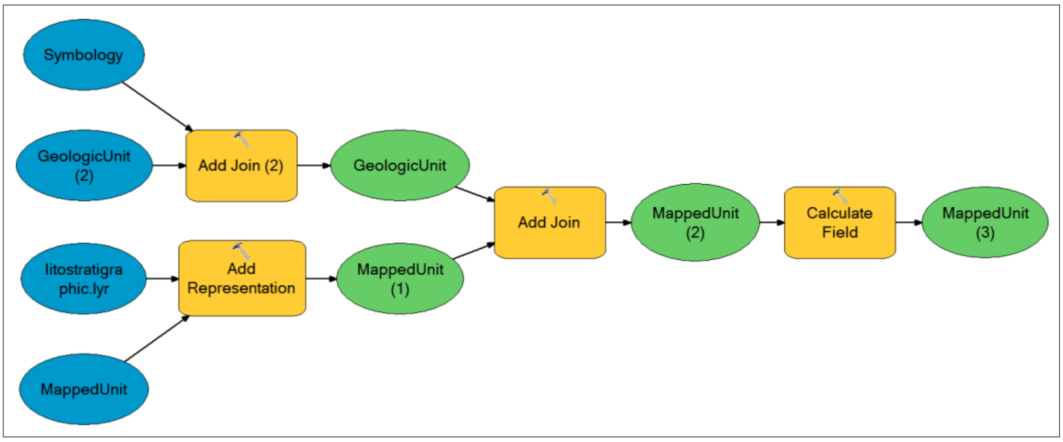


Figure 11: Implemented processes used to calculate the cartographic representation rules needed for the production of the lithology map. Model obtained in Model Builder, ArcGIS Desktop®.

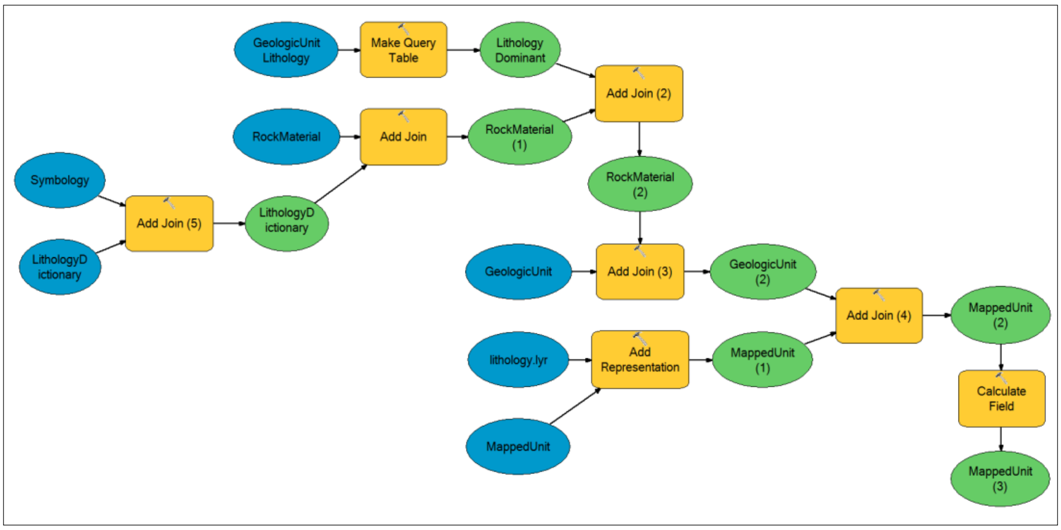
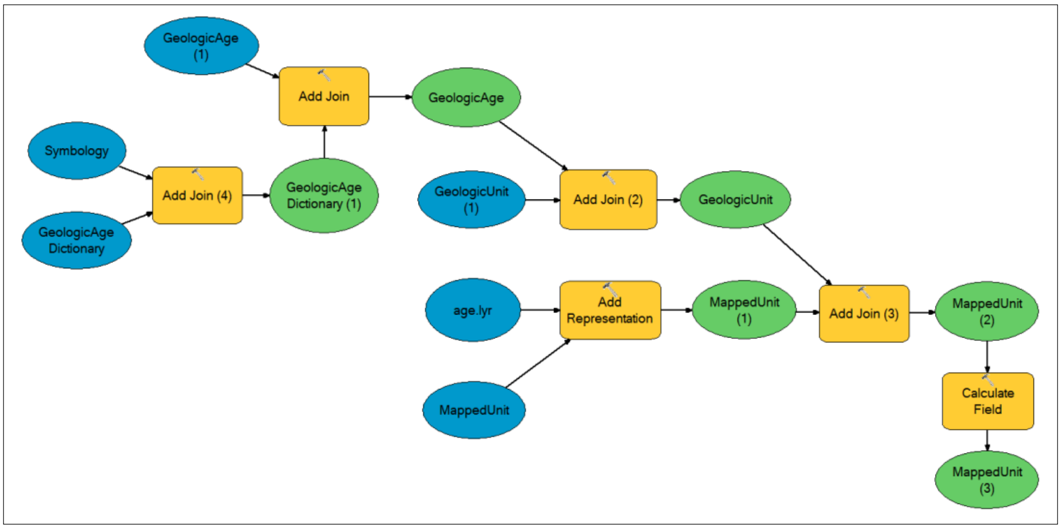


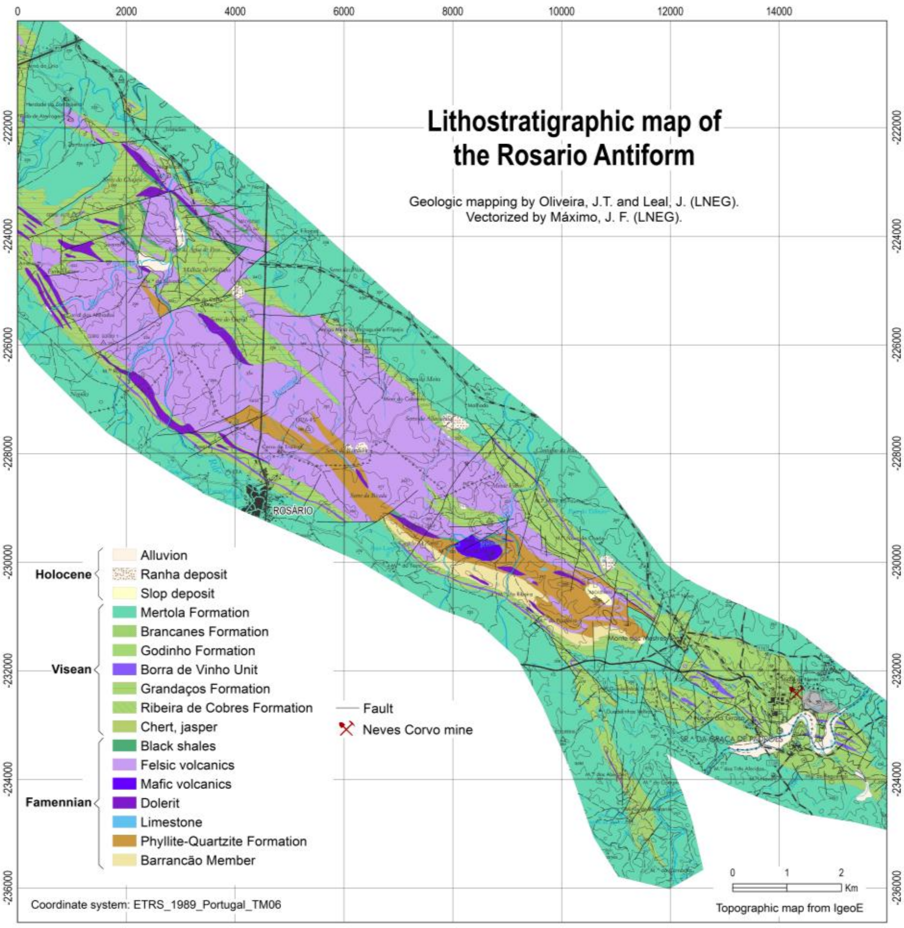
Figure 12: Implemented processes used to calculate the cartographic representation rules needed for the production of the age map. Model obtained in Model Builder, ArcGIS Desktop®.



4.2. Results

The models that were build up to prepare the three types of geological maps proved to be well structured and may be applied to other kinds of thematic maps with the due adaptations. The Lithostratigraphic Map of the Rosario Antiform (Figure 13) shows the existence of seventeen lithostratigraphic units with distinct lithologies. These units are organized according to their spatial distribution and age. The spatial distribution is governed by the tectonic structure that makes up the antiform while the ages represented correspond to the Famennian stage (Upper Devonian), to the Upper Visean stage (Lower Carboniferous) and to the Holocene stage. The faults that cut the antiform with a dominant NE-SW orientation are particularly important because they can disrupt the geological units and even the copper rich massive sulphide ores in the Neves Corvo mine, in this case causing complementary difficulties in their exploitation.

Figure 13: Lithostratigraphic map of the Rosario Antiform.



The Lithologic Map (Figure 14) shows that in the area covered by the antiform eleven types of lithologies are dominant. This means that there are lithologies that are repeated in the seventeen lithostratigraphic units identified in figure 13. It should be mentioned that the dominant lithologies represent only the dominant proportion among other lithologies that compose the units.

The Age Map shown in figure 15 has only three units which mean that there are several geological units that have a similar lower age. As underlined in figure 13, seven have an Upper Famennian age (around 359 million years), seven an Upper Visean age (around 328 million years) and three from Upper Pleistocene to Upper Holocene age (<117 thousand years).

Figure 14: Lithologic map of the Rosario Antiform.

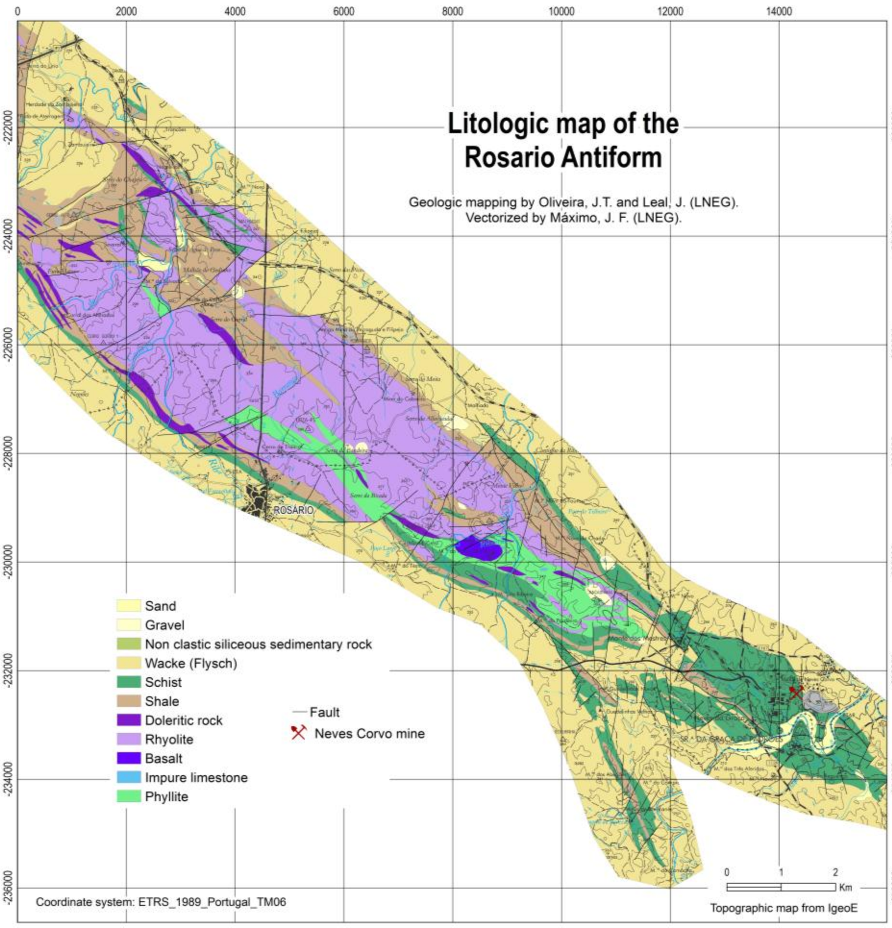
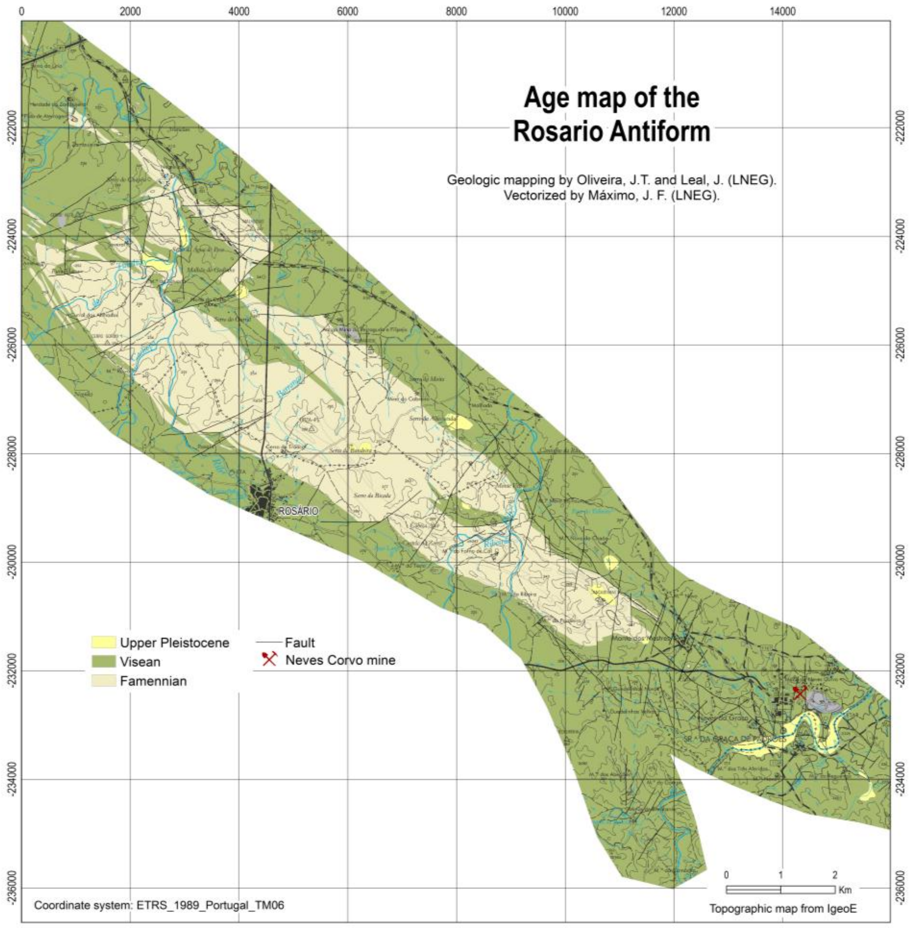


Figure 15: Age map of the Rosario Antiform.



5. CONCLUSIONS AND WAY FORWARD

To comply with the INSPIRE obligations LNEG must harmonise the geological mapping data and then make it available in accordance with the data specifications which will be soon approved by the INSPIRE Committee. The LNEG's need to respond to these requirements was the main reason for which this work has been developed. The main objective of this work was to implement the INSPIRE GE to LNEG digital geological map production. This purpose was successfully achieved and goes further since the INSPIRE GE model was extended in order to meet the requirements of Portuguese geological mapping. The main result obtained was an infrastructure that responds efficiently to the production of geologic maps, constituting a first step towards data harmonisation and inter-operability in the INSPIRE context. Furthermore, it is prepared to incorporate other themes that need to be modelled in the future (e.g. Palinostratigraphy, Geochemistry, Geochronology). Noteworthy, is its integration in a universal and open standard modelling environment, with access to the normatives and requirements of INSPIRE as well as to other UML data models (e.g. GeoSciML). The implementation of the database in the LNEG's spatial data infrastructure also allows the centralized data access by different user profiles making the geological data availability and reuse easier.

The development of the case study allowed to:

- Conclude its feasibility in geological mapping production;
- Contribute to geologic data harmonisation;
- Structure the geologic mapping data from the Rosario Antiform allowing the implementation of the geoprocessing operations in the production of lithostratigraphic, lithologic and age maps.

However, the migration of the remainder geological mapping data to the database will certainly raise some problems regarding the semantic harmonisation whose resolution may include the development of ontologies.

After the approval, by the INSPIRE Committee of the IR regarding data inter-operability specifications for geology, LNEG must provide their geological mapping data within two years for the new recently collected data and seven years for the remainder. In parallel, LNEG should gradually proceed to data harmonisation in order to make it interoperable. Concerning this point, LNEG can use this pilot-project as a basis to restructuring the geologic data model that still is in use with the implementation of the following actions:

- Mapping between tables and attributes from the existing data model and the INSPIRE GE model;
- Adding new tables, attributes and relationships, in accordance with the INSPIRE data specifications;
- Mapping between geological concepts used in the Portuguese geological maps and the proposed in the controlled vocabularies defined by INSPIRE;
- Ensuring the proper registration of specific terms used in the Portuguese geological maps within INSPIRE vocabularies with the creation of unique URI;
- Creating the INSPIRE identifiers according to the rules established by the INSPIRE specifications.

Apart from data harmonisation, INSPIRE also recommends checking data consistency at the following levels that should also be considered:

- Consistency between geological mapping data;
- Consistency of geological mapping data and its topographic base;

- Consistency of geological mapping data at different detail levels;
- Transfrontier data consistency (to assure the coherence between the Portuguese and Spanish geological maps).

ACKNOWLEDGEMENTS

The authors would like to thank Sparx Systems for having extended the Enterprise Architect license making the development of this work possible. Special thanks also goes to José Tomás Oliveira from LNEG who has carefully read and commented this paper and also helped with the translation.

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