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INSPIRE Geology Data Model Implementation in Digital Geological Map Production in Portugal: A Preliminary Approach*

Aurete Pereira[1], Gabriel Luís[2], Pedro Cabral[3]

[1,2]Laboratório Nacional de Energia e Geologia, Lisboa, Portugal;
aurete.pereira@lneg.pt; gabriel.luis@lneg.pt

[3]Instituto Superior de Estatística e Gestão de Informação, Universidade Nova de Lisboa, Portugal; pcabral@isegi.unl.pt

Abstract

This work describes the implementation of the INSPIRE Geology data model (INSPIRE GE) for digital geological map production at the Portuguese Laboratory of Energy and Geology (LNEG). The process of harmonising geological mapping data involves the restructuring of the LNEG's current data model into the extended INSPIRE GE, which aims a more efficient, interoperable and harmonized management data structure. The methodology, which is compliant with the Portuguese geology requirements, was applied to the Rosário antiform, a geological structure located in the Iberian Pyrite Belt. Three maps were produced: (i) a geologic map representing the geological units organized according to their spatial distribution and age; (ii) a lithologic map representing the most important rock types; and (iii) an age map representing the lower boundary age of the geological units. This study improves current LNEG's data structuring and geological map production flow. It also shows that the INSPIRE GE implementation is feasible and that it constitutes the first step toward data harmonization and interoperability in LNEG geological mapping activities.

Keywords: INSPIRE, LNEG, geological mapping, data harmonization, interoperability, GIS, SDI.

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1. INTRODUCTION

Recent advances in communication and information technologies make possible sharing and real-time integration of geographical data through the Internet. The entities that produce geological data have been faced with increasing difficulties regarding aspects such as management, standardization, harmonization, and sharing of data.

In Europe, the Geological Surveys from different countries started working together in 2003 to address these issues under the coordination of the Comission for the Managment and Application of Geoscience Information (CGI) from the International Union of Geological Sciences (IUGS) (Asch et al., 2004). The action of this commission has been guided by the work developed by the Interoperability Working Group (CGI/IWG) (CGI/IWG, 2013), which developed a common geoscience conceptual model that has been the base of the GeoSciML (Geoscience Markup Language) standard (Sen and Duffy, 2005). This standard is a Geographic Markup Language (GML) schema used to transfer information about geology through the Internet that draws on pre-existing geoscience data models, particularly the North American Data Model (NADM) (North American Geologic Map Data Model Steering Committee, 2004).

In a simple and standardized way the GeoSciML describes the basic elements of geological mapping, enabling communication between the databases of several geological surveys without the need to change their original formats and structures (Laxton, 2008). Problems related with semantic harmonization of geological terms and rock classification used in the geological maps were worked out by the Geoscience Terminology Working Group (CGI/GTWG) (CGI/GTWG, 2013), which is building up a controlled set of multilingual vocabularies to be used with GeoSciML.

Recently the OneGeology project adopted the GeoSciML as a standard for on-line geological data sharing among all participating countries (Laxton et al., 2010). The OneGeology-Europe project (1G-E), funded by the European Union, also uses GeoSciML and a subset of the CGI/GTWG terms with specific additional terms for Europe (Serrano et al., 2009). This project, signed by twenty European countries, seeks to make the first freely-available European geological map at 1: 1,000,000 scale through the 1G-E Geoportal (OneGeology-Europe, 2013).

Acting as Geological SurveyTte Portuguese LNEG participates in the 1G-E project with the 1:1, 000,000 scale geological map, and has partially adjusted its database to the GeoSciML. Additionally, the geological terms used were harmonized according to the data specifications defined by the project Work Package 3 (Asch et al., 2010). This action was an enormous challenge to the

Institution as the specific conventions used to describe geological data have been in use for a considerable time (Antunes, C., 2011). Despite these challenges, the 1G-E project promoted the acquisition of new working methodologies and was determinant for the adoption of International Organization for Standardization (ISO) and Open Geospatial Consortium (OGC) standards (e.g. CSW, WMS, WFS), which are used in LNEG's geoPortal (LNEG, 2013). It also raised an awareness of the need for a new standardized and harmonized structure for geological mapping.

The 1G-E project also contributed to the progress of the INSPIRE Directive of the European Union (EU) by testing and evaluating the ongoing design of the geological data specifications, also based in GeoSciML, carried out by the INSPIRE Thematic Working Group Geology (TWG-G). This Directive, which came into force on 15 May 2007, established an Infrastructure for Spatial Information in the European Community (INSPIRE), necessary for sustainable environmental policies (European Commission, 2007). The scope of this Directive focuses on the infrastructures for spatial information that are created and maintained by the 27 Member States (MS) and covers 34 themes distributed in three annexes. To support the establishment of INSPIRE, several required key components were specified through the Implementing Rules (IR) (e.g. metadata, data specifications, network services, data and service sharing, and monitoring and reporting procedures).

On 21 October 2013, the European Commission approved the last IR regarding the themes of annexes II and III, in which the themes related with geosciences were incorporated. This is a milestone for the interoperability of geological datasets in the EU, since every new dataset will have to be compliant by 2015 and every existing dataset by 2020. The IR approval was preceded by the elaboration of data specifications made by the Thematic Working Groups. Regarding Geology, the TWG-G elaborated the geological data specification, including a geology data model (INSPIRE GE) available in the INSPIRE website (INSPIRE, 2013a).

In order to be compliant, LNEG must harmonize the datasets about geological map, mineral resources, energy resources, and natural risk areas. Of these themes, the one related to the geological map, described in the Geology theme from annex II, is the subject of the present work. The geological map data harmonization involves either changing and storing existing datasets or transforming them via publication transformation services in the INSPIRE Geoportal (INSPIRE, 2013b).

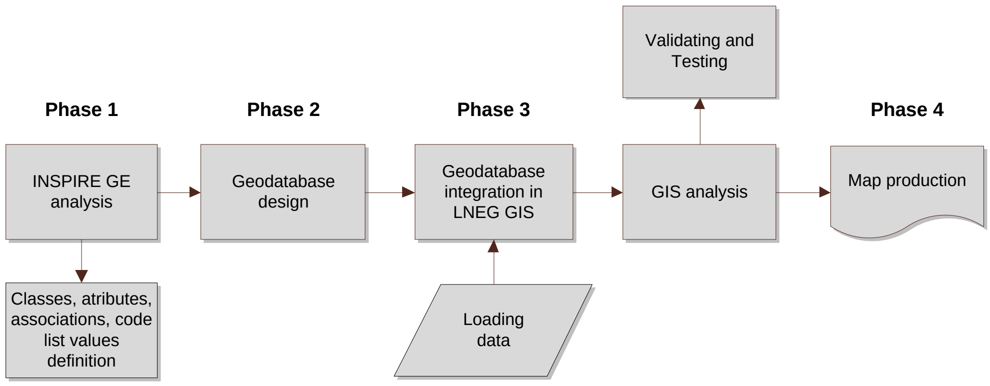
In this work we present a methodology for harmonizing geological data using a case study in Portugal, centered in Rosário Antiform, Iberian Pyrite Belt. It is assumed that the data harmonization of the Portuguese geological maps is possible only with the adoption of the INSPIRE GE model and its extension, which requires changes to the underlying data structures that support its production. Also required is the correspondence between the geological terms used in the Portuguese geologic maps and those included in the INSPIRE code lists, accessible through the INSPIRE code list register (INSPIRE, 2013c). Furthermore, the resulting database must be compatible with the geographical information system (GIS) software currently in use in LNEG (ArcGIS from ESRI) and flexible enough to incorporate other layers. It should also resolve current integrity data problems resulting from the dispersal of the databases in LNEG used in geological map production.

Although this study is supported by LNEG, it should not be construed as this Institution's official position.

2. METHODS

The methodology used in this work included the phases depicted in Figure 1.

Figure 1: Methodological Workflow



In phase 1 a thorough analysis of the INSPIRE GE model and geological data specifications document (D2.8.II.4, version 3.0 rc3) was carried out. In phase 2 a Geodabase (ESRI's ArcGIS data storage format) was designed and structured with the Enterprise Architect software from Sparx Systems and its UML profile for ArcGIS (Sparx Systems, 2012). The geodatabase format was selected because LNEG is currently using ArcGIS software for geological map production. Phase 3 consisted of the implementing the Geodabase in LNEG's Geoscientific Information System, which is based on ArcGIS and Microsoft's SQL Server technologies (a framework that enables the creation of a central data repository for spatial data storage and management). Subsequently, the data about the Rosário Antiform were loaded into the Geodatabase. Phase 4 consisted of validating the Geodatabase, which was done through several geoprocessing operations carried out to produce three thematic maps concerning the Rosário Antiform: (i) a geologic map; (ii) a lithologic map, and (iii) an age map.

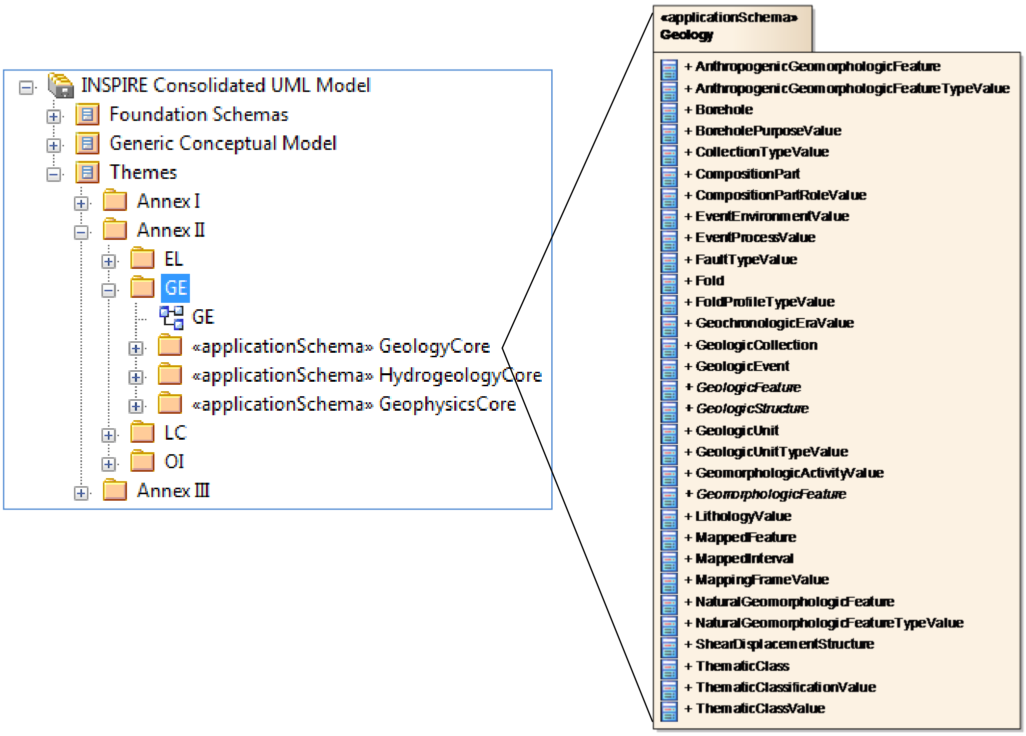
2.1. Geodatabase Design

The Geodatabase design included the modeling of the classes from the GeologyCore application schema included in INSPIRE GE model, shown in Figure 2. This core data model contains the main types of geological features usually included in a geological map: *GeologicUnits*, *GeologicStructures*, and *GeomorphologicFeatures*. The geometry of these features is described in the *MappedFeature* class referring to points, lines, and polygons. The data model also enables the description of the lithological/stratigraphical characteristics of the geological units through associations with *CompositionPart* and *GeologicEvent* classes. The description of the landforms (*GeomorphologicFeatures*), usually not represented on Portuguese geologic maps, were also modeled. The classes *Borehole*, *GeologicCollection*, *MappedInterval*, and *ThematicClass* were not modeled for the time being but they should be modeled in future versions of this work. Figure 2 also shows the domains, which are a special kind of class, whose names include the suffix *Value*.

When creating a new ArcGIS project in the Enterprise Architect, a workspace is defined representing the Geodatabase with three packages: *Features, Domains*, and *Spatial References*. Within the "Features" package, five feature classes were created. The coded value domains were created inside the "Domains" package. The «ETRS_1989_Portugal_TM06» coordinate system was defined in the "Spatial References" package. This spatial reference system was later assigned to the "Features" package.

The «ETRS_1989_Portugal_TM06» coordinate system was chosen according to the INPIRE requirements related with spatial reference systems (Annex II (1.3) from European Commission Regulation N^{o}1089/2010) (European Commission, 2010a).

Figure 2: GeologyCore Application Schema Classes.

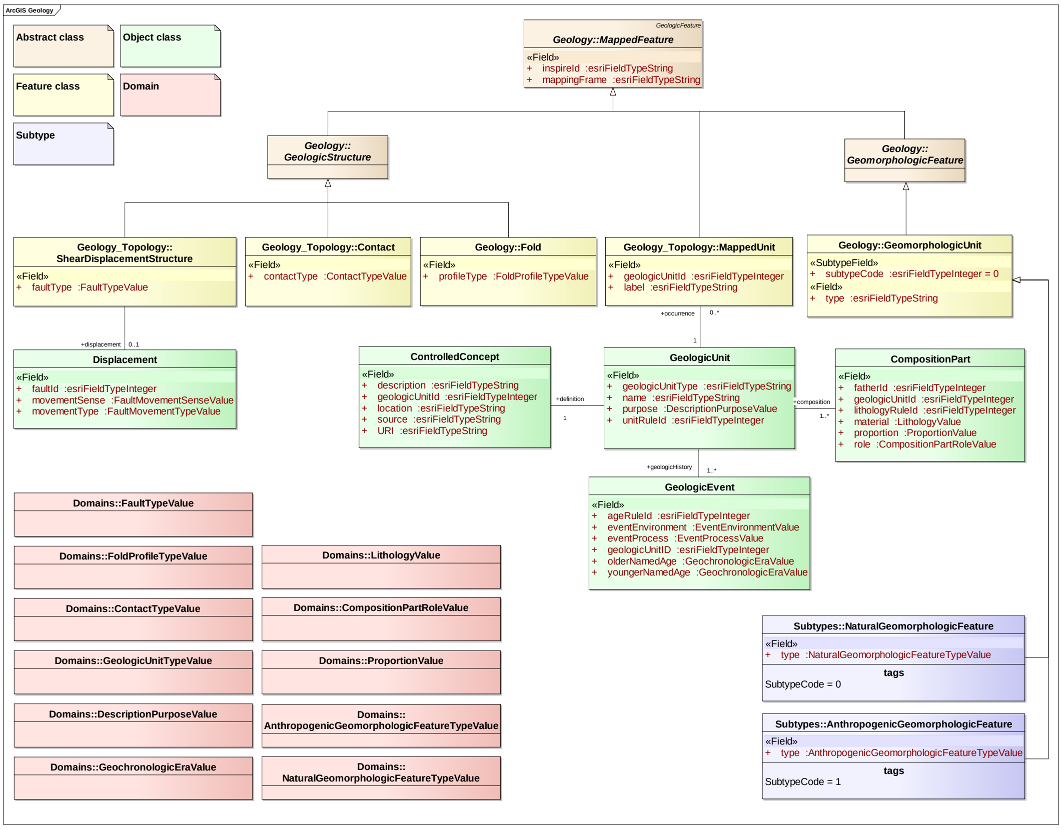


Source: INSPIRE Thematic Working Group Geology, 2013.

Figure 3 shows the diagram of the Geodatabase designed in Enterprise Architect, with its main classes, attributes, and associations. The abstract classes are represented with the brown color, the feature classes are in yellow, the subtypes are in blue, the object classes (Tables) are in green, and the domains (Coded Value Domains) are in pink. Some key-elements for interpreting the diagram of Figure 3 are the following:

- All feature classes have an INSPIRE identifier attribute (*inspireId*), for the external spatial object identifier (a requirement from Article 8 (2)(a) of the INSPIRE Directive) (European Commission, 2007);
- All classes have an internal numeric identifier (ID) corresponding to the primary-key;
- The UpperCamelCase and lowerCamelCase conventions were adopted. The former for designating the classes and associations, the latter for attributes and classes' roles on the associations;
- Whenever possible the extensions to the core data model were made using the GeoSciML v3.1 (recommendation number one from the TWG-G) (INSPIRE Thematic Working Group Geology, 2013).

Figure 3: Geodatabase diagram in Enterprise Architect.



The geological units are related with the mapped units in a one-to-many association. The geological structures include three feature classes: *ShearDisplacementStructure, Fold*, *and Contact.* The *Contact* class is an extension to the core model and represents the geological contacts. Graphically it corresponds to the lines that involve each of the polygons of the mapped units. The cartographic representations vary according to the type of contact (*contactType*) (e.g. stratigraphic, intrusive, gravimetric, tectonic) between the geological units. The *ShearDisplacementStructure* class includes the faults. The geologic map faults are represented by lines with different cartographic representations depending on the type of fault (e.g. reverse fault, thrust fault, strike slip fault). The faults are also characterized according to the cinematic, thus the *Displacement* class was added. The *GeomorphologicFeatures* includes geomorphologic units represented by polygons, lines, and points. In this paper only the geomorphologic units of polygon type (*GeomorphologicUnit*) were modeled and these were divided into two subtypes: *NaturalGeomorphologicFeature* and *AnthropogenicGeomorphologicFeature,* to distinguish natural relief forms from those originating through human intervention.

The geological units were associated to a controlled vocabulary (*ControlledConcept*) that contains additional information about the geological units, namely the place where it was defined (*location)*, the bibliographic reference (*source*), a free description (*description*), and a URI (Uniform Resource Identifier) to identify each geological unit on the Internet. The *ControlledConcept* class is an extension to the core model.

The *CompositionPart* class contains a descriptive field of the lithological constituents (*material*) of the geological units, its role (e.g. only part, part of, facies) and proportion (e.g. all, dominant, major, subordinate, rare). The *lithologyRuleId* attribute to hold each lithology cartographic representation rule was added as well as the Father identifier (*fatherId*) to represent hierarchy between the lithology terms. The material values are constrained by the *LithologyValue* domain. The allowed values for this domain comprise the values specified by the TWG-G (Annex C of D2.8.II.4_v3.0 document). However, this domain is of type "open", meaning that it can be extended if a term is not yet available. Any new values added should be made available in the INSPIRE code list register (INSPIRE, 2013c).

The *GeologicEvent* class contains the attributes for describing the age of the lower boundary (*olderNamedAge*) and of the upper boundary (*youngerNamedAge*) of each geological unit. The *ageRuleId* attribute was added to hold the cartographic representation rule of each lower boundary age. The terms for describing the ages are constrained by the domain *GeochronologicEraValue*. This domain is controlled by the International Commission on Stratigraphy of the IUGS, and the allowed values are those specified in the International Chronostratigraphic Chart (Cohen et al., 2013) and the extended values for the Pre-Cambrian rocks and Quaternary units that were defined by the TWG-G (INSPIRE Thematic Working Group Geology, 2013) based on the experience from the 1G-E project.

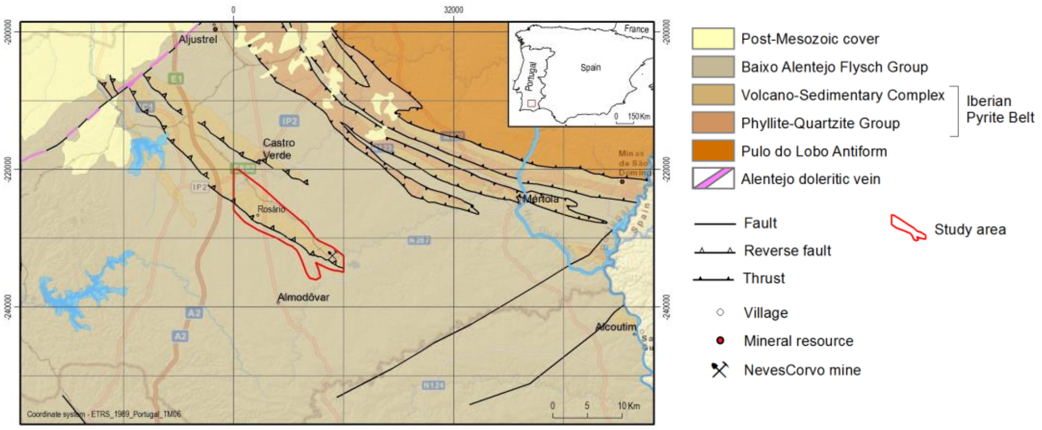
3. CASE STUDY

The Rosário Antiform is a geological structure that belongs to the Iberian Pyrite Belt, located in the Castro Verde municipality of Alentejo, in Portugal (Figure 6). This structure was selected to serve as the case study for the following reasons:

- The region covers approximatelly 100Km^2, and is well studied because of its high potential in base metals. At the southeast of this geological structure is located the Neves-Corvo mine, a major copper producing mine in Europe;
- The datasets were available in the ESRI's shapefile format, making it interesting for the implementation of INSPIRE Directive; and
- This area belongs to Sheet 46C - Almodôvar of the Geologic Map of Portugal at 1:50,000 scale, which is currently in the phase of production by LNEG.

The Geodatabase XML file obtained in 2.1 was imported directly into the GIS. It was then uploaded with real geological data and several geoprocessing operations were carried out to produce the geological maps. The geological data at 1:25,000 scale of the Rosário Antiform were used (Oliveira et al., 2013).

Figure 6: The Rosário Antiform, Outlined in Red Inset Shows the Location of the Study Area in South Portugal.



Source: adapted from Geologic Map of Portugal scale 1:1,000,000, LNEG, 2010.

3.1. Data Harmonization

In the pre-existing data structure, the lithological/stratigraphical characteristics of the geological units of the Rosário Antiform were described in a single attribute table which was then associated with each of the mapped units through a *join* operation. In this work this table has been divided into two classes: the *CompositionPart* for lithological description of geologic units and the *GeologicEvent* for ages. These two classes were associated with geological units using one-to-many type associations.

The semantic data harmonization consisted of mapping the correspondence between the Portuguese and English geological terms. In general, this was a straightforward process because of the small area of the case study. Nevertheless, some of the terms had to be adapted to the most generalized term of the INSPIRE lithology code list. For example, "jasper" and "chert", two rock types that occur in the area, were classified as "non-clastic siliceous sedimentary material". Some fields could not be populated since they have not yet been defined, e.g. the URI of geological units.

The fault traces were aggregated into fault segments and the type and sense of movement was inferred.

3.2. Results

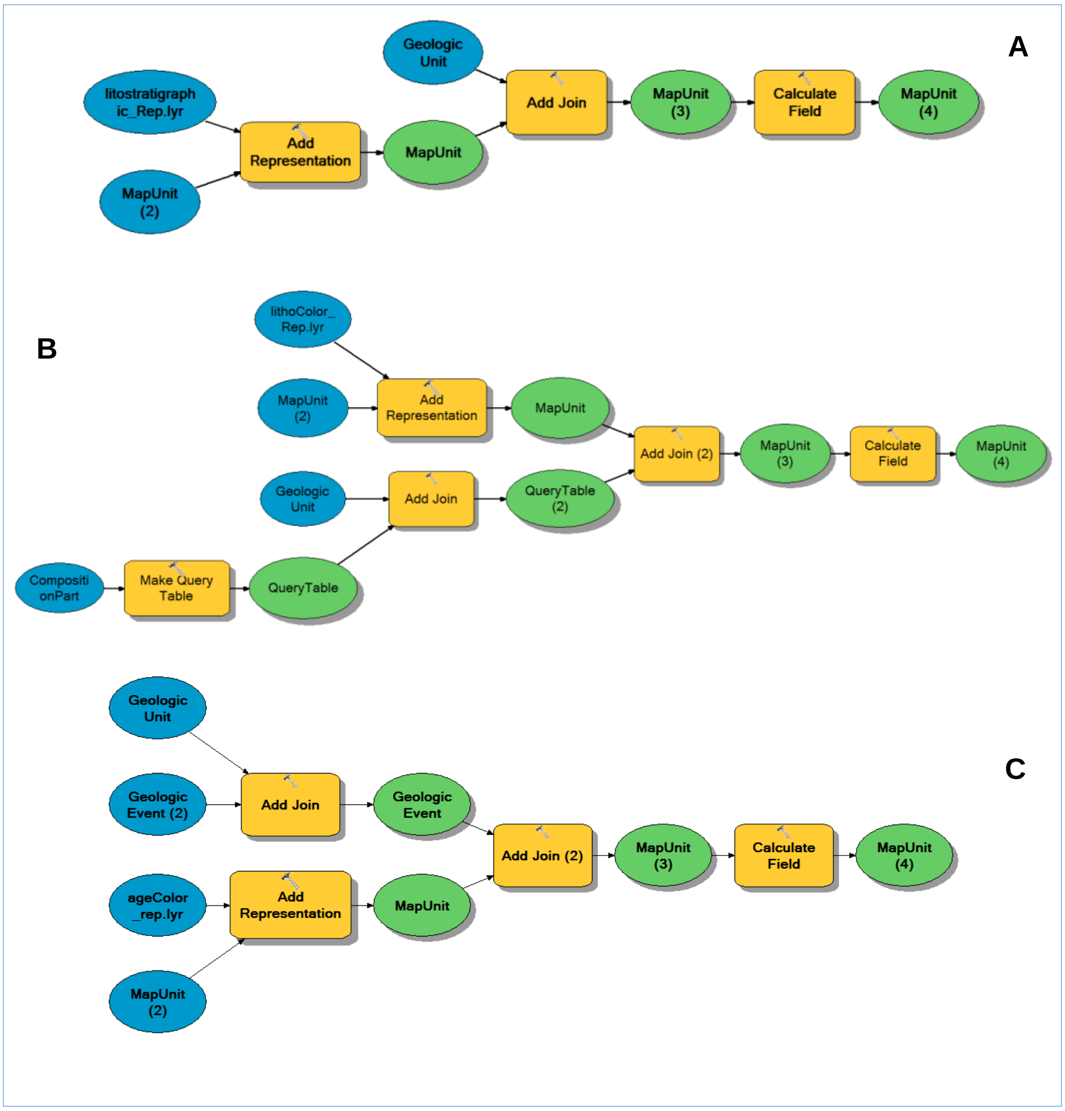
Three models were developed in ArcGIS ModelBuilder for the production of the geologic, lithologic, and age maps (Figure 8). These models used geoprocessing operations for the automatic calculation of three cartographic representations, one for each type of map. The ArcGIS *Add representation* tool was used for creating different types of thematic maps. The symbols used in the lithological and age maps were defined according to the INSPIRE geology data specifications (section 11.3.1 and 11.3.2) (INSPIRE Thematic Working Group Geology, 2013). For the geological map, the selection of the symbols was made using the following documents:

- ISO 710/II:1974 Representation of sedimentary rocks and ISO 710/III:1974 Representation of magmatic rocks;
- Color codes according to the Commission for the Geological Map of the World (CGMW, 2013); and
- Digital Geological map production standards LNEG's Catalog (Cunha T., 2008).

The operations shown in Figure 8 are the following:

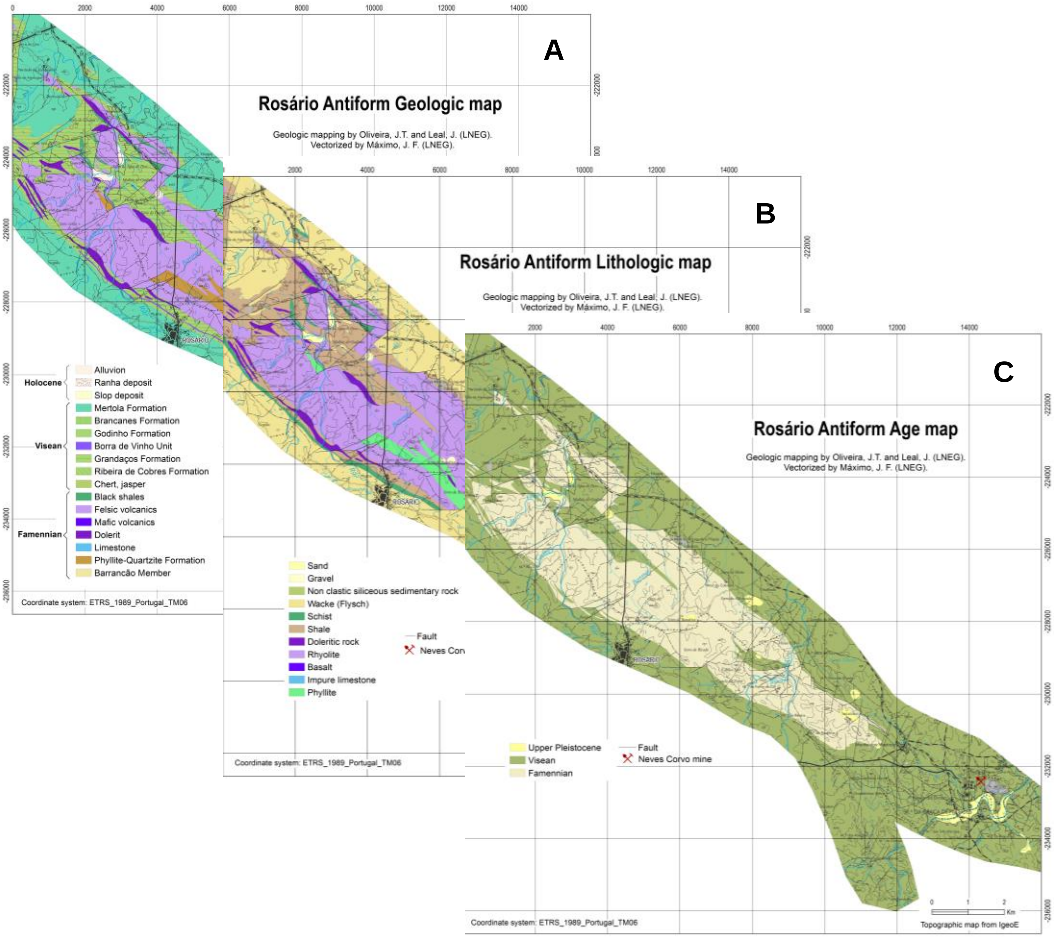
- *Add representation* tool, by importing previously created symbol files (lyr files). This operation was executed three times in order to add the three different types of cartographic representations to the mapped units;
- Population of the cartographic representation rules for geological units, lithologies, and lower boundary ages: *unitRuleId*; *lithologyRuleId*; *ageRuleId*;
- *Join* and *Calculate Field* operations, to obtain the geological units representation rules (Figure 8A);
- *Join* and *Make Query Table* and *Calculate Field* operations, to obtain the "all", "dominant" and "major" lithologies' representation rules (Figure 8B);
- *Join* and *Calculate Field* operations, to obtain lower age boundaries representation rules (Figure 8C).

Figure 8: Model Builder Models Used to Calculate the Cartographic Representation Rules for: (A) Geologic Map; (B) Lithologic Map; (C) Age Map.



The geological maps represented in Figure 9 were obtained in ArcGIS, after selecting the appropriate cartographic representation.

Figure 9: Rosário Antiform Maps: (A) Geologic; (B) Lithologic; (C) Age.



4. CONCLUSIONS

The proposed methodology answers effectively to the goal of the study. Its future implementation in the production of geological maps will enable the reformulation of the current working procedures and benefit the users of geological data. The Enterprise Architect software enabled the automatic generation of the data structure to be used in ArcGIS. This made possible its improvement using an iterative approach in an open standard modeling environment according to the INSPIRE requirements. Other advantages include:

- Compatibility with the GIS that supports the production of geological maps;
- Data integrity assurance because it is stored in a centralized management environment;
- Effective data structuration improvement in a production environment;
- Facilitation of geoprocessing operation due to the new data structure;
- Interoperability and reuse of geological data in map production.

Although the developed Geodatabase is compliant with the geological data specifications, the IR from October 2013 should still be verified by applying the guides from the Abstract Test Suite (Annex A from D2.8.II.4_v3.0 rc3 document) (INSPIRE Thematic Working Group Geology, 2013). Moreover, the use of a small study area oversimplified the problem addressed in this work. However, the future migration of the remainder of the geological map data will certainly raise new challenges regarding the semantics, and may include the development of ontologies (e.g. Ludascher et al., 2003; Woodcock et al., 2010, Ma et al., 2012).

Future work will include the specific Portuguese geological terms in the INSPIRE list of values and the creation of the external object identifiers (*inspireId*). Data consistency between 1:50,000, 1:200,000, 1:500,000, and 1:1,000,000 scales (used in LNEG map production) and in border regions should also be ensured (INSPIRE Drafting Team Data Specifications, 2013). The network of services to search, view, and download geological maps should be created/updated according to the INSPIRE requirements (European Commission, 2009; 2010b) and published on the INSPIRE GeoPortal to enable worldwide users to access and use Portuguese geological datasets. Some of these services may be charged according to the LNEG's data policy and, for these cases, e-commerce services should also be created.

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