GEOHERITAGE AND GEOSITE DATA REPRESENTATION: AN ONTOLOGY DRIVEN PERSPECTIVE

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Summary

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Abstract

Geoheritage is recognized by UNESCO as part of the (natural) cultural heritage. It is the part related to the history of the Earth, and a representation on how the processes acted (and act) to change our planet. The tangible and intangible characteristics of cultural heritage also apply to geoheritage: the tangible features are the rocks, the landforms, the water bodies, and all that appears on the Earth surface; the intangible features are the processes and the events that created the tangible features. There are several theories and criteria to select the elements of the Earth that are worthy to be considered as “geoheritage”, among the countless elements of the abiotic nature, which accounts for geodiversity. Most of these criteria are based on the recognition of the relevance that a given element has for humankind. However, these theories do not reach an agreement in the attribution of the geoheritage status to elements of geodiversity. Generally, national institutions bypass this problem focussing on the representation of the geosites, which are locations that feature some elements of geodiversity, which is of interest for the local communities and institutions. The result is that it may be difficult to compare data of sites and elements that are managed by different institutions.

This thesis addresses information and knowledge about geoheritage features. Our aim is to propose a representation method of the data about geosites and elements of geoheritage that, on the one hand, enhances interoperability among the geosite data, on the other hand, offers a tool for decision makers (e.g., managers of national/geoparks) when there is the necessity of acting toward programs of protection of the most relevant features.

Our method is based on the design of a semantics driven database to host the information about the elements that compose the geosites (elements of geodiversity). We provide a complete and coherent representation of the information about the geodiversity elements, grounded on ontology-based relations and controlled vocabularies, on which is furtherly built the representation of the geosites.

We start from a review of the literature about geodiversity, geoheritage, geosite, focussing on the main concepts that are relevant for their description. In particular, we introduce a value-interest system to implement a characterization of geoheritage and geosite. Leaning on pre-existing ontologies, we design an ontology driven database for the representation of the geodiversity data, as well as an interface tool for the collection of data. The interface, tested by international testers (from Italy and Poland), will apply the approach to some groups of relevant case studies. Finally, discussion and conclusions will underline the novelties of this method with respect to the present situation and propose new perspectives of knowledge representation for geoheritage.

CHAPTER 1

INTRODUCTION

In this chapter we overview the general concepts and activity related to the present thesis. In particular, we will introduce the concept of Geodiversity, Geoheritage and Geosite, along with the criteria for the assessment of their importance, and the representation of their data. On this brief overview we present the issues that ground our research questions. Finally, we present the material and methods used to approach the questions and to achieve our proposed model.

1.1 - INTRODUCTION TO THE CONCEPTS OF GEODIVERSITY, GEOHERITAGE, GEOSITE

The main concepts on which this work is based deal with a specific frame of the geosciences, i.e. the exploration of some groups of elements of the geosphere that are considered of a special importance for the humankind, which are elements of geoheritage, and their occurrence in the territory, i.e., the geosites. In order to define and study these concepts, it is essential to first introduce the concept of geodiversity, on which they are based and to which they are closely related. In this section we briefly present these concepts in order to introduce the global framework and theoretical bases of this work. Anyway, the concepts of geodiversity, geoheritage and geosites will be treated in more detail within chapter 2, State of the art.

Geodiversity is defined as “The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems, and contributions to landscapes” (Gray, 2013). It is an intrinsic characteristic of our planet, both at a global and at a local level, and the essential base for all life on the Earth. In fact, along with biodiversity, geodiversity is a component of natural diversity (Brilha, 2018), representing the biotic and abiotic elements of the natural environment, which are very closely related (Tukiainen et al., 2022).

To underline the importance of geodiversity, Gray (2013) hypothesized a “non-geodiverse” planet, made by only one type of rock, a quartzite, and with no processes, e.g., plate tectonics. Geometrically, it is a perfect sphere. This also influences the weather, which is uniform. This general uniformity would present some advantages: no geologic hazards like earthquakes or landslides, no reliefs to cross, easy prediction of the ground conditions. However, it would be a very big obstacle for the development of every form of life, among which the humans. Uniform surface processes acting on a uniform bedrock would mean a very uniform soil; adding the lack of reliefs (no altitude climate variation) this would mean that a very few animal and plant species would develop. No metals or building material are present, the only material is the quartzite which is very hard to model. About the energies, no coal or oil are present in the crust, and the surface processes are limited (no energy from streams or wind). Probably, humankind would not exist or would be strongly primitive. This dystopian planet offers no resources for a hypothetical society; this is the opposite of the real Earth, rich in resources and benefits for life and society. These benefits are identified and described as the Geosystem Services (Gray, 2008; Gray at al., 2013, Webber et al., 2006); more detail in section 1.2, and Chapter 2. Mostly, the Geosystem Services are benefits deriving from the existence of geodiversity; the Ecosystem Services (Reid et al., 2005) are the benefits derived from the existence of the ecosystem and biological diversity. Finally, geodiversity has high relevance in some cultural and recreational activities, such as the geotourism. In fact, according to Gray (2018), several geoparks promote themselves by presenting the geodiversity of their territory. For example, the Gea Norvegica Global Geopark (Norway) hosts a very diverse range of geodiversity elements, reported as examples in many textbooks of several geoscience disciplines (Dahlgren, 2006).

Some elements of geodiversity are considered of special importance for some people (e.g., nations, local communities, …); these special elements are called geoheritage. The importance of geoheritage is acknowledged by numerous scientific papers and by UNESCO, which specifically includes geoheritage within the definition of the natural heritage. Geoheritage comprises those parts of geodiversity that have special significance or value for a given group of people. As widely explained in Chapter 2, the concept of geoheritage can be related to many definitions and interpretations, but the most common term is the direct relation with the geodiversity: in fact, geoheritage is described as elements of geodiversity of particular importance, usually referred to as "values". As stated by Gray (2018), geoheritage is part of the known geodiversity: it will thus increase as new elements of geodiversity are found and identified as being of particular value. Vice versa, geoheritage can be lost if damaged; it is thus very important to correctly identify elements of geoheritage, in order to apply the proper preservation policies. As clearly specified by Pescatore et al. (2023), not all the recognized elements of geoheritage stand into protected areas (e.g., national parks and other natural reserves) in which they will be subject to special protection rules established for the area. Hence, some special efforts should be planned for the conservation of geoheritage; this is called geoconservation. The concept of geoconservation, first defined by Legge and King (1992) as "*protection of significant geological and landscape features because of their scientific, educational, research, aesthetic and inspirational value to humans*". This definition addresses geoheritage, as it refers to special elements with some values that correspond to the values that are cited for geoheritage.

When considering special elements of geodiversity, or elements of geoheritage, there is no reference to its location. A rock outcrop is an example of in-situ geodiversity element (geoheritage, if it is particularly rare or relevant); a sample of the same rock, or maybe a fossil that was preserved in the rock itself, extracted from the outcrop and exposed in a museum display case is an ex-situ element of geodiversity/geoheritage. The in-situ elements of interesting elements of geodiversity, namely those that are in the place where natural processes have created or placed them, are called geosites. The definitions of geosite relate them more or less directly to the concept of geoheritage; in fact, some of the definitions are based on the recognition of a geological interest on the elements that are present in the territory that is indicated as a geosite. However, in literature, the relation between geoheritage and geosite is very strong. Indeed, when inventorying the geological heritage of an area, or a nation, it is usual to create inventories of the geosites.

As briefly presented in this section, these concepts are closely interrelated, and everyone is important for the description and the assessment of the others. However, the multitude of definitions for each concept leaves some space for ambiguity when coming to indicate if a given element is geoheritage, or a given area a geosite. Each of these concepts has its own evaluation criteria (deepened in the next section, 1.2), that has, again, some level of variability. This will be the starting point of the present research, with the goal of discussing in detail the relation between these concepts, their evaluation criteria and finally propose a method for their representation in a coherent and unambiguous system.

1.2 - EVALUATION OF THE IMPORTANCE OF THE ELEMENTS OF GEOHERITAGE AND OF THE GEOSITES

Many efforts are documented in literature for the description and the assessment of the elements of geodiversity, geoheritage and of the concept geosite. In fact, for the assessment of some elements as geoheritage or the definitions of a geosite, it is of crucial importance to establish why they are important. As evidenced by the definitions and the numerous inventories reported in the literature, there is one descriptive type of importance for each of these elements (geodiversity, geodiversity, geosite).

Geodiversity is the diversity in our abiotic environment (Gray, 2013). It is a characteristic of our planet, something that is the direct consequence of the existence of so many different elements in our geosphere. This aspect is intrinsically important, but there is a more detailed system for the description of the benefits that the humans receive from the existence of the geodiversity: this is named geosystem services (Gray, 2013, 2019). The idea comes from the system services of biotic nature, designed for the description of how the biosphere influences and supports human society (Reid et al., 2005). Several authors, first of all Gray (2008), noticed that this system of description of the services was easily applicable to the geosphere. In fact, some of the services that are indicated by the Millenium Ecosystem Assessment (MEA), Reid et al. (2005), are directly related to elements of the geosphere, while others can be seen both from the point of view of the biotic and abiotic nature. For example, the regulating services, about the control of the climate or the control of water quality and quantity, are strictly related with the elements of the abiotic nature. Similar considerations apply to the cultural services. Despite this deep relation of bio- and geo-spheres in the contribution to the ecosystem services, the scientific literature reports that the abiotic elements are not considered in the description of the services (Kubalíková, 2020). From this base, the geosystem services, consisting of 25 types of services classified into 5 groups (namely provisioning, regulating, supporting, cultural, and knowledge) describing how the elements of geodiversity can be a benefit for the humankind, and how they can contribute to the wellbeing of the society. For example, the regulating services concern the control of the climatic events that influence the life of humans, as well as the life cycle of the cultivation that is meant to become food, or the cultural and knowledge services that concern the intellectual and spiritual life of humans. Such elements can have a contribution in the intellectual and spiritual growth of the single person or of a community. More detail on the Geosystem Services in Chapter 2.
Hence, through the geosystem services it is possible to identify the elements of geodiversity that are important for human society and the reasons for this importance. The direct consequence is the application of geoconservation practices, to protect the environment and the life on our planet. All the elements of geodiversity are important for the environment, but some of them are essential for the society, towards which they have a key role, and deserve special care.

Geoheritage has a different indication of the importance; this is addressed as "value", i.e., the value of a given element of the geodiversity. While the attribution of a value is a generally accepted criterion, the proposed lists of values are different. The main values that recur and are in common are the Scientific, Aesthetic, Cultural and Educational; an element of geodiversity to which one of these values is attributed can be considered part of geoheritage. For example, the Ayers Rock (Fig. 1.1), Uluṟu-Kata Tjuṯa National Park, Australia, is a particular type of landform, named inselberg (or island mountain); it is a prominent isolated residual knob that rises abruptly from the extensive surroundings of flat lowlands (Hilario et al., 2022). This element, that is clearly distinguishable in the landscape, has a value from the scientific point of view, due to the witness of the geological processes that operated in the area in the Precambrian age. Along with the scientific value, this element of the local geodiversity has also a very important role in the spiritual life of the local community, the Aboriginal people, who consider this relief as a sacred mountain deeply integrated in their folklore and enriched with rock paintings. This attributes a cultural value to the element.
Hence, some elements of geodiversity have a value for someone (person, community, …): that value makes an ordinary element of geodiversity to achieve the geoheritage status (Brilha, 2018).

Figure 1.1 - “Uluru from a Helicopter”, photo by Corey Leopold[1]

To the geosites, a third way to express their importance is applied. In national inventories, as well as academic publication, the geosites are always associated with their “interest”. Usually, the interests are differentiated in *scientific* interests, which concern the disciplinary fields that study and describe the elements that are visible in the geosite, and *contextual* or *other* interests, which are the other interests that can be associated in addition to the scientific ones. For example, the area with Ayers Rock is considered a geosite, with a scientific interest due to the unusual landform that the monolith represents (the inselberg) and with a contextual interest, due to the spiritual beliefs of the local community. As for the values, there are several groups of interests that are used by the different institutions that worked on a geosite inventory, but generally for the scientific interests, they refer to the main disciplines of geoscience. For example, Tab. 1.1 collects all the scientific interests that Hilario et al. (2022) used for the characterization of the 100 first geosites in the world.

The three main concepts that are deepened in this work, namely geodiversity, geoheritage and geosite are highly related, but as discussed in this section they are evaluated and marked following different criteria of evaluation: geosystem services for the geodiversity, values for geoheritage, and interests for the geosites. Despite the strong relation between the concepts, highly explored in the literature (see chapter 2), the relation between interest and values within the geodiversity/geoheritage is only discussed by Díaz-Martínez and Fernández-Martínez (2015).

[1] Photo from https://www.flickr.com/people/97708873@N00; Licence cc-by-2.0 https://creativecommons.org/licenses/by/2.0/deed.it

Engineering Geology	Geothermal	Palaeontology
Geoarchaeology	History of geosciences	Petrology
Geobiology	Mineralogy	Stratigraphy and sedimentology
Geochronology	Volcanology	Tectonics
Geomorphology and active geological processes	Igneous and metamorphic petrology	Impact structures and extraterrestrial rocks

Table 1.1 - Identified interest in Hilario et al. (2022)

1.3 - WORKING METHODOLOGIES ON GEOHERITAGE AND GEOSITE REPRESENTATION

When aiming at describing the cultural heritage of a given region, or nation, the most direct and used reference is the heritage sites, which are cultural and/or natural sites considered to be of "Outstanding Universal Value" and have been inscribed on the World Heritage List[2]. Similarly, when describing the geological heritage of an area, or a nation, the materialization of this heritage passes through the presentation of the local geosites (Prosser et al., 2018), which are usually collected into inventories. Several studies and consequent design of inventories are testified by works in literature or online, related to different areas. For example, the Chablais geopark presents an inventory of 85 geosites[3] that were assessed by following a method inspired by Reynard et al. (2007) and De Wever et al. (2006), using as main criteria Geological / Paleogeographic value, Integrity and preservation, Rarity and representativeness, educational value, and as additional criteria the Ecological value, Aesthetic value and Cultural value. The Chablais geopark, however, is included in a wider area of the southern France, named Auvergne-Rhône-Alpes, which has in time a geosite inventory[4] which contains some of the geosites which are inventoried for the Chablais geopark only.

A similar situation involves the Sesia Val Grande UNESCO Global Geopark. On the website, 34 geosites are listed and described[5]. Vice versa, checking the Italian national inventory of the geosites[6] a much lower number of sites is marked on the map for the area of the geopark.

These are two examples of how the geosites are the operative part of the description of the geological heritage of a given area. However, this heritage "changes" at different scales. In fact, as reported by de Lima et al. (2010) a geosite inventory should first of all be designed after precise aims, values and use. For example, Brilha (2016) proposes a method for the assessment of the geosites, which is somehow different depending on the dimensions of the area considered. In particular, two operative guidelines

[2] https://whc.unesco.org/en/list/

[3] Geosites of the Chablais Geopark: https://www.geoparc-chablais.com/en/science-and-research/the-geosites-inventory/

[4] Geosites in Auvergne-Rhône-Alpes https://www.auvergne-rhone-alpes.developpement-durable.gouv.fr/les-geosites-en-auvergne-rhone-alpes-a10155.html?lang=fr

[5] Geosites in Sesia Val Grande Geopark http://www.sesiavalgrandegeopark.it/index.php/it/geologia/geositi

[6] Geosites in Italy https://sgi.isprambiente.it/GeositiWeb/

are defined for areas which are minor or major of about 3-4000 Km^2, more or less the average area of a municipality or a protected area, which can be the object of a cheap and fast field survey. In fact, the field work is an important step of the geosite assessment, a step that comes immediately after bibliographic research. After the fieldwork, during which the preliminary list of sites is modified and/or confirmed, and several information are registered, the final part is the assessment of the scientific value and the degradation risk, aspects that are mostly assessed during office work (in case, enhanced by other fieldwork), following lists of criteria for attribution of points to several key aspects.
This path of assessment aims at describing the geosites from the point of view of their usage, e.g., for scientific purposes as examples of natural abiotic elements or processes.
This overview shows that there are several models for the geosite inventory. The choice of one or another depends on the aim of the work; everyone proposes a self-coherent way of representing the geosites of the studied area.
We also have a plethora of models for the geological description of the geosites. Although geological frameworks have been established since the 1980's (Erikstad, 2008; Wimbledon, 2011), we can notice that several national inventories (see details in Chapter 2) manage the geological description of the geosites in different ways. For example, in some inventories the most of the knowledge is addressed in a textual format (for example, the Italian geosite inventory has the most part of geological information contained in text files attached to the online forms), while in some cases there is a more structured infrastructure for collecting geological data (e.g., the Polish database form has several fields filled with controlled vocabularies, plus a text field). This shows a high variation of geological data collection and management that ends up leaving more space, in the geosite data description, to other aspects, like the geographical data or the usage data, which are usually more structured than geological data. As we will deepen later, our aim is to act in this framework, proposing an integrated model to represent the geological information of the geosites.

1.4 - ISSUES, OPEN QUESTIONS AND GOAL OF THE WORK

As we will see in the next chapter (2, State of the art), there are numerous definitions of these concepts, as well as assessment methods and guidelines for the attribution of an element to one of these categories (geosite and geoheritage, in particular). The consequence is that, both in literature and in a law context (from local to international), there is no uniformity in considering what is geoheritage and how to act for its conservation. In fact, this is a delicate issue under discussion in literature, which regards geoethics and the difficult decision on what is the right balance within the use of geoheritage elements and resources and the way of conserving them for the future generations. Also, from the point of view of the general audience, it must be noticed that the importance of geoheritage and geodiversity in general is not popular among the non-scientific communities, who are much more aware of the importance of biodiversity and climate. For example, organizations like WWF, and their awareness campaigns about the threat of extinction of many species (like the pandas), have a great impact on the media. Similarly, in general, people are concerned with the climatic variations and the impact that the climate has on human life. Usually, very little is told about the crucial role that geodiversity has in these matters, being the basis of the biodiversity on Earth, as well as the climate control (Kubalíková, 2020).
A very important issue that deserves some discussion is the lack of a common point of view in the identification of the elements of geoheritage. In fact, many different models are proposed for the

identification of the elements of geoheritage, mostly related to the attribution of a value to the elements. However, the lists of values and their importance only partially overlap. We lack a systematic approach, in particular, if we need to coherently identify what is and what is not geoheritage (or geosite). This is particularly relevant in inter-regional or international contexts: every region, nation, or group of experts apply different methods for the inventory of geoheritage and geosites. The result is that data about similar features are not comparable and interoperable. This issue is much more evident if we look at the management of the data about geosites. In fact, many institutions like nations, localities, national parks or geoparks have their own method of selection and representation of the geosites. On the web, it is possible to find several national geosites viewers, with interactive maps and databases, but we can notice how the knowledge is differently managed (as discussed in section 1.3). The consequence is that if we need to compare data about international geosites, we need to apply a huge effort of documentation and manual inferences and research. Automatic research and comparison will be exceedingly difficult. In a world that is increasingly based on digital management of data, this aspect yet needs to be improved.

As a conclusion, we can formulate a general research question and goal of the work; given the strong relation, acknowledged in the field literature, between geodiversity, geoheritage and geosite:

- can we evaluate this relation exploiting semantic and ontological studies, and can we model this relation in a rigorous way, avoiding ambiguities?
- Can this model support a system for the organization of the knowledge about the geoheritage and geosites?

The grounding hypothesis of the present work is that coherent definitions and models of these three concepts should be of great support for the management of the geological heritage of an area.

Hence, this thesis will deepen these concepts and propose a grounded method for the collection and representation of the information, also offering practical tools that are meant to support the management of the data in a multidisciplinary context.

- First, to support the geoscientists by offering a coherent knowledge encoding in which they operate.
- Second, to support the institutions (nations, regions, local public entities, geoparks or national parks…) in the management of the geological information about natural reserves.

A practical tool will be designed and tested to support such target users (researchers and managers) in achieving a harmonic and homogeneous representation of the knowledge, with a consequent improvement of the information access (search and queries options).

The major impact should be recorded in the comparison of data context, for example, in searching information for similar features, both at a local scale and at international scale. A side effect will be the improvement of the machine-readable aspects of the organization of the knowledge, by representing the geological data of the geosites.

1.5 - MATERIAL AND METHODS

In this section, we summarize the operative steps of the present research that will be furtherly deepened in the chapter of this thesis.

1.5.1 - Methods: operative steps

This research requires the articulation of a path consisting of several steps, some dedicated to a theoretical study, others the development of ontologies and further design of databases and prototypes of applications for collecting data on geosites. Also, some field activity is performed on the one hand to know in person the case studies, on the other hand to test the system on the field. In this section we are going to resume the operative steps.

Semantic studies

The first and basic step of the present research is the semantic studies of the main concepts of the research, with the goal of achieving a deep knowledge of their meaning and creating a base for a coherent representation. This aspect (that will be deepened in chapter 3) is the basis for the following steps. This aspect of the work concerns the theoretical study of the concepts, based on the deepening and comparison of the definitions that are present in literature. In fact, through the semantic studies, a coherent relation between the concepts is underlined and made explicit, both for the concepts in themselves, and their evaluation indices (the geosystem services, the values, and the interests respectively for geodiversity, geoheritage and geosites). The semantic studies address how these elements are related and cooperate in the description of the geological elements and heritage of the humankind.

Encoding of the knowledge

Once established a coherent relation between the concepts, we make the newly achieved knowledge explicit through an ontological representation, with the encoding into axioms of the concepts. With ontological representation, it is possible to represent in an unambiguous and explicit way the hierarchies of the concepts and their mutual relations. This is possible due to the creation of axioms, which are formulas containing the necessary and sufficient conditions that a given item must have to be included in a given group of items (which are called classes). The axioms are made of hierarchical indications (indicating which super classes subsume which subclasses) and properties that can connect transversally classes to other classes or particular items.

One strength of the ontological representation is the possibility of leveraging previously encoded areas of the knowledge. In our case, we are dealing with geological elements; so, an ontology for geoheritage and geosite relies on an ontology for the description of the geological elements, namely OntoGeonous (Lombardo et al., 2016, 2018). Recovering previously encoded knowledge is very important for several reasons. First, to avoid repetitions of the description of the knowledge, an aspect that would lead to incoherences in the data processing. Second, to exploit the facilities of the Semantic Web (Berners-Lee et al., 2001) and Linked Data paradigm (Bizer et al., 2009), which allows for a machine-readable representation of the knowledge and connection to all the encoded knowledge.

We are going to encode the concepts of geoheritage, geodiversity and geosites, leaning on the preexisting encodings in the linked data cloud, with special care on their mutual relation (are they

sibling concepts, or, are they in a parent-daughter relation? Is their relation established by a property?). A relevant part of the encoding work was devoted to the relation between the interest, which describe the geosites, and the values, which describe the geoheritage elements; a space is devoted to the exploration of the role of geosystem services in this value-interest system.
In chapter 3 the aspects about the semantic studies and the encoding of the knowledge will be deepened.

Validation of the theoretical model through case studies

To validate the theory, this method of representation of the knowledge is applied to case studies coming from several areas in two major countries, Italy and Poland. The method is tested on geosites, following two main directions:

1. In literature, it is assessed the relation between geoheritage and geosites; hence, studying the geosites we are studying potential elements of geoheritage.
2. We aim at testing the model of the relation between interest and value; as already specified, the geosites are described by their interests, while geoheritage by their values.

For Italy, there are several examples of descriptions of glacier related geosites from Susa Valley, and for the Sesia Supervolcano and the Granites of the Maggiore Lake from the Sesia Val Grande UNESCO Global Geopark.
For Poland, there are three areas taken into account: the Wielkopolski National Park, with geosites related to the Scandinavian Glacier evidence; the Wolin National Park, with morphologies related to the Scandinavian ice cap; finally, the surroundings of the Karkonosze National Park, with the geosites related to the magmatic intrusion activity of late Carboniferous.
These case studies were selected for several reasons. First of all, the possibility of representing different types of geological features. For example, the geosite of Wolin feature glacial morphologies and deposits, like those in Susa Valley, while the Sesia Supervolcano geosites feature several aspects of magmatic processes, like those in Karkonosze. This allows us to explore how this method of representation works when applied to different geological settings and verify the completeness of the description.
In second place, describing geosites of similar type (e.g., the several glacier-related geosites, or the magmatism related geosites) allows for testing the interoperability of data that crosses geographical areas, as countries in this case.
Third, we aim at demonstrating that this method of description does not mean to be a replacement of the present-day representation methods, but it aims a working at a deeper level with respect to the interfaces, connecting the data below the visible interface, which can be modelled in infinite ways through the use of the labels, according to the singular inventory representations.

Operative tool

As a practical outcome of the present research, an ontology-driven database structure for the organization of the data about the geosites and of the elements that are present in the geosites themselves (that could be geoheritage) has been designed. Along with the database, a tool for an easy filling in of the database has been implemented.
The database-filling tool system, called GeOntoLogic Site, leverages on the prototypes presented in Mantovani et al. (2020a, b). Building on OntoGeonous, the ontology for the geosciences with special focus on the geological mapping task, a database was designed for the collection of all the data that are necessary for a complete and correct description of the geosite elements. GeOntoLogic Site leverages

on the descriptions of the geological elements in OntoGeonous and the related database (called OntoGeoBase), integrating the information that concerns the description of the geosites and the attributes of geoheritage. The final output is a visualization of the data about the geosites in a publicly accessible website, in which the geosites are displayed, described, and connected with the elements that are visible in the geosites themselves.
The tool has been designed on the Omeka-S software, with the collaboration of the Computer Science Department of the University of Turin, which administrates the server that hosts the system and makes it accessible.
This tool has been tested during several sessions, to prove its usability. The testers were mostly students from courses treating the geodiversity and geoheritage theme, but some of them came from other backgrounds.

Evaluation of the method and of the obtained results
The success of the research, and of the system, is related to the improvement of the interoperability of data. This is concrete when the search of data about geoheritage and geosites are easy to find and compare within an information system, as can be geo visualizers and databases.
Representing a selection of geosites on the Omeka-s interface of GeOntoLogic Site, allowed to prove the efficiency of this system of data representation for applying advanced queries of search for the geosites. As we will see in chapter 5 and 6, the system supports this task, allowing for an easier recovery of data and explicit connection between geosites that have some aspect in common.

1.5.2 - Materials: used software

For the development of this research project, we used several software. In this subsection, we propose a review of them, with the activity for what they were used.

Ontology and Protégé
The ontology design, as well as the reasoning tests for the coherence of the system are performed with the use of Protégé software (Musen, 2015). This is a very solid and long duration project, started in the 1980’s by researchers from Stanford University, with the goal of helping developers to construct reusable ontologies and to build knowledge-based systems. It had a very good success, as in the first decade of the new millennium two thirds of the Semantic Web community used Protégé (Cardoso, 2007), while in 2015 over 250.000 people have registered to use the software, and about 500 companies use Protégé to build their ontologies (Musen, 2015). During the years, Protégé was restyled several times; the version used for the present research is identified with the ID 5.5.0, downloaded from the official website in November 2021[7].
This software allows to represent in separated forms the classes of an ontology, as well as its properties (distinguished in data and object properties) and the existing instances. Modelling the hierarchies and the properties, it is possible to create the axioms of the various classes, described in a machine-readable language. However, for human readers, it is possible to add comments to explain what a given class or property is, its definitions, and add labels to the elements of the ontology in order to make the naming of the single elements easier. A very important aspect of Protégé is the possibility of uploading other

[7] Download Protégé from: https://protege.stanford.edu/software.php#desktop-protege

ontologies, which makes it possible to integrate the preexisting encoded knowledge to support the encoding of the new knowledge, in harmony with the paradigm of linked data. Another essential aspect is the presence of reasoning tools, whose task is to check the consistency of the prescribed rules within the axioms that describe the classes. This ensures the achievement of a representation of the knowledge which is self-coherent and also coherent with the preexisting knowledge.
The final result is the ontology, contained in a ".OWL" (Web Ontology Language) file.

Descriptive tool and Omeka-S

To test the method and the system for data collection, a new tool was created by exploiting the facilities of Omeka-S. Omeka-S is a CMS (content Management System) whose primary goal is to allow for easy creation and management of websites for content showcases. Its website describes it as a "*web publication system for universities, galleries, libraries, archives, and museums. It creates a local network of independently curated exhibits sharing a collaboratively built pool of items and their metadata*"[8].
In particular, for the aim of the present thesis, the Omeka-S installation by the Computer Science department from the University of Turin was used, in particular the platform designed for the BeArchaeo project. The choice of using this tool is due to its high versatility. First, it is possible to upload the ontology files (in .OWL format) that contain the encoded knowledge in the form of classes and properties, that can be used for the description of the items. Within the system, the vocabularies can also be created, either as lists of terms, or lists of URLs or lists of items inserted in the system. When all the descriptive elements are present in the platform, it is possible to model the forms for the description of the items, named resource templates, that operate in the back end of the systems. However, the most exploited facility within the context of this research was the front-end organization for the collection of data. Through Omeka-S it is possible to create websites with collections of items (in our case, geosites) as well as forms for the collection of data about geosites. In fact, a guided procedure for the description of the geosites was designed for supporting the collection and description of geosites and of the elements composing the geosites, in accordance with the rules that were designed with the ontological studies. This was the object of the tests that have been performed in Poland and Italy (see chapter 5).

Geosite location, database and QGIS

Geographic Information Software (GIS) are the best choice for representing and analysing geospatial data. For the aim of this thesis, Quantum GIS was selected, that is a free and open-source software. The downloaded version is 3.22.0-Białowieża, downloaded in November 2021 from the website[9].
QGIS allows for the representation of the data in point, line and polygon form, organized in different layers. Each layer has a related database, which is possible to design independently for each level, and with the possibility of creating filling-in forms for guiding the user in the database compilation. The choice of representing the geodatabase in QGIS depends on the possibility of applying the proposed descriptive model directly on the field, collecting data directly in the file format in which it can be used. The final result is similar to the forms and the database that were tested and filled in Omeka, that was selected because of an easier setting of the tests; in fact, using the front end, it does not require any installation by the users, differently from using shape files (.SHP) that required the installation of GIS software.

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[8] Omeka-S website: https://omeka.org/s/
[9] Website of QGis: https://qgis.org/it/site/

1.6 - ORGANIZATION OF THE THESIS

The thesis is organized as follows.
Chapter 2 is dedicated to the review of state of the art. In particular, a deep review of the field literature will be presented, along with the review of the present-day systems of geosite data collection and visualization and, finally, an introduction to the knowledge models for the geosciences.
In Chapter 3 all the semantic studies on the main concepts, along with their encodings, will be presented. A special attention will be given to the concept of value, and the relation of the values with the interest. The goal of the chapter is to present all the theoretical work for the representation of geoheritage and geosite data, till the final proposal of a knowledge model, designed on semantic and ontological bases. The operative tool, namely the database, is presented in Chapter 4, along with an applicative tool designed on the Omeka-S platform. The tools will be presented along with examples from the case studies from Italy and Poland, that are widely presented in Chapter 5.
The case study geosites will be used for the testing of our database, by their classification in those tables, and for testing the applicative tool with volunteers.
Discussion on the proposed method and advancement on the field are finally reported in Chapter 6, along with the final remarks and future perspective in research.

CHAPTER 2

STATE OF THE ART

In this chapter we are going to overview the state of the art in the field. In particular, we are going to analyse in depth the concept and definitions of geodiversity, geoheritage, and geosite (section 2.1), comparing their evaluation criteria (geosystem services, values and interests). We also analyse the present-day methods for the data representation for the geosites (section 2.3). Finally, we review the knowledge models for the geosciences (section 2.3).

2.1 - DEEPENING THE CONCEPTS

There are many works in literature that explore the concepts of geodiversity, geoheritage, and geosite, sometimes in common terms. In the following sections, we will overview the main aspects of these concepts, first independently and finally in relation.

2.1.1 - Geodiversity and the geosystem services

The concept of geodiversity does not have a long history, and it is quite a new one among the concepts that turn around the sphere of geosciences. According to Gray (2008), the concept was first proposed in the early nineties, inspired by the more known concept of biodiversity, by Wiedenbein (1993) and Sharples (1993). Since then, many authors have discussed the topic providing definitions and interpretations (for an overview, see Brocx and Semeniuk, 2007). At the present day, the most acknowledged definition for geodiversity is the one by Gray (2013): *"The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems, and contributions to landscapes".* It is a general concept that includes the variety of abiotic elements and phenomena occurring on Earth (Gray, 2018). Boothroyd and McHenry (2019), who analysed a corpus published between 1993 and 2019, found that 88% of the documents lean on this definition (presented either literally or implicitly referring to it). However, this is only one side of geodiversity: according to Chrobak-Žuffová et al. (2021), geodiversity is defined in several context:

- Geological, in the meaning expressed above, based on the definitions by Gray (2004, 2013) and Zwolinski (2004)
- Geological and anthropogenic, related to the diversity of the earth surface due to the natural processes (both endogenous and exogenous) and human activity (Kozłowski et al., 2004a; 2004b)
- Geographical, in term of geocomponents and landscape diversity (Kostrzewski, 1998; Mizgajski, 2001)
- Anthropocentric, in terms of socio-economic relevance for humans (Guthrie, 2005), or sustainable development (Mizgajski, 2001; Panizza, 2009; Gray, 2018a; Herrera-Franco et al., 2020)

In the present work we are referring to the definition by Gray (2004, 2013), as our general task lies in the geological context. According to Gray's definition, geodiversity is an intrinsic quality of our planet. Every abiotic (non-living) element that is present on the Earth surface and interior contribute to the geological diversity. Note that the geodiversity can be discussed at various scales. At a global scale, for example, we consider the processes at the whole Earth level, such as the plate tectonics that directly influences the asset of the continents and of the creation/destruction of oceans and mountain belts. At a local scale, we consider the diversity of the materials, landforms and processes that act modelling one defined area. Even at a microscale geodiversity can be found, for example the association of different microfossils or different granular sediments into a sample of a sedimentary rock (Gray, 2013).
However, some discussion is carried out in literature on the meaning of this term. In fact, Brox and Semeniuk (2007), after Joyce (1997) and Semeniuk (1997), introduce the aspect of the limitation of this term to a defined area. In fact, the authors suggest avoiding the use of the term geodiversity to describe every existing abiotic element on the Earth (according to the authors, the term geology would be wide enough), but to apply the term to spatial related cases, i.e., specific areas or regions. This discussion is

still on going in literature, as documented in the papers by Brocx and Semeniuk (2019) and the following debate (Gray and Gordon, 2020, followed by Brocx and Semeniuk, 2020), devoted to the matter of scale in the definition of geodiversity, as well as on the relation between geoheritage and geodiversity (as we will see in section 2.1.4). This definition and perspective on geodiversity, according to the work performed by Boothroyd and McHenry (2019), is found among the 12% of the documents published in the years between 1993 and 2019 (Gray, 2021).
Indeed, the issue of the scale gets a very high relevance when dealing with the assessment of the geodiversity. Specifically, when approaching the evaluation of the geodiversity of a specific area, depending on the size of the area and the evaluation scale, there will be different responses. In fact, it is a delicate and crucial issue to choose the correct set of data for each scale of work (Zwoliński et al., 2018). As reported by Forte et al. (2018), there can be problems when attempting to compare the value coming from the geodiversity assessment of two or more areas which were studied at different scales.
Nowadays, in literature there are several methods for the assessment of geodiversity, classified and described in detail by Zwoliński et al. (2018) in three main groups:

- qualitative methods: highly based on the experience of the person or team that is performing the assessment, these methods are highly sensitive to the aspect to the scale.
- quantitative methods: the most common and with multiple types. These methods mostly derive from field instrumental measurements, numerical calculations or geoinformation analyses of raw data. Generally, they require highly specific knowledge and instruments, so they are expensive methods.
- qualitative/quantitative methods: an intermediate approach between the previous two.

In conclusion to their work, Zwoliński et al. (2018) suggest ontologic studies as the possible perspective in the study of the geodiversity assessment.
Several authors draw a particular attention to the assessment of geodiversity for the management of geoheritage of defined areas (Asrat et al., 2012; Bollati et al., 2015; Ferrero et al., 2012; Gray, 2008; Pereira et al., 2013; Rocha et al., 2014). This point of view, despite its broad agreement, is in contrast with the position taken by Brocx and Semeniuk (2007, 2019, 2020), who reject the relation between high geodiversity and geoheritage. The relation between occurrence of geoheritage in high geodiversity areas are also deepened in Guerini et al. (2024).

2.1.1.1 - Evaluation of the importance of geodiversity

In chapter 1 we recalled how a non geodiverse world could have been, and the consequences of this hypothetical aspect on the life on Earth (Gray, 2013). However, our world has a very high geodiversity, which is the source of so many benefits for society. This is described by the geosystem services. The geosystem services are the abiotic equivalent of the ecosystem services. A deep review of the concept of geosystem services is found in Frisk et al. (2022).
The geosystem services are inspired by the ecosystem services for the living nature. At the beginning of the millennium, a general review of the ecosystem services was published, the Millennium Ecosystem Assessment (Reid et al., 2005). However, it is noticed that in this review the role of the abiotic nature is completely ignored (Gray, 2019). The first reference to the concept of geosystem services is found in Gray (2005). In the following years several works have been published on the topic, in particular Gray (2008), Gray (2011), Gray et al. (2013), provided a first draft of the geosystem services. The services and their organization into groups was inspired both by the ecosystem services presented in Reid et al.

(2005), and in the nature functions presented in de Groot (1992), Gray (2004) and Webber et al. (2006). The representation of the geosystem services evolved in time, taking its form, different from the one originally meant for the ecosystem services. Various versions were published, till getting to the newest one in Gray (2021). The main modification was firstly proposed by Gray (2011), in which a new group of services was proposed. Originally, there were four groups, namely regulating, supporting, provisioning and cultural. Gray (2011, 2013) and Gray et al. (2013) proposed a new group, separating some of the services included in the cultural group, naming the new group "knowledge".

Regulating	Provisioning	Cultural
1. Atmospheric and oceanic processes	9. Food and drink	16. Environmental quality
2. Terrestrial processes	10. Nutrients and minerals	17. Geotourism and leisure
3. Flood regulation	11. Energy sources	18. Cultural, spiritual and historic meanings
4. Water quality regulation	12. Geomaterials	19. Artistic inspiration
Supporting	13. Industrial minerals	20. Social development
5. Soil processes	14. Ornamental products	15. Fossils for sale
6. Biodiversity & habitat provision	Knowledge	23. Environmental monitoring and forecasting
7. Land and water as a platform	21. Earth history and geoheritage	24. Geoforensics
8. Burial and storage	22. History of georesearch	25. Education and employment

Table 2.1 - Geosystem services in their latest version, by Gray (2021).

Deepening the groups of services, represented in Tab. 2.1 we can summarize the services as follows:

- Regulating services, concerning the processes that operate on the earth, like oceanic, atmospheric, or terrestrial processes. For example, the Gulf current is one of the main agents acting on the central Europe climate system.
- Supporting services, concerning the use that living creatures (humans, but also animals and plants) can make of the landscape. For example, the geodiversity allows for the existence of plains, where humans can build cities and airports, as well as rocky walls where the eagles can nest.
- Provisioning services, concerning the retrieval of resources, like building materials (from stone materials to metals or RAE) to water and food (different climates offer different types of cultivations).
- Cultural services, concerning the culture that the population develops in relation to the environment in which they live. For example, we can think about the different customs and cultures developed in the different continents, or the inspiration in the art context that comes from the natural landscapes.

- Knowledge services, concerning the knowledge that we can achieve from the study of the elements of geodiversity. For example, the deepening of knowledge about the history of our planet, but also information for daily life, like weather forecasting.

The geosystem services approach is a method to describe a part of the natural capital of our planet (Gray, 2019). The natural capital is “the world's stocks of natural assets which include geology, soil, air, water and all living things” (definition from the “Natural capital forum”[10], Gray 2019). This definition is completed by the “Natural capital coalition”[11], that considers both renewable and non-renewable resources in the natural capital. The natural capital is related to both living and non-living elements that are important for human society development. The geosystem services, hence, are joined by the ecosystem services in the description of the natural capital.

2.1.2 - Geoheritage and its values

UNESCO (2009) defines the Natural heritage, which “refers to natural features, geological and physiographical formations and delineated areas that constitute the habitat of threatened species of animals and plants and natural sites of value from the point of view of science, conservation, or natural beauty. It includes private and publicly protected natural areas, zoos, aquaria and botanical gardens, natural habitat, marine ecosystems, sanctuaries, reservoirs etc”. In this thesis, we are focussing on the geological part of the natural heritage, named geoheritage.

The term “geological heritage” was used for the first time at the *First International Symposium on the Conservation of our Geological Heritage* at Digne, France (Anon, 1991; Martini, 1994). After the 2nd international conference on geological and landscape conservation, Malvern Hills (UK), in 1993 by Joyce (1994) within the conference proceedings (O’Halloran et al., 1994), the shortened form “geoheritage” became the mostly used term to indicate the concept, still used today.

In literature, it is possible to find many definitions of geoheritage, provided in the tens of years by the authors who addressed the topic, all presenting some differences and common aspects. From the definitions (see Tab. 3.2 in the next chapter), it is possible to identify two characterizing points in the definition of geoheritage:

1. Geoheritage is considered as a part of geodiversity with an outstanding relevance to humans. In fact, all the definitions deal with the concept of geodiversity: “elements”, “components”, “part” of geodiversity.
2. The concept of value is used to describe the relevance of an element of geodiversity that becomes an element of geoheritage. Only when an element is recognized to have value it becomes part of geoheritage.

For this reason, it is of crucial importance to identify the values that make common elements of geodiversity becoming “special”, getting the geoheritage status. These values can be found in the definitions (most of the definitions contain explicit references at the values) as well as in lists explored in scientific papers (Sharples, 2002; Brilha, 2018; Georgousis et al., 2021) or national inventories (USA National Park Service, NPS). However, these lists present some differences: in fact, not all the values are shared.

[10] www.naturalcapitalforum.com
[11] https://naturalcapitalcoalition.org/natural-capital-2/

	Dong et al. (2013)	Georgousis et al. (2021)	Kubalíková (2013)	Szepesi et al. (2017)	Vasiljević et al. (2011)	Sharples (2002)	NPS[12]	Brilha (2018)		
Scientific	✓	✓	Scientific research	✓	✓	✓	✓	✓	8	100%
Aesthetic	✓	✓	✓		✓	✓	✓	✓	7	87,50%
Educational	✓	✓	✓		✓	✓	✓	✓	7	87,50%
Cultural		✓	Cultural development	Cultural/ historical		✓	✓	✓	6	75%
Economic	✓			Socio-economic			✓	✓	4	50%
Ecological		✓				✓	✓		3	37,50%
Intrinsic	✓					✓		✓	3	37,50%
Recreational	✓					✓	✓		3	37,50%
Inspiration			✓		✓				2	25%
Sense of place			✓			✓			2	25%
Artistic							✓		1	12,50%
Functional								✓	1	12,50%

Table 2.2 - Geoheritage values from the lists in papers and definitions. In the right part of the table, the number of citation and the percentage in relation to the analysed selection.

In Tab. 2.2 there is a list of values that come from papers and definitions. In some cases, the terms were not perfectly aligned, thus we reported them in the table in their secondary form (e.g., "Scientific research" for Kubalíková is associated with the "Scientific" value in the others lists). As it is possible to notice in Tab. 2.2, only the scientific value is fully shared, while the Aesthetic, Cultural, Educational values have a very high level of sharing.
We briefly analysed the four most shared values, resumed in the list below, after the comparison of the definitions (more details on the definitions in Appendix 1).

- Aesthetic value deals with the inspiration that natural landscape give to the humans, outstanding examples of natural beauty (Sharples, 2002; Georgousis et al., 2021; NPS, 2022), such as the Iguazu waterfalls, a system of almost 2700m of waterfalls of exceptional beauty which attract millions of people every year (Brilha, 2018).
- Cultural value deals with the identity of a community, the spiritual life (Sharples, 2002; NPS[12]), mythology (Georgousis et al., 2021); in general, it has to do with the local communities, and how they feel about particular elements of their living surroundings. An example is the Ayers Rock, the natural monument in the Uluru-Kata Tjuta National Park (Australia), which is a sacred mountain for the Aboriginal population (Brilha, 2018).

[12] https://www.nps.gov/index.htm

- Educational value is attributed to those elements that are exceptional teaching and have a key role in the education of students (but also to non-scientific communities) about the processes that act on our planet, its history, and its characteristics (NPS[12]). For example, Terras de Cavaleiros UNESCO Global Geopark (Portugal) attracts many university students from all over the world by the presence of a complete ophiolite section, witness of the obduction of Palaeothetys oceanic lithosphere over the Allochthonous Basal Complex (Brilha, 2018).
- Scientific value is strictly related to educational value, especially from Sharple's point of view. However, it is possible to underline a difference from the educational value if we consider the scientific value related to the importance that some elements have for the research activities and advancement in the scientific knowledge (NPS[12]). For example, the GSSP (Global Stratigraphic Section and Point) are the best points of outcropping of a geologic period limit: a wonderful example is the limit between "Selandian" and "Thanetian" (the last two Stages of the Paleocene Epoch, corresponding to 59,2 My ago), in Zumaia, Spain (Brilha, 2018).

It is generally acknowledged that a geological feature to which is attributed one of these values could be considered geoheritage. However, this topic is under discussion, as it is suggested in literature to restrict the geoheritage status to those elements that have the scientific value (Brilha, 2016, 2018), to prevent the term from being misused. In fact, it should be specified that the values reported in the related column of Tab. 2.2 are considered as values to be attributed to elements of geodiversity to be considered exceptional (Brilha, 2018).

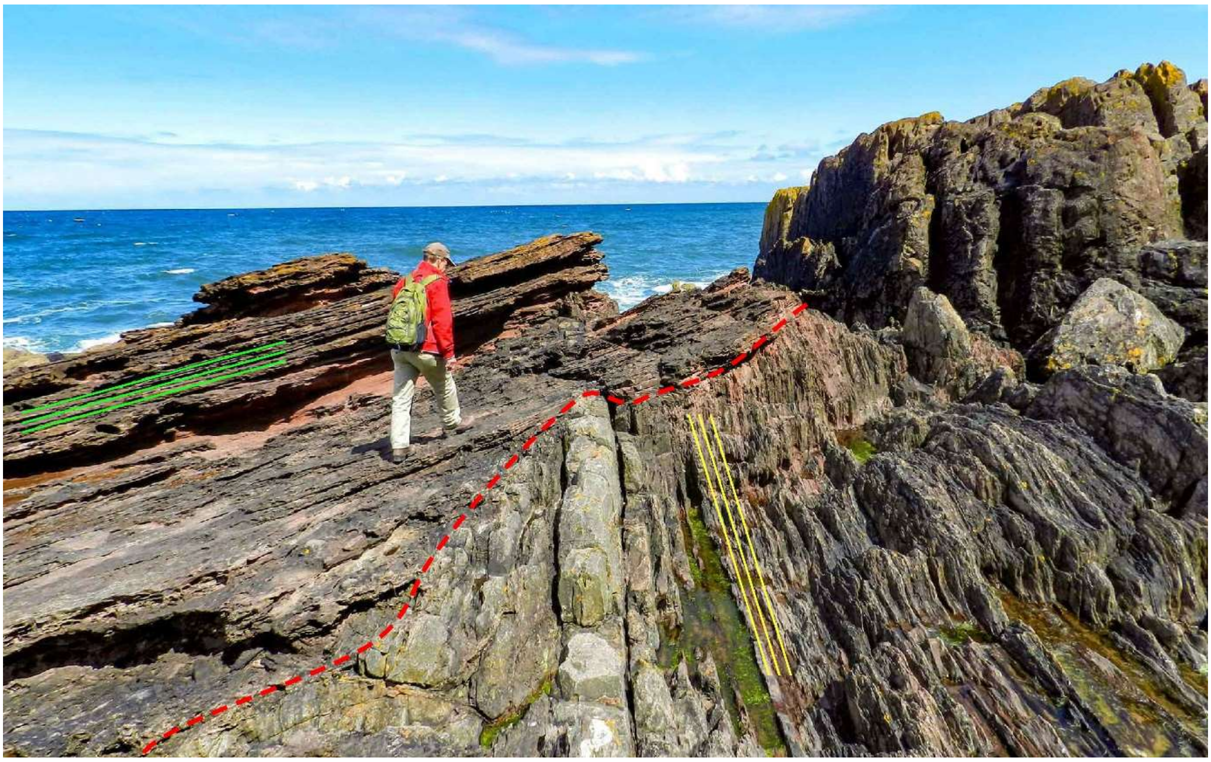

Figure 2.1 - Hutton's unconformity in Siccar Point[13]. In yellow, the stratification of the older (Silurian) graywackes; in green, the stratification of the younger (Devonian) sandstones; in red the unconformable contact between the units.

[13] Modified from the original photo. Credits: https://iugs-geoheritage.org/geoheritage_sites/siccar-point/

For example, the site of Siccar point, with the Hutton's Unconformity (Hilario et al., 2022, Fig. 2.1), has been of fundamental importance for the development of geoscience, because it shows an unconformity, namely the superposition of a geologic unit with given inclination of strata on other units with different characteristics of inclination. In this way, a non-zero angle is detectable between the planes of the strata; in Fig. 2.1, note the angle between the yellow and green lines (while the red spotted lime is the contact between the units). The inference of Sir Hutton in 1795 was that the Earth was subject not only to weathering and destructive processes, but also to a regenerative power, with processes that are capable of long-term modifications of the Earth's structure. Such sites (called geosite, see section 2.1.3) are of acknowledged and globally shared Scientific value.

An issue to discuss is how those values can be attributed to the elements of geodiversity. In Sharples (2002) some criteria are suggested. For example, the aesthetic value can be acknowledged to a feature that is frequently subject of artistic inspiration, like the Fuji mount, Japan, that is the principal subject of a very high number of pictures and paintings. Scientific value can be attributed to elements that are used as a type-site, i.e., that exemplifies a given element or process. According to Brilha (2016, 2018) the scientific value can be attributed to these elements that possess special characteristics of representativeness, integrity, rarity, and scientific knowledge. However, as discussed before, other authors do not restrict the value to the scientific one, allowing for other values to be considered, among which Aesthetic, Cultural and Educational are the ones in common.

It is not clear, after all, if there is a unique set of criteria to evaluate the elements of geodiversity for classifying them as elements of geoheritage. In general, this process goes through the description and the classification of the geosites, features that will be explored in the next section.

2.1.3 - Geosites

Geosites are defined as "site location area or territory in which it is possible to identify a geological or geomorphological interest for conservation" (Wimbledon, 1995), or, more recently, as "key localities of particular geological interest" (Newsome and Dowling 2018; Brilha, 2018). Other definitions put in direct relation the geosite with the geoheritage (García Cortés and Carcavilla, 2013; Brilha, 2018).

When describing the geological heritage of an area (e.g., region, nation), it is common to reference the geoheritage sites or the geosites present in that area, e.g., presenting inventories of the most relevant geosites in the addressed area (Prosser et al., 2018). Brilha (2016) proposes a method for the geosite inventory which, however, is based on evaluation of some aspects concerning geosites and their degree of usability or degradation risk. The author, however, specifies that such inventories have a local relevance and cannot be easily applied to evaluate geosites from large areas. Vice versa, Wimbledon (1999) reported about the GEOSITES project, supported by IUGS and UNESCO, with the design of a database for the representation of geosites unified at an international level. Such initiatives evolved in the ProGeo initiative (Wimbledon, 2012) and some achievements are reported in Diaz-Martinez et al. (2016). One big effort was performed by Hilario et al. (2022) by publishing the list of the first 100 geosites in the world. Several inventories are also related to some nations, like the "Geological Conservation Review" project in the United Kingdom (Ellis et al., 1996) or the "Irish Geological Heritage Programme" in Ireland (Parkes and Morris, 2001). Some inventories are accessible online, with related databases and visualizers, like for Brazil, Italy, Poland, Portugal (see below, section 2.2). Another example are the local inventories related to small regions, parks, urban areas (Ferrando et al., 2021;

Fuertes-Gutiérrez and Fernández-Martínez, 2010; Louz et al., 2023; Hajdù et al., 2023; Zwoliński et al., 2017).
However, a relevant aspect should be noticed about the geosite representation. taking as an example some of national inventories for the geosites, we can notice that most information concerns geographical, touristic and management aspects, leaving a smaller space for the description of other relevant aspects, which are the geodiversity elements that compose the geosites. As we will see later, in the analysis of two national geosite viewers (Italy and Poland), the description of the geology is more or less deepened and does not seem to have a primary role in the description of the geosites. This aspect is reflected also in literature, in which many works privilege touristic aspects (Reynard, 2004; Słomka and Kicińska-Świderska, 2004; Dmytrowski & Kicińska, 2011).
A general shared aspect, which is also reported in the definition is the relation of the geosite with the interest: to be a geosite, an area must be described through its interest. As for the values, there are plenty of lists of interests which are recurrent in the description of the geosites. Geosites are also the reference element of the management of the geological heritage in the law contexts, as represented by several regional laws in Italy (e.g., the Piemonte Region law for the conservation of the geosite, signed in October 2023[14]).

2.1.4 - Geodiversity, Geoheritage, Geosites from a global perspective

As highlighted in the previous sections, these three concepts are strongly related in their definitions. According to Gray (2013) and Gray et al. (2013), geodiversity is an intrinsic characteristic of our planet, something that exists independently of our awareness. The scientific community is exploring this characteristic, and discovered its role among the human society, describing it through the geosystem services, as well as exploring its relationship with the more known biodiversity (Tukiainen et al., 2022). Among the elements that compose geodiversity, some elements are of special value for humankind, and are considered as geological heritage. According to this point of view, with no knowledge about geodiversity, there will be no identification of the geoheritage elements. In fact, as reported by Gray (2018), the known elements of geoheritage are depending on the known and existing elements of geodiversity. On the one hand, some elements of geodiversity, and consequently some potential elements of geoheritage, can be discovered and described, maybe for the advancing in the research or even just because of their appearance after human activities of natural processes (e.g., anthropic excavation of a new road, or natural fluvial excavation or glacier retreat). On the other hand, some elements of geodiversity and geoheritage can be destroyed if not properly protected. An example is the Cava Meitre geosite (Aigotti et al., 2004), Susa Valley, Piemonte Region, Italy, in which there was in outcrop a fold that used to display the deformation phases of the metamorphism of the area. In absence of a law for the preservation of the geological heritage, that outcrop was destroyed by the mining activity. Also, natural events can be a threat for the elements of geoheritage: during the flood in Sesia Valley in 2020, some of the geosites recognized on the area of the Sesia Val Grande UGGp (those in correspondence of the Sesia river) were damaged by the mud deposition. A deep knowledge

[14] For the full text of the Regional Law, see:
http://arianna.cr.piemonte.it/iterlegcoordweb/dettaglioProgetto.do?urnProgetto=urn:nir:regione.piemonte;consiglio:testo.presentato.pdl:11;258&tornaIndietro=true

of the geodiversity and of the elements that compose it, along with the agents that can be a thread for them, is the crucial base for the knowledge and of the representation of geoheritage.

This connection between geoheritage and geodiversity, although it is so widely acknowledged in literature, finds two different points of view in literature. On the one hand, the emphasis on the dependency relation of geoheritage on geodiversity, in which geodiversity is the “backbone of geoheritage” (Gray, 2018), mostly acknowledge among the occidental researchers on the field (as testified by the book edited by Reynard and Brilha (2018a), collecting numerous research papers on the field). On the other hand, the refusal to attribute a father-son relationship to the two concepts, proposing vice versa a sibling relation of the two concepts (both geoheritage and geodiversity would be “sons” of the wider concept of geology), as proposed by Brocx and Semeniuk (2019, 2020). A point raised by Brocx and Semeniuk (2007, 2020) in support of their point of view on geoheritage and geodiversity is that a site does not have to be highly geodiverse to be of geoheritage significance (see also Joyce, 1997; Pereira et al., 2012; Ruban and Yashalova, 2018). In fact, sites of low geodiversity can have enormous values, hence being geoheritage, while sites of high geodiversity can have a low significance, hence not showing heritage relevance (Brocx & Semeniuk, 2007; 2020; Joyce, 1997).

Finally, there is a relation with the geoheritage and geosites: in almost every paper, the concepts are strictly in relation, leaving little space for the distinction, which is declared in the definitions, but not in the application. In fact, when describing the geological heritage of an area, locality, nation, and so on, it is normally displayed the group of geosites that are present in the addressed territory.

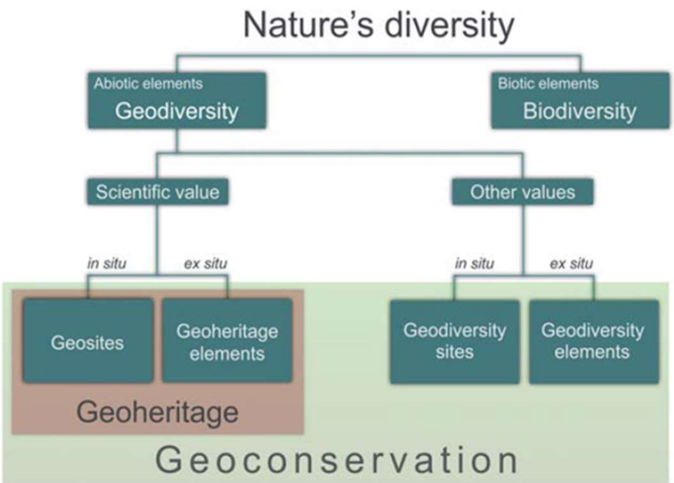

Figure 2.2 - Schema by Brilha (2018) on the relation between values and elements of geoheritage and geosites

Brilha (2018) represents the relation among these concepts in a schema (Fig. 2.2). The dualism between geodiversity and biodiversity characterizes the two aspects of nature diversity (collecting abiotic and biotic elements respectively). Then, some values can be recognized in the elements of geodiversity; these values define if an element of geodiversity can achieve the geoheritage status. As mentioned before, Brilha suggests restricting the group of geoheritage to those elements with scientific value, but this suggestion is still under discussion. Finally, elements of geoheritage can be *in-situ*, meaning that we find them in the place where they were generated by natural processes, or *ex-situ* meaning that we find them in a place that is not their original one. For example, a landform or a rocky outcrop could be “in-situ” elements of geoheritage, because it is obvious that it cannot be removed by the humans from their original place; these will be called geosites. Minerals, fossils, rock samples, and every other abiotic element that can be moved from its original position and shown, for example, in a museum, can be ex-situ geoheritage elements. Note that the author underlines the importance of actions of geoconservation for every geodiversity site and elements, suggesting a responsible use of the resources (material on not material) provided by our planet.

2.1.5 - Conclusion on the review of the literature

The bibliographic research underlines a deep connection between the concepts of geoheritage, geodiversity and geosite. In particular, the concepts of geoheritage and geosite are often so strictly related that it can be difficult to distinguish between them (e.g., the dependence of the assessment of geoheritage from the assessment of geodiversity, Bétard and Peulvast, 2019; Najwer et al., 2023). Vice versa, there are also contrasting theories that describe differently the relation between geoheritage and geodiversity (see Brocx and Semeniuk, 2007; 2019; 2020). This is reflected also from a representation point of view, as the databases and visualizers for geosites are the base for the representation of the geoheritage and of the geodiversity of a given area. The reason is that these are the easiest ways to represent relevant features, as they are potentially used both by institutions and communities. In the next sections we are going to analyse the present-day representation of the geosite data.

2.2 - PRESENT DAY COLLECTION AND REPRESENTATION OF DATA

As mentioned in the previous sections, when willing to describe the geological heritage of a given region, the most used way is to list the geosites that are present in the addressed region. In fact, many nations have a geosite visualizer, usually a map of the nation with geosite markers (as points or areas) and connected to their descriptive form and database. In this section, we are going to analyse some of the geosite visualizers, namely the Brazilian, Italian, Polish and Portuguese ones (further detail in Appendix 2). These four national geovisualizers represent only a brief case study. They were selected by the one hand for the easy access from the web (links in the footnote[15]) at the day of the research in summer 2022, and by the other hand to showcase an overview inside and outside Europe of geovisualizers with different management of data. This brief survey focusses on the graphical representation on the map, on the quick data visualization, and on the wider descriptive forms.

- Graphical representation: every nation has different criteria for the selection of the symbols. Except for Portugal, in which the symbol is not categorized, the other nations represent the geosites following different criteria: Brazil and Italy choose a management criterion (respectively validation and relevance), while Poland choose a classification of the type of object. The latter criterion provides a first general idea of what the single geosite could be.
- Quick data representation: except for Brazil's database, which also provides geologic information, the other databases are much more devoted to the geographic and management information about the geosite. To retrieve geologic information, we need to search in the detailed description.

[15] The websites were accessed in summer 2022; the Brazilian geoportal now needs a licence to access.
Brazil: https://geoportal.cprm.gov.br/geosgb/ (needed licence to access from 2023)
Italy: https://sgi.isprambiente.it/GeositiWeb/Default.aspx (needed free registration to access)
Poland: https://geologia.pgi.gov.pl/geostanowiska/
Portugal: https://geoportal.lneg.pt/mapa/#

- Descriptive form: the descriptive forms are very differently organized. For what concerns the geologic information, the Brazilian and the Polish forms are the most detailed ones: in fact, they have a dedicated section that is rich in details. The Brazilian one has a dedicated section with separated fields to describe the different types of rocks, based on the different relevant aspects when describing, e.g., sedimentary or metamorphic rocks. The Polish form has several fields for the description of the origin, the rock type, the landform type, the age… Italian and Portuguese forms have a more limited amount of information about geological aspects: the Italian one only displays genetic processes, with related ages. In the Portuguese the geological information is only distributed in the textual description. A detailed textual description is also provided in the Polish and Italian forms. For example, in the Polish form there is a textual field in the form for the geological information, with a general description of the geological context and details that could not be inserted in the other fields. Similarly, in the Italian form there is an attached text file (not mandatory and thus not always available) with the description of the geosite, developed as free text.

2.2.1 - Closed and open text fields

A general consideration is that the knowledge is partially displayed into closed fields with controlled vocabularies (for example, lithology and age) and partially displayed in the open text fields (or file, in the case of the Italian form). The consequence of this organization has an impact when we need to perform advanced searches of geosites, or we need to compare geosites, at international or even national level. For example, the Italian geosite descriptive form offers a limited number of fields of which it is possible to perform an advanced search: the only explicit fields, as mentioned above, are about lithology, origin, and their age. However, a check on randomly chosen geosites showed that most of these fields are filled with mixed information and would not allow a precise response to the searches. For what concerns the Polish database, the fields that are available for such searches are some more and filled with terms from controlled vocabulary. However, some examples on groups of geosites underlined how for a querying process this information is not enough. In fact, the knowledge about the single geosite is much better represented (and understandable by a human reader) in the open text field, especially for what concerns the general context, while the closed fields offer punctual information on a very precise topic. In the next subsection, we will explore an example of an experiment of data retrieval to explain the problems in this kind of representation.

<u>Example: the geosite related to the Karkonosze granitic pluton intrusive history</u>
An example of test on the geosite data retrieval is in the area around Karkonosze National Park, in the southwest of Poland. This national park is the Polish part of a wider park, shared with the Czech Republic. The main geologic feature is a granitic pluton, with an area of 600 km^2, which has influenced the local geological and geomorphological asset. In fact, at the beginning of Carboniferous the geological asset was characterized by a metasedimentary geologic section, mostly made of paragneiss and mica schists (Kusiak et al., 2014). Around 300 million of years ago, a post collisional magmatic mass intruded this metasedimentary section, generating two main features that are visible today:

- The Granites of Karkonosze, created by the cooling of the magma that set into external (and cold) crustal settings.

- The Metamorphic crown around the granitic mass: the heat coming from the magmatic mass caused a high temperature metamorphism in the rocks that were directly surrounding the magmatic mass itself. So, in contact with the granites of the pluton, it is possible to find a belt of hornfels, created at expenses of the paragneisses and mica schists that were present before the arrival of the magmatic mass. The rocks that were far enough from the magmatic mass were not influenced by the heat, and maintained their lithologic characteristics, and are still today the witness of the previous geologic situation.

Many geosites of the Polish side of Karkonosze are related to this geologic history. However, could we set a query to find all these geosites? Which could be a comprehensive criterion? For example, we could perform a search based on a lithological criterion, e.g., searching either the granites, or the hornfels. In this case, we will leave out all those geosites that does not have the selected rock, with the consequence of not achieving a complete result, whilst we would find other geosites that nothing has to do with the Karkonosze Pluton intrusive story, but that are characterized by the same lithology. Other combinations of criterion, for example lithology and age could restrict the range of research but will not probably supply a perfect result. E.g., a composite search "granites" OR "hornfels" for lithology, with an age "Carboniferous" will find other geosites made of those rocks with similar age.

2.2.2 - Conclusion on the geosite representation

The example of the last section aims at showing how the closed field in the national database viewer has a limited amount of information that is not informative enough for search. In fact, even just to understand the general context of a single geosite, a human reader must lean on the open text description. Our aim is to propose a tool that can represent the knowledge about the geosite also exploiting the knowledge that is now "hidden" in the open text fields.

This goal can be achieved through a method based on the semantic studies of the concept of geosite and geoheritage, and the further modelling of ad-hoc tools for their description and collection of data. For this task, it is necessary to lean on knowledge models for the geosciences in general and on specific models for the geoheritage field. In the next section we will deepen the aspect of the knowledge modelling, starting from the general basis, and getting to specific existing models for the geosciences.

2.3 - KNOWLEDGE MODELING - ONTOGEONOUS AND ONTOGEOBASE

In this section we are going to address the state of the art in knowledge modelling, focussing on geosciences.

According to Cuena and Molina (2000), the knowledge modelling consists in the process of abstraction of the knowledge itself, in order to support reasoning processes independently from the representation methods. This abstract level of knowledge, named *knowledge level* by Newell (1982), allows us to describe a knowledge domain in terms of rules and relations. Based on several key aspects and definitions about the knowledge modelling, such as the concept of task Chandrasekaran (1983, 1986), Wielinga et al. (1992), model of components of expertise Steels (1990), the role limiting method McDermott (1988) and the ontology concept Gruber (1993), two main ways of knowledge modelling organization are identified (Cuena and Molina, 2000). The first is the task-oriented principle, defined as a goal to be achieved through modelling. This goal is obtained by completing the necessary tasks and subtasks. The second, is the domain-oriented principle, based on the organization of the knowledge in ontologies. An ontology, in the context of information sciences, "defines *a set of representational primitives with which to model a domain of knowledge or discourse. The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members). The definitions of the representational primitives include information about their meaning and constraints on their logically consistent application"* (Gruber, 2008). An ontology focuses on the description of a given knowledge domain which can be furtherly reused in support of description of other knowledge domains through the relations, expressed by properties.

Several types of ontologies can be identified, based on the level of generality (Guarino, 1998; Scherp et al., 2011):

- Foundational ontologies, also known as upper-level or top-level ontology (Euzenat and Shvaiko, 2007; Oberle, 2006), that serve as a base for modelling other ontologies, and contain general concepts that can be reused in many different fields of study. For example, they provide a structure for the classification of the most general concepts, like object, or site, or temporal influence on the objects (the theory of endurant and perdurant, Huang, 2016)
- Core ontologies deal with the knowledge of a specific field of study (hence, being narrower that the foundational ontology), but covering several domains of that field from a generical point of view (Oberle, 2006)
- Domain ontologies, which describe the objects and their relation is a specific domain of knowledge, considering the meaning that the concepts have in that specific domain (Euzenat and Shvaiko, 2007)

These three types of ontology can be linked: the more specific rest on the more general, which thus connect different domains of knowledge.

The bases of the knowledge modelling have application in a growing number of fields, from the sciences to the humanistic fields. In the next sections, we are going to explore the application of the knowledge modelling within the geosciences field, reviewing some knowledge models and ontologies.

2.3.1 - Knowledge modelling in the geosciences field

According to Mantovani et al. (2020a), the representation of geological data knowledge is a debated issue in literature. In recent decades, data management has undergone a significant transformation from mostly analogic to mostly digital format. This process not only involves data processing operations, but also the very first stages of data collection (McCaffrey et al., 2005; Pavlis et al., 2010; Whitmeyer et al., 2010, De Donatis et al., 2016), by using small laptops or tablets during field surveys. This transition to a digital format of data, on the one hand, allows for an easier management and sharing of the data; on the other hand, this has created a need for data harmonization, in order to make them interoperable.

To enhance the interoperability of geological data, various attempts at knowledge modelling can be found in the literature, either into a natural language format or in a machine-readable language.

Some examples of the natural language knowledge modelling are NADM (NADM 2004), the INSPIRE data specification (as European reference; https://knowledge-base.inspire.ec.europa.eu/index_en) and the GeoScience Markup Language at an international level along with the related vocabularies (Raymond et al., 2012; CGI Data Model Working Group, 2012).

For what concerns the encoding of geological knowledge, several ontologies covering numerous parts of the geoscience sphere can now be found in literature. Some examples are ontologies for the field activity and geological mapping (Brodaric, 2004; Hwang, 2012; Boyd, 2016), for the geologic time scale (Ma et al., 2011), lithological materials (Richard, 2006; Sinha et al., 2006), ontology of fractures (Zhong et al., 2009), and algorithmic interpretation of sedimentary facies for the individuation of geologic processes (Carbonera et al., 2015). Other ontologies attempt to cover the geoscience domain from a more general perspective. Some examples are the GeoCore ontology (Garcia et al., 2020), GeoScience ontology (Brodaric and Richard, 2021), and the OntoGeonous ontology (Lombardo et al., 2016, 2017, 2018).
Most of them are based on top level ontologies, among which we can find SWEET (Semantic Web for Earth and Environment Technology, Raskin and Pan, 2005; Raskin, 2006), on which is resting OntoGeonous (Lombardo et al., 2016, 2017, 2018), BFO (Basic Formal Ontology, Arp et al., 2015), on which is resting GeoCore ontology (Garcia et al., 2020), and others, like SUMO (Suggested Upper Merged Ontology, Niles and Pease, 2001), DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering, Gangemi et al., 2002) and UFO (Unified Foundational Ontology, Guizzardi, 2005).

In line with the principles of the semantic web and linked data (Berners-Lee et al., 2001; Bizer et al., 2009), knowledge that has already been encoded should be reused rather than re-encoded. As a result, many of the resources mentioned above are interconnected. For example, OntoGeonous and GeoScience ontology are two different encodings based on the GeoScienceML standard. Looking more in depth of OntoGeonous it exploits SWEET as a top-level ontology (Raskin and Pan, 2005; Raskin, 2006) and integrates the CGI vocabularies.

In the next section we will take a closer look at the OntoGeonous ontology and its application to the geological mapping, which is the representation of the data of the Piemonte geological map (Piana et al., 2017a, b) and the ontology driven geodatabase, named OntoGeoBase (Mantovani et al., 2020a; 2020b). OntoGeonous and OntoGeobase will be the theoretical bases on which the applicative studies to geoheritage and geosites will be based and described in the next chapter of the present thesis.

2.3.2 - OntoGeonous and OntoGeoBase

OntoGeonous is an ontology for the representation of the geological data, with a special focus on the data concerning the features that are normally represented in the geological maps. Among the groups of ontology listed in introduction of the present section, it can be classified as a domain ontology (Lombardo et al., 2018), resting on the top-level SWEET ontology (Raskin and Pan, 2005; Raskin, 2006). The ontology is inspired by the knowledge representation of GeoScience Markup Language (GeoSciML), in which the main concepts covering the domain of geology (e.g., Earth materials, geological units and stratigraphy, geological time, geological structures, geomorphology, geochemistry) are defined and put into mutual relation. The standard should also support the task of geological mapping by providing a simplified version for representing geological features on digital maps[16] (Raymond et al., 2012). The conceptual framework of the standard is widely explained and defined through textual description and representation in UML format, in which the mutual relation between the concepts is made explicit and

[16] GeoScienceML, scope: https://docs.ogc.org/is/16-008/16-008.html#1

graphically represented. The main concepts are usually described by connected standard vocabularies (CGI Data Model Working Group, 2012), describing a wide range of aspects in the geology domain.
The main organization of OntoGeonous is inspired by the basic taxonomy proposed by GeoSciML; in fact, the ontology is the result of several merged ontologies, meant to represent four principal concepts that are of relevance for the description of the feature involved in the geological mapping process. Namely, the four sub-ontologies are:

- Geologic Units, for the description of the material part of the Earth, like rocks or deposits[17];
- Geologic Structures, for the description of the geometrical asset in which those materials are displayed[18];
- Geomorphologic features, for the description of the landforms, i.e. the shape of the Earth's surface[19];
- Geologic events, for the description of the event that occurred in geological history and had an influence on the Earth surface or interior[20].

The top concept (or class), under which these four sub ontologies are grouped, is named Geologic Feature, which in GeoScienceML[21] is defined as "a conceptual feature that is hypothesized to exist coherently in the world". These 5 classes are put into a taxonomy as represented in Fig 2.3.
The main taxonomy (in brown in Fig. 2.3) is related to other taxonomies and groups of concepts. Namely, the CGI vocabularies, that support the characterization of the single concepts, or the SWEET ontology (Raskin and Pan, 2005; Raskin, 2006), which provides concepts that were encoded prior to OntoGeonous and can therefore be used within the ontology in accordance with the Linked Data paradigm (Bizer et al., 2009).

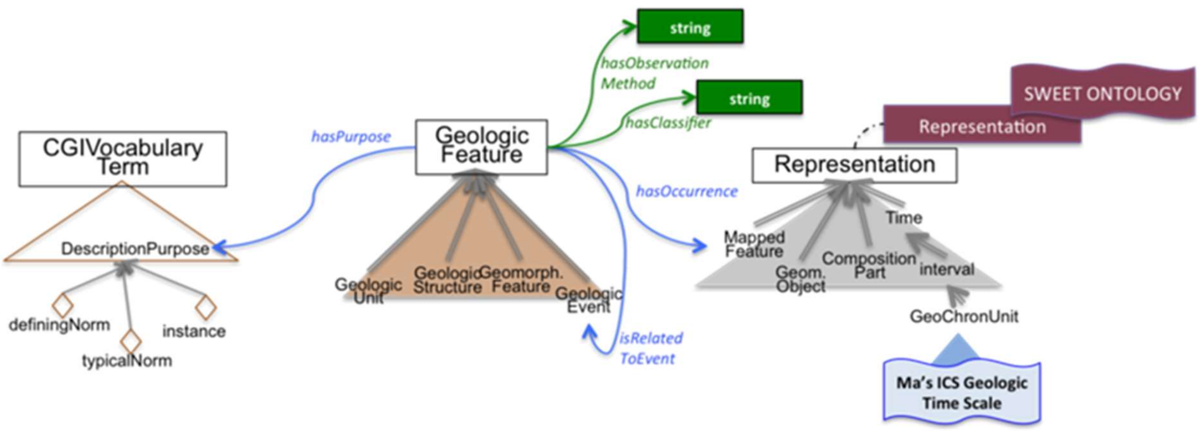

Figure 2.3 - Schematic representation of OntoGeonous and the related standards and vocabularies

The four subclasses (Geologic unit, Geologic structure, Geomorphologic feature, Geologic event) are themselves parent classes of namesake ontologies. In fact, each of them has subclasses, describing types of units, structures, and geomorphologic features (or landforms) through the attribution of characteristics described by properties, both inspired by GeoScienceML, and proposed after deep studies on the semantics of every single concept. Each class is provided with its axiom, which describe the relation of that type of object with other objects of the ontology (Dou and Mcdermott, 2006);

[17] GeoScienceML, Geologic Unit: https://docs.ogc.org/is/16-008/16-008.html#48
[18] GeoScienceML, Geologic Structure: https://docs.ogc.org/is/16-008/16-008.html#82
[19] GeoScienceML, Geomorphologic Feature: https://docs.ogc.org/is/16-008/16-008.html#97
[20] GeoScienceML, Geologic Event: https://docs.ogc.org/is/16-008/16-008.html#70
[21] GeoScienceML, Geologic Feature: https://docs.ogc.org/is/16-008/16-008.html#34

namely, they are formulas collecting the necessary and sufficient conditions that a given item must have to be included in the class. These conditions are expressed through hierarchies (i.e., this class is part of that broader class) and through properties (e.g., this item must be in relation to a precise type of object or to a precise value). The properties can connect an item to another item or to a value (e.g., numerical values, or terms from a controlled vocabulary, mostly from CGI). In this way, the relation between items and vocabularies is encoded into a machine-readable language and described in a coherent context, validated by reasoning tools.
In the context of geological data management, this organization can offer several advantages. First, this organization can support an unambiguous description of the geological elements. For example, if an element is described as a fault, it is because it can be included in the class "Fault" (in turn subclass of "Geologic Structure") due to its characteristics, which are expressed by ontology properties, that reflect the necessary and sufficient conditions for an element to be included in the "Fault" class. In this case, an element, to be a fault, must (condition 1) be a planar surface along which (condition 2) some displacement has occurred with (condition 3) a "brittle" deformation style. Every element with these three characteristics will be considered as faults. If even just one of these three characteristics is valued differently, the element is not a fault (e.g., if the condition 2, presence of displacement, does not hold, that is no movement occurred along the surface, the element is not a fault, but it is a fracture). Vice versa, if there are other relevant observations about a given fault, it could be further classified into a specific subclass of fault (e.g., low/high angle fault due to the value of the dip angle, or Strike-Slip fault, due to the movement type).
Second, every element has an URL address, through which it is possible to access the associated resources (e.g., description and definition). The encoding of the geological elements (through the properties), along with their description in natural language (definitions from the URLs) offer the possibility of describing the object in an explicit and transparent way that limits the ambiguity and supports the traceability of the interpretation path.
In the context of geological mapping, this presentation method aims to make explicit the relationship between the geological features represented in the map. For example, two lithostratigraphic units (which is a type of geologic unit, normally used in the geological maps, identified for their lithology and their stratigraphic role) might be in a "part of" relation (e.g., the Borgone Orthogneisses in the wider geologic unit of Dora-Maira). The direct stratigraphic relation between these elements can be easily inferred by a geologist by looking at the map and at the map legend, through the application of his/her own geological knowledge. However, if this relation is explicit in a graphical form, there should be a way to make explicit this relation also between the data. For this reason, the ontological structure of the data inspired the structure of an ontology driven database, named OntoGeoBase (Mantovani et al., 2020a, b). This relational database is structured in several tables that collect one or more types of features that are represented in the same type of layer (in GIS applications, there can be points, lines or polygons layers). The columns of the tables are designed after the ontology axioms. In fact, each column corresponds to a property of the ontology and the filling-in of the required information aims at satisfying the ontology rules, both with values (e.g., numbers or values from predefined controlled vocabularies) or with other elements described in other tables of the database. Hence, if aiming to represent the relation between two geological units and their bounding contact (Contact 1), we will have two items collected in the Lithostratigraphic Units table ("Unit A" and "Unit B"), and one contact in the table of geologic structures. In the first table, a column (namely "bounded by") will be filled with the reference to the "Contact 1" for both the Unit A and Unit B rows. Vice versa, in the structures table, the row for Contact 1 will have the reference to both the Unit A and Unit B in the columns labelled as

“Bounds”. Both the columns “Bounds” and “Bounded by” are the transposition of the homonymous ontology properties.
This representation method allows for

a) a rigorous and complete representation of the features that are included in a geological map.
b) a coherent description in of the relation between the geological features.

This model, mainly designed for the geological maps, finds its application in the description of the features of the geological map of Piemonte (Piana et al., 2017a, b). However, it is suitable for the description of these geological features in general. In the next chapters, we will see how this model can be applied to the description of the geological features in the geosites.
In the next chapter, we are going to introduce the materials and methods that were used within the context of this research. In particular, we are briefly reviewing the operative steps and the software that were used for the development of the work.

CHAPTER 3

CONCEPTUALIZATION AND ENCODING OF GEODIVERSITY, GEOHERITAGE, GEOSITE AND THEIR VALUES

The goal of the present chapter is to discuss and present the knowledge model for the concepts of geodiversity, geoheritage, geosite. To support their description, and the attribution of their importance, we will also discuss the relation between the methods of describing their significance (specially values and interests). In particular, values and interests will be reviewed starting from the assessment of their relation, discussed in Díaz-Martínez and Fernández-Martínez (2015), and deepened through the study of the concept of value, introduced as a general concept by Perry (1914). According to Perry, an object has a value if it satisfies an interest of someone. With this work, we aim at exploring this relation among the values of geoheritage and the possible interests that can be related to those values. Before exploring this relation, however, we introduce the semantic knowledge model for the main concepts. The second step will be the introduction of the value-interest system. Finally, we present the global model with the relation between all the considered elements. The .owl files with the encodings are in the Zenodo repository[22].

[22] Link to the repository (V2): https://doi.org/10.5281/zenodo.12591979, Mantovani (2024)

3.1 - INTRODUCTION TO THE STUDY STEPS

The key aspect of producing an ontology is to encode the knowledge within a given domain from its description and definitions in natural language into some formal representation. This is based on the description of the elements through the representation, in a machine-readable language of the related concepts, with relation within the same ontology or connecting concepts in different ontologies. Every considered type of element will become a class (which is a group of objects with the same characteristics); the classes can have two types of relations: one is the hierarchical or taxonomical relation (parent or sibling relations), the other is the transversal relation through the properties. These relations are expressed in the axioms, formulas that contain the necessary and sufficient conditions that an instance or individual must have to belong to a given class. Hence, the final goal of the procedure that we are going to explain is to produce the knowledge model and the axioms.

The first essential step is to define the knowledge domain that we aim at representing. In this case, it is the knowledge concerning the geoheritage; after a short overview of the concept, it comes as a direct consequence the inclusion in the study of the concepts of geodiversity, which is considered in every definition of geoheritage, and geosite, usually addressed as the locality in which geoheritage elements stand.

The study of the concepts starts from the collecting of the definitions that are present in the literature. The idea is to collect and integrate all the knowledge that is available about every single concept, for further analysis and design and representation of the model. These definitions are collected and analysed in their natural language format, i.e., the human language. The definitions are fragmented into the simplest concepts that describe only one aspect of the analysed concept. Once identified, all the fragments of the definitions are ready to be encoded into machine readable language: hence, every fragment will express a relation of that type of object with other objects. These relations could be hierarchical (parent-daughter or sibling relation) or expressed by properties that connect elements from different hierarchies.

The combination of these properties and hierarchical relations defines the axiom of the classes, collecting the necessary and sufficient conditions for an item to be included in that class.

We are going to deal with some basilar ontology elements, namely the classes, groups of objects, the individuals that populate the classes, and the properties that connect the previous element types.

Tab. 3.1 summarizes these element types, plus a recap of the AND/OR operators, that establish the relations within the axioms. In Fig. 3.1 these elements and their relations are graphically represented, in order to introduce the symbology that will be used to represent the ontology items in this Chapter.

ELEMENTS OF AN ONTOLOGY		
Element type	Definition	Example
Class	OWL classes are interpreted as sets that contain individuals. Classes can have subclasses or be subclass of some other class. Two or more subclasses of the same class are named sibling classes	The class **Cat** would contain all the individuals that are cats in our domain of interest. The class Cat is subclass of **Animal** and sibling class of **Dog**
Instances/ Individual	Represent objects in the domain in which we are interested	"*Mia*" and "*Buhl*", my cats, member of the class "**Cat**"
Properties	Properties are binary relations on individuals, classes, or classes and individuals - i.e. properties link two individuals or classes together.	"*Mia*" <u>hasFosterSibling</u> "*Buhl*" and "*Ivi*", defining the sibling relation between my cats and dog
OPERATORS		
AND	Implies that two conditions must be satisfied together	A Dalmatian dog has colour "black" AND "white"
OR	Implies that at least one of the conditions bounded by OR must be satisfied: OR exclusive: only one condition OR inclusive: more than one condition may coexist	A Labrador can be either Black or yellow (not black and yellow) A cat might have colour "black", or "white" or "black AND white"

Table 3.1 - Description of some of the elements of an ontology (Horridge, 2011). In this table are present only the elements that are used within this work (other operators exist, but they are not reported in this table).

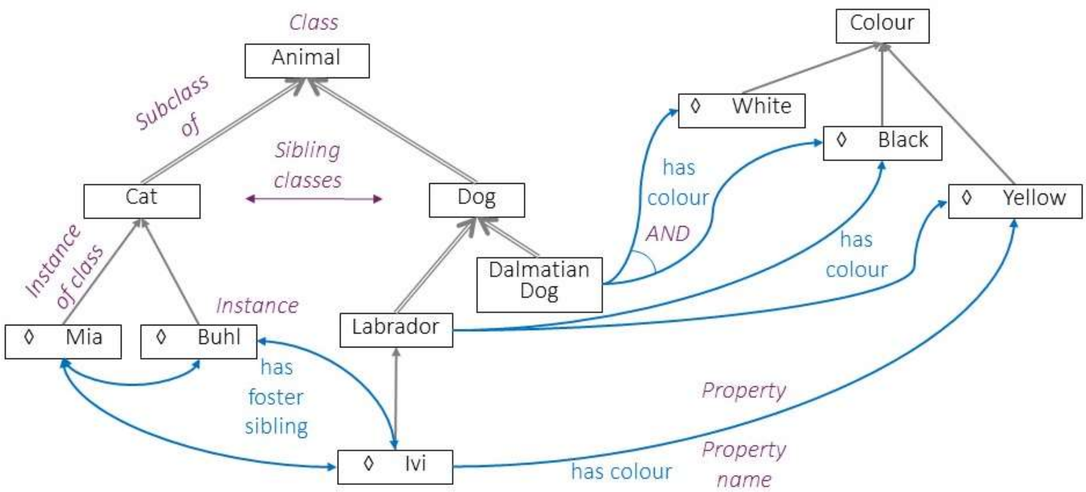

Figure 3.1 - Graphic representation of the elements of an ontology, with purple italic writings to indicate the element types. Classes (black squares) and instances (black squares and diamonds) are connected by their possible relations: subclass relation (double grey arrow), instance-class relation (single grey arrow) or property relation (blue arrow). The arch between the properties "has colour" for the Dalmatian dog indicates the AND operator.

<u>Example: Fish axiom</u>

For example, let's take a simplified characterization of the fish. A very approximate definition of the fish is that they "are animals that live under water". This definition contains two essential information:

- "fish are animals" indicates that the class "Fish" is a subclass of the wider class "Animal"; it is a hierarchical relation

- "fish live under water": what distinguishes the class "Fish" from other subclasses of "Animal" (siblings of Fish) is the characterization of their life environment, which is "live under water". This fragment will be translated into a property: this property describes the relation between the Fish and its habitat. The types of habitats will have a class themselves, with subclasses among which one could be "underwater habitat". The property (which we can name "lives in") will relate the type of animal with the type of habitat in which it lives.

Hence, an instance that we supposed to be a fish, to be part of the class "Fish" has to be an animal and possess the property "lives in" that connects it to an instance of the class "underwater habitat", for example a lake (which is a type of underwater habitat). A "Fish" is different from an "Orangutan", which exclusively lives on trees (different habitat).

Finally, we define the axiom of the "Fish", which is dependent on the conditions expressed in the protoaxiom (i.e. the list of the fragments of the definition with their transposition in ontological relations):

- "Fish are animals": `subclass of Animal`
- "that live under water": *`lives in`* `SOME Under Water Habitat`

The organization of these conditions, connected by the AND/OR operators (introduced in Tab. 3.1) is the final axiom:

```
FISH equivalent to:

Animal
AND
lives in SOME Under Water Habitat
```

It should be noted that the classes and properties discussed in this example are not connected with any existing ontologies (such as the ontology for biodiversity by Walls et al., 2014), and the definition is extremely simplified. About the definition used in this example, we should note that it is targeted to a very specific task: for example, if we want to characterize fish according to their habitat, we can recall the property that they live underwater; however, if we want to characterize the role of fish in a diet, we can address their nutritional values.

3.2 - SEMANTIC STUDIES AND ENCODING OF THE "GEO" CONCEPTS

The aim of this section is to go through the studies and the encodings for the concept of geoheritage and other associated concepts, which are geodiversity and geosite. First, we analyse the definition, identifying the classes of object that we need to characterize, then we select the criteria for the definition of those classes, finally we translate the indication in the machine-readable language and propose the final axioms and models for the knowledge. Focussing on our goal, which is the creation of a model for the representation of the knowledge about geoheritage and geosite to aid the field work, we rely on the OntoGeonous[23] ontology, an ontology which is meant to describe the knowledge contained in a geological map. We will also exploit the controlled international standard vocabularies.

[23] GitHub repository for OntoGeonous: https://github.com/vlombard/ontogeonous

In the next chapters, regarding the design of an operative tool and the related tests, we will discuss pros and cons of the use of these standard vocabularies.

3.2.1 - Geoheritage

We will start with the analysis of the concept of geoheritage. As discussed in the previous chapters, almost all the definitions have two features in common: (i) every element of geoheritage is an element of geodiversity, and (ii) each element of geoheritage must be assigned a value from a predetermined list. This aspect is better underlined in Tab. 3.2; all the considered definitions are fragmented and compared in their macro component, in order to underline the two main aspects and how they are almost completely shared. For geoheritage, the definitions underline quite a simple structure; in fact, the table is organized with two main columns, one collecting the information regarding the macro type of object (i.e., the superclass) and the other describing the constraints that differentiate the elements of geoheritage from the elements of its superclass (i.e., the conditions that are expressed by the properties). Below, we analyse the information that is present in the table, to support the design of the knowledge model for the concept of geoheritage.

	Concept	Subclass of	Constrained by
Brilha (2018)	Geoheritage, or geological heritage in its extended form [..]	is materialized by [..] elements of **geodiversity**, namely minerals, fossils, rocks, landforms and their landscapes, soils, and active geological and geomorphological processes.	[...] by exceptional elements [...]
Brocx And Semeniuk (2007)	Geoheritage:	Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, paleontological, geomorphic, pedologic, and hydrologic attributes, at all scales [...]	[...] that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference.
Dong et al. (2013)	Geoheritage refers to	the existing **geodiversity** in a given place [...]	[...] awareness about the value of geoheritage sites (scientific, aesthetic, educational, tourism, economic, intrinsic)
Georgousis et al. (2021)	Geoheritage includes	those elements of **geodiversity**	that have scientific, educational, cultural, aesthetic, and ecological value for humans
Gray (2018)	Geoheritage are	those parts of the identified **geodiversity** of the earth	that are deemed to be worthy of conservation because of their importance/value.

Kubalikova (2013)	The term geoheritage was defined as	those components of natural **geodiversity**	of significant value to humans, including scientific research, education, aesthetics and inspiration, cultural development, and a sense of place experienced by communities [...] things we would wish to retain for present and future generations
NPS[12]	Geologic Heritage	encompasses the significant geologic features, landforms, and landscapes characteristic of our Nation	which are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values. Geoheritage sites are conserved so that their lessons and beauty will remain as a legacy for future generations.
Sharples (2002)	Geoheritage comprises	those elements of natural **geodiversity**	which are of significant value to humans for non-depleting purposes which do not decrease their intrinsic or ecological values
Szepesi et al. (2017)	the geological heritage (or geoheritage) and the geosites	refer to particular types and locality of **geodiversity** elements	that have acquired scientific, cultural/historical and or socio-economic value
Vasiljević et al. (2011)	Geoheritage	only components of **geodiversity**	that have significant value to humans, with scientific, educational, aesthetical and inspirational meaning can be considered as geoheritage. Furthermore, geoheritage is considered to be the concept that comprises existing cases of geodiversity, identified as having conservation significance
Vujičić (2011)	Geoheritage	The components of **geodiversity**	that have scientific, educational, aesthetical and inspirational significance [...]and they are identified as having conservation significance

Table 3.2 - Definitions of geoheritage fragmented in their simplest concepts and mutually compared.

Subclass of

If we analyse the third column of Tab. 3.2, we will see that almost every author directly cites geodiversity in his/her definition, stating that geoheritage is part of geodiversity. In the table, every reference to geodiversity is highlighted in bold (this occurs in 9 definitions out of 11). The direct inference of these statements would be that geoheritage is a subclass of geodiversity. However, the reference to geodiversity is associated with the specification that it is "elements", "components", "parts" of geodiversity that can possibly satisfy the conditions to be geoheritage. Hence, for our encoding, we will focus on the elements of geodiversity, introducing a class, named `Geodiversity Element`[24] (from here, GdE). We will analyse this class in section 3.2.2.

[24] Note that the classes are expressed in a singular form and their writing is in camel case.

The definitions by Brocx and Semeniuk and NPS, differently, do not contain the reference to geodiversity, preferring base their definitions on the concept of geology in general, providing a list of the geological elements that can be possible candidates for achieving the geoheritage status.

Constraints

Not all the items that belong to the `Geodiversity Element` class can also be considered as geoheritage. In Tab. 3.2, we can notice that all the definitions restrict the geoheritage to those elements with a special value, or importance, or significance, or because they are exceptional (red highlighting in the table). In particular, the reference to the value is the most used: an element of geodiversity with a value is geoheritage. In particular, several definitions (and also other sources, as reviewed in Chapter 2) provide lists of values that are defining geoheritage. For the definitions of the class for geoheritage, however, we can just define that the necessary and sufficient condition for an item of the GdE class to be considered as geoheritage is that it must be characterized by a value for geoheritage. Such values are collected into a vocabulary of values (that we are going to deepen in section 3.3). So, the restriction can be defined by the relation of an element from GdE class with a term from the Values vocabulary, a relation that can be described by a property named "*hasValue*"[25].

This is a specific vocabulary for the values of geodiversity. However, in the definitions of geoheritage, many different lists of values are proposed, containing different terms. This topic will be discussed in the next section (3.3); for now, we define a placeholder for such a vocabulary, that can be named "`GeoheritageValue`".

Geoheritage: target feature type

Finally, we can consider the class that we are going to study and describe. We ought to remember that we consider classes as sets that contain individuals, described using formal descriptions that precisely state the requirements for membership of the class (e.g., the class Cat contains all the individuals that are cats in the study domain, see Tab. 3.1).

Geoheritage is a collective term that refers to the group of special (geological) elements. Hence, this is not a concept that is adequate for our purposes. Since we are evaluating the elements of geodiversity, similarly, we can consider that we are characterizing "Elements of geoheritage", the summa of which makes the geological heritage.

This is a sort of cultural heritage: "*Cultural heritage includes artifacts, monuments, a group of buildings and sites, and museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artifacts, sites or monuments. The definition excludes ICH related to other cultural domains such as festivals, celebration etc. It covers industrial heritage and cave paintings*." UNESCO (2009).

In this definition of cultural heritage, they are the singular elements, i.e. monuments, artefacts, or traditions (intangible cultural heritage), that compose the cultural heritage. Being cultural (or geological) heritage can be considered as a status that specific elements can get; in particular, some elements of geodiversity can get the status of elements of geoheritage (class name: `Geoheritage Element`, GhE).

Summary and axiom

[25] As for the classes, the properties are written in camel case, but with the first letter in minor case

From the study of the definitions of geoheritage we have created some ontology elements that are necessary for the description of this concept.

1. We defined class Geoheritage Element, that is a geologic feature (actually based on geodiversity) that has been attributed the status of Geoheritage with respect to its relevance to humans. In accordance with the definition for the Cultural Heritage, this applies to both the tangible and intangible elements (e.g., rock and processes respectively).
2. The class `Geoheritage Element` is subset of a wider class, `Geodiversity Element`.
3. The distinction between a general instance of GdE class and an instance that is included in the GhE class is the attribution of a value. In machine readable language, this is encoded in the property that we named *`has Value`*.
4. The property defines the connection between our target class (GhE) and the list of values that are collected in the vocabulary named "`GeoheritageValue`".

These elements can be collected in an axiom that define what is an element of geoheritage (see also Fig. 3.2) in our study domain:

`GeoheritageElement` EQUIVALENT TO
`GeodiversityElement`
`AND`
`hasValue SOME GeoheritageValue`

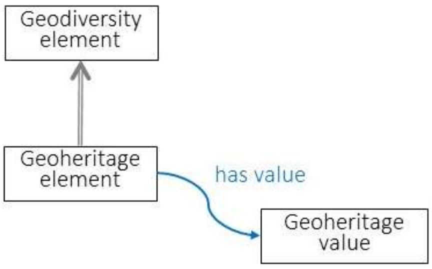

Figure 3.2 - Schema of encoding of the `Geoheritage Element` class

3.2.2 - Geodiversity

As discussed in the previous chapter, the definition of geodiversity is quite shared in literature. As reported by Boothroyd and McHenry (2019), most of the authors accept the definition proposed by Gray (2013). However, a smaller part of the authors prefers the definition by Brocx and Semeniuk (2007). The main difference is the limitation of the study of the geodiversity to a limited area (independently on the size) but rejecting the application of the concept at a global (planetary) scale.

B&S (2007)	the natural variety of	of geological (features)	geomorphological (features)	pedological (features)	hydrological features	of a given area	[...]their formative processes	
G (2013)	The natural range (diversity)	of geological (rocks, minerals, fossils)	geomorphological (landforms, topography, physical processes).	soil	hydrological features			It includes their assemblages, structures, systems, and contributions to landscapes

Table 3.3 - Definitions of geodiversity fragmented in their simplest concepts and mutually compared (B&S: Brocx and Semeniuk; G: Gray).

In fact, if we fragment and analyse the definitions of geodiversity (Tab. 3.3), as we did for the geoheritage definitions, we will see that almost every aspect of the definitions fit. Most of the used words are the same (geological, geomorphological, ...). Some exemptions are in the first column, i.e., variety VS range and diversity. We searched these terms on the WordNet tool (Fellbaum, 2005): variety and diversity belong to the same synset, as in Fig. 3.3; moreover, biodiversity stands as a hyponym (narrower concept) those terms (in our case, we can also consider geodiversity along with biodiversity).

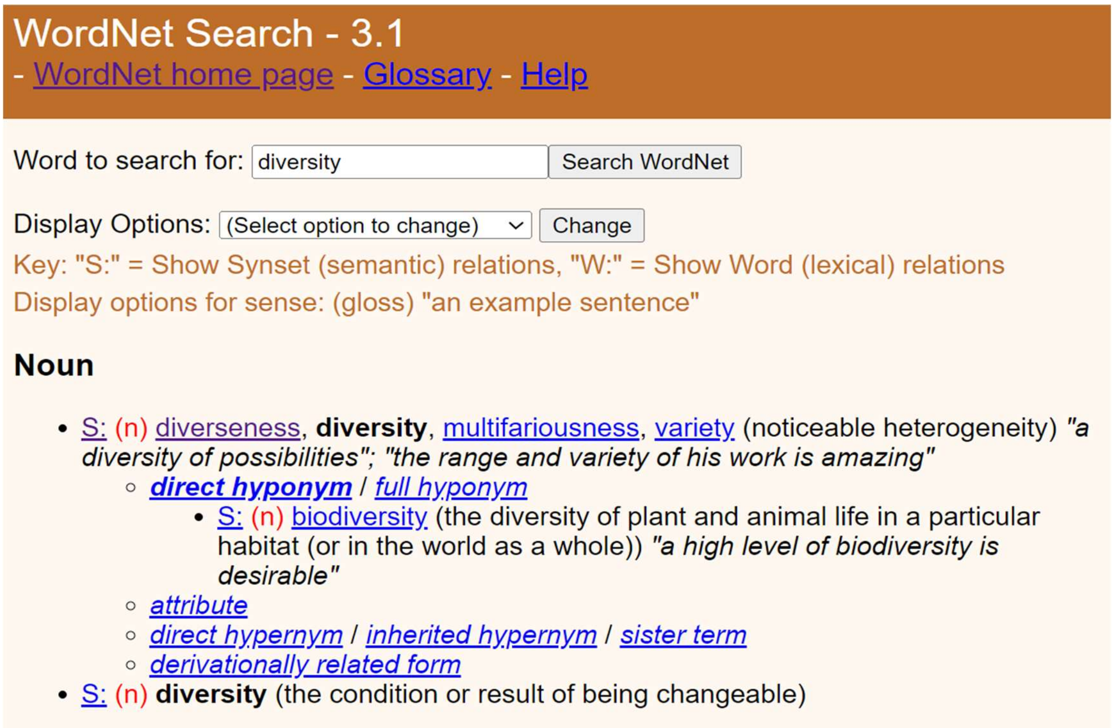

Figure 3.3 - Biodiversity as a hyponym of diversity (screenshot from Wordnet[26]): from our point of view, we can also include geodiversity.

[26] Link to the search engine of WordNet, set on the word "Diversity" as displayed in Fig. 3.2: http://wordnetweb.princeton.edu/perl/webwn?o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&s=diversity&i=1&h=100000#c

The other difference in terminological use is soil VS pedological. However, these are respectively the considered element (soil) and its related adjective, or reference to the discipline that studies soils.
In general, the two definitions agree down to the list of elements considered valid for describing geodiversity. The diversities fall in the final parts of the definitions, namely:

- the global/local perspective of geodiversity: as previously discussed, the some authors consider geodiversity from both a global and local points of view (the geodiversity as a characteristic of our planet, and the geodiversity of an area, that can be evaluated through assessing methods), in accordance with the definition by Gray (2013), which does not constrain the concept to a given area; some others, in accordance with the definition by Brocx and Semeniuk (2007) restrict the geodiversity as a characteristic of a well-defined area (a region, a nation…)
- the processes: the definition by Brocx and Semeniuk (2007) refer to the processes that are responsible for the generation of all the features previously listed. The reference to the processes in Gray's definition, vice versa, is explicitly related to the geomorphological feature, i.e., in the definition are cited the physical processes in the brackets that deepen the geomorphological features, along with landforms and topography). Hence, the reference to the processes in the first definition is more comprehensive than the second, as also the processes that created, e.g., the geological features and the soils.
- Relations among the elements: in the definition by Gray, the associations of elements of geodiversity are taken into account. Hence, not only the singular elements make geodiversity, but also particular association of them. For example, an association of landforms with different origins, like glacial and fluvial.

Geodiversity and geodiversity elements

The definitions of geodiversity indicate a characteristic of our planet, something that exists independently from our awareness, either at local or global scale. As discussed for geoheritage, geodiversity cannot be considered as a class. There cannot exist instances of "geodiversity", but there are elements that, together, display the geodiversity. These elements are the elements of the abiotic nature, the ones listed in the definitions of geodiversity, namely geological, geomorphological, pedological, hydrological features. These are the elements that characterize the geodiversity; we can collect them in the `Geodiversity Element` class that we introduced in the previous section. Some instances from the GdE class are those that can be associated with a value and consequently identified as a geoheritage element (and thus be classified in the GhE class). For this purpose, we are going to elaborate on the elements that are listed in the definitions. If leaning on the definitions, there are no specified constraints for these elements, hence we will not set any property. Elements of geodiversity in the literature (Gray, 2013) includes features of different nature (e.g., landforms and processes, materials features and immaterial structures) that must necessarily be re-assigned in an ontological model. These are the Geologic features (in Gray, furtherly specified as rocks, minerals and fossils), Geomorphologic features (in Gray, furtherly specified as landforms, topography and physical processes), Soils and Hydrologic features.
We are going to discuss these elements in order to create a structure for the classification of the elements that could be geoheritage. The task is to support the representation of the elements of geoheritage from the point of view of the field work, usually associated with the production of geological maps. Geological maps are graphic interpretative representations of the geological elements on a map, usually including rocks (represented through geologic units), the mutual relations and

geometries of those rocks (represented through the geologic structures), and the landforms. There are also specific maps for the soils and for the hydrological/hydrogeological features. Hence, all the elements that are cited in the definitions of geodiversity are normally represented in maps.
Since we are operating in the semantic web context, and in accordance with the linked data paradigm, we aim at exploiting existing sources of encoded knowledge. As introduced in the previous chapters, we are leveraging on existing ontologies for the geosciences. In particular, we build upon OntoGeonous (Lombardo et al., 2016; 2018), which is based on the international standard GeoScienceML[27]. In the following subsections, we will deepen the proposed subclasses for GdE in order to characterize the possible elements that can be geoheritage candidates.

Geologic features (rocks, minerals and fossils)

The top class in OntoGeonous is named `Geologic Feature`. This class contains general geological features that are supposed to exist coherently in the world, and that can correspond to a map legend item[28]. However, this class does not correspond to the geologic feature of the geodiversity definitions, which is meant more or less as the bedrock features, the rocks, and its component, the minerals, along with the fossils, possibly hosted in sedimentary rocks.

Within GeoScienceML, these three elements are included as follows:

- The rocks (blue circle in the picture) are described by their lithologies, through the CGI simple lithology vocabulary[29]
- Minerals and fossils are both represented in the Earth Material UML schema (Fig. 3.4):
    - minerals are part of the Geology Basic: Earth Material (green circle in the picture), and described by a Vocabulary, Mineral Name Term (that is placeholder, since no terms are listed)[30].
    - fossils (yellow circle in the picture) are included in the “Organism” under the Earth Material Abstract Description[31]

This organization provides a description of the rocks through their lithology, and of the minerals and fossils (through vocabularies that are only meant as placeholders and not populated). If considering “ex-situ” elements of geodiversity, for example samples that are in a museum, this description could be sufficient.
However, if considering “in-situ” elements, some more information can be added, in particular for what concerns the rocks. In fact, when dealing with a geological map, usually the rocks are not only described by their lithology, but through a combination of characteristics. For example, their lithology and their stratigraphic settings (lithostratigraphic units) or their deformation or evolutive story (Lithotectonic units). These features, within the GeoSciML standard and the OntoGeonous ontology, are described within the class `Geologic Unit`.

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[27] GeoScienceML website: www.geosciml.org
[28] GeoScienceML, Geologic Feature: https://docs.ogc.org/is/16-008/16-008.html#34
[29] CGI simple lithology vocabulary: http://resource.geosciml.org/classifier/cgi/lithology
[30] GeoScienceML, UML for the Mineral: https://geosciml.org/doc/geosciml/4.1/documentation/html/index.htm?goto=1:1:4:2:286
[31] GeoScienceML, UML for the Organism: https://geosciml.org/doc/geosciml/4.1/documentation/html/EARoot/EA1/EA1/EA4/EA2/EA290.htm

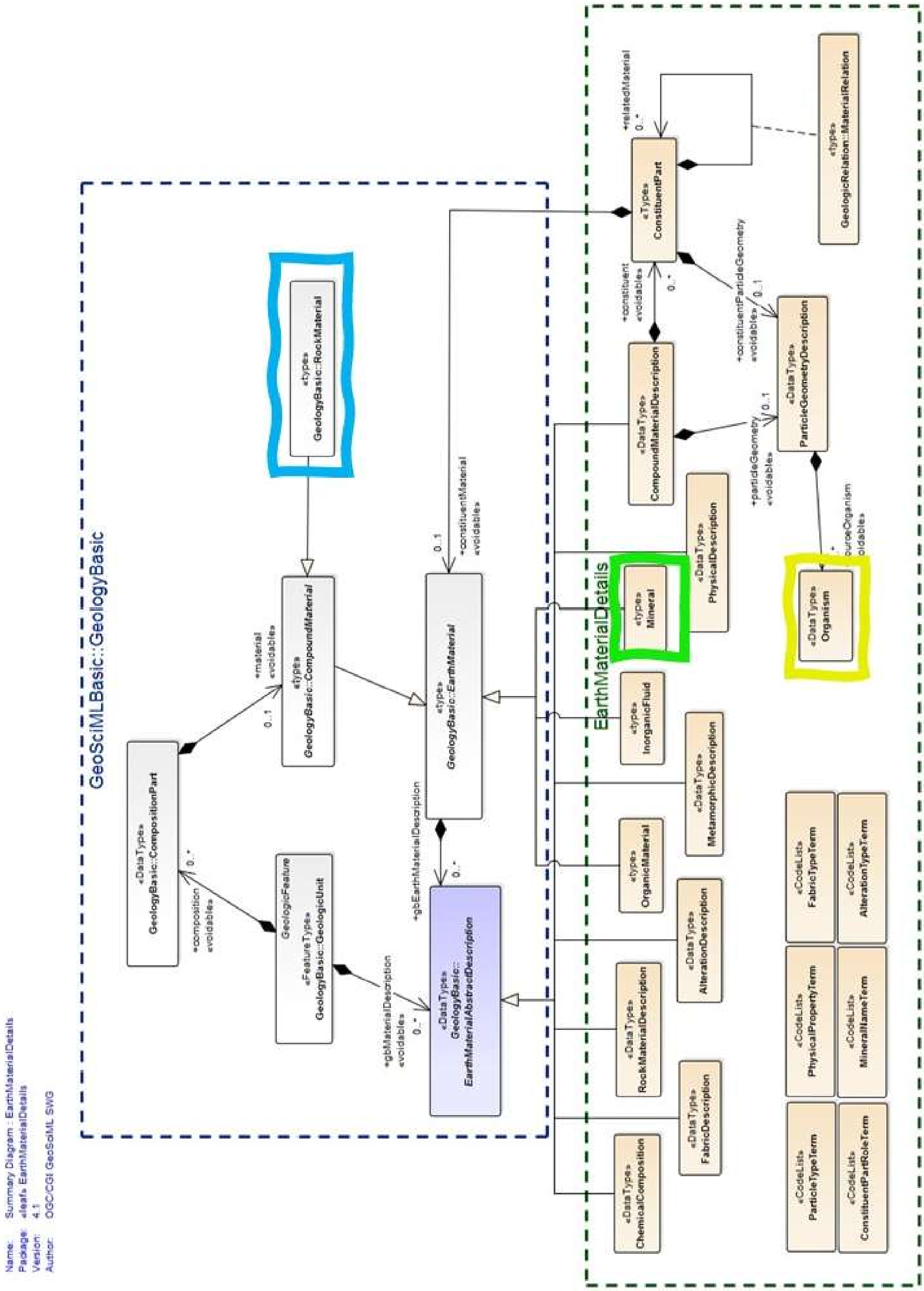

Figure 3.4 - Earth Material schema (modified from GeoSciML UML[32]). In the upper part, the Basic Geology package, linked to the Earth Material Details. Rocks (blue), minerals (green) and fossils (yellow) are represented in the schema.

[32] GeoScienceML, UML for the Earth Material Details: https://geosciml.org/doc/geosciml/4.1/documentation/html/EARoot/EA1/EA1/EA4/EA2/EA270.htm

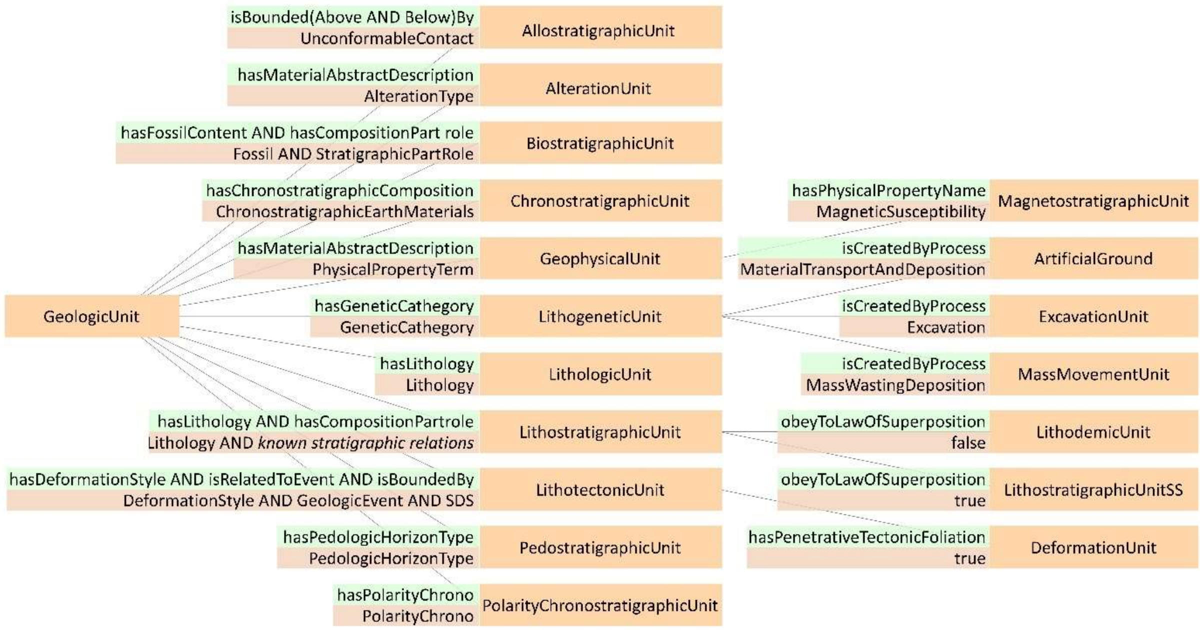

Figure 3.5 - Subdivision of the geologic units, from WikiGeo[33]

The **GeologicUnit** class is meant to collect instances that are bodies of material in the Earth that are represented in a geological map. Based on the discriminatory characteristics, there are several types of geologic units (usually, only some of them are represented in a unique geological map). In Fig. 3.5 there is a subdivision of the geologic units based on their characteristics, which are encoded in the OntoGeonous ontology. The main types of Geologic Unit are represented in the brown squares in the centre of the picture, while in the left part there are some of their subclasses (e.g., Deformation Unit is a subclass of Lithotectonic Unit). The characterization of all these classes is based on the properties and the values that are required for the classification of an item in that class. For example, a Lithostratigraphic unit must have a lithology specification (type of rock) and a part role specification (role of that specific instance as a part of a wider stratigraphic section).

Out of the three elements that are cited in the geodiversity definitions (namely, rocks, minerals, and fossils), two are relevant for the definition of some of these classes. The characterization of the fossil content is mandatory for the definition of a Biostratigraphic Unit, while the type of rock (lithology) is discriminating for Lithologic and Lithostratigraphic Unit.

In conclusion, the geodiversity elements that are listed in the first parts of the definitions (those that are called geologic features in the definition) can be encoded in two different ways, depending on whether they are in-situ or ex-situ. For the in-situ elements that are represented on a map, we propose the use of the **GeologicUnit** class and subclasses from the OntoGeonous ontology. For the ex-situ elements, the characterization of rocks, minerals and fossils might be sufficient; however, we can also apply the classification in geologic units to, e.g., a sample of rock in a museum, or an erratic boulder, of which we might know the original geologic unit.

[33] Link to the WikiGeo geologic unit pare: https://www.di.unito.it/wikigeo/index.php?title=GeologicUnit

Geomorphological feature (landforms, topography, physical processes)

Within GeoScienceML, the Geomorphology describes features that comprise the shape and nature of the Earth's land surface (i.e., landforms), both created by natural or anthropogenic processes[34]. In this context, the elements of geomorphology are a synonym of landforms, and they design the Earth's surface, thus describing the topography[35]. In the knowledge model proposed by GeoScienceML there is a subclass of `Geologic Feature` for this type of features, i.e., the `Geomorphologic Feature` class. However, this class contains both natural and anthropogenic features, included in the two sibling subclasses of `Geomorphologic Feature`. Since the geodiversity is the "*natural* range of..." we shall not consider the anthropogenic features, but only those features that are created by natural processes. This class is named **`Natural Geomorphological Feature`**[36], and it is encoded, along the other subclasses of `Geologic Feature`, in the OntoGeonous ontology[37].

Among the elements listed in this part of the definition there are also the physical processes. As previously stated, the processes are already considered within the description of the types of natural geomorphological features. However, their relevance is not only in relation with the features that they have created (i.e., processes that acted in the past for generating landforms), but also in consideration of active processes. The CGI vocabularies include a vocabulary for processes, which is named Event Process[38]. This vocabulary offers a list of terms for the description of the processes that can describe those that are occurring on the Earth surface. However, the purpose of this vocabulary is the description of the geological events feature types: it is not a feature that has a process, but the event to which that feature is related.

`Geologic Event` is one of the subclasses proposed by GeoScienceML for the `Geologic Feature` class. It is an event that acted in geological history that modified some geological features[39]. To be defined, it must be provided with an age (both expressed numerically or with named age, with terms coming from the Geologic Time Scale), but also information about the acting process or environment can be added (a vocabulary for the event environment is provided by CGI). Along with `Geologic Unit` and `Geomorphologic Feature`, also `Geologic Event` is included in OntoGeonous[40], with a proposal of subdivision based on the process.

In conclusion, the geodiversity elements that are considered in the "geomorphology type" by the definitions, can be represented by two of the classes which are proposed by the standard GeoScienceML and encoded in OntoGeonous. These classes are **`Natural Geomorphologic Feature`** (subclass of `GeomorphologicFeature`, in which no anthropogenic morphologic feature are includes) and **`Geologic Event`**, a class collecting abstract features that make the basis for the description of the processes, both active in the past or at the present day.

[34] GeoScienceML, geomorphology: https://docs.ogc.org/is/16-008/16-008.html#96

[35] Topography is the study and description of the physical features of an area, for example its hills, valleys, or rivers, or the representation of these features on maps (https://www.collinsdictionary.com/dictionary/english/topography)

[36] GeoScienceML, Natural Geomorphological Feature: https://docs.ogc.org/is/16-008/16-008.html#100

[37] GitHub repository for OntoGeonous, Geomorphological Feature: https://github.com/vlombard/ontogeonous/blob/master/OGN_1.5-GeomorphologicFeature.owl

[38] CGI vocabulary for Event Process: http://resource.geosciml.org/classifier/cgi/eventprocess

[39] GeoScienceML, Geologic Event: https://docs.ogc.org/is/16-008/16-008.html#71

[40] GitHub repository for OntoGeonous, Geologic Event: https://github.com/vlombard/ontogeonous/blob/master/OGN_1.4-GeologicEvent.owl

Soil/pedological features

The soil, which is the upper strata of a section, lying over the bedrock, is the result of alteration processes on the rocks. According to the organization and the properties proposed by GeoScienceML, these are the discriminatory characteristics for the **`Pedostratigraphic Unit`**, a subtype of Geologic Unit that is derived from some alteration process of the upper part of the bedrock. This unit is encoded within the subclasses of Geologic Unit in OntoGeonous, already discussed for the "geologic features" part of the geodiversity elements.

Hydrologic features

Hydrologic and hydrogeologic features are not considered in OntoGeonous. There is a reference to a specification for the ground waters in GeoScienceML, which are also encoded in SWEET ontology[41] (Raskin and Pan, 2005; Raskin, 2006).

"and their formative processes" (Brocx and Semeniuk, 2007)

We should take into account that not only "geomorphological features" *sensu* geodiversity are created by natural processes. Every other feature is in the environment due to some process that acted for its creation. Hence, the description of the Geologic Event, as discussed in the section dedicated to the landforms, can be applied for every element within those in the geodiversity sphere. This means an enhancement of the meaning of geodiversity, that includes both the active processes, and the evidence of past geological processes, of which rocks, landform and structures are the result and their tangible witness.

"It includes their assemblages, structures, systems, and contributions to landscape" (Gray, 2013)

In Gray's (2013) definition some other elements are listed.

- Structures: within the subclasses of `Geologic Feature` proposed by GeoScienceML and encoded in OntoGeonous, one last class was not discussed in this section yet. It is the class concerning the geometrical characterization of the rock materials, namely the `Geologic Structure` class[42], which in OntoGeonous is considered as sibling of the Unit, Event and Geomorphological Feature classes. This class collects faults, folds, planar structures within the rocks, such as stratification or foliation, or boundaries between rock units. They are features of high relevance while drawing a geological map and provide a significant contribution to the setting of the landscape, and consequently to the geodiversity.
- "Assemblages and systems" mean association of the previous discussed elements. Within the encoding of OntoGeonous, a new class, not proposed by GeoScienceML was hypothesised. It should collect association of Geologic Features. Originally, it was meant to collect structure associations, such as fracture sets, but special association of other geologic features may be relevant to describe, like associations of landforms or units. This class, briefly discussed in WikiGeo[43] is still a work in progress and needs further deepening. However, can describe such elements within the field of geodiversity.

Contribution to landscapes can be associated with the description of the topography, already discussed in this section.

---

[41] Link to the Hydrologic feature in SWEET ontology: http://sweetontology.net/realmHydro

[42] GeoScienceML, Geologic Structure: https://docs.ogc.org/is/16-008/16-008.html#82

[43] WikiGeo page with the description of the Geologic Association concept: https://www.di.unito.it/wikigeo/index.php?title=GeologicAssociation

Conclusion on the Geodiversity Element class

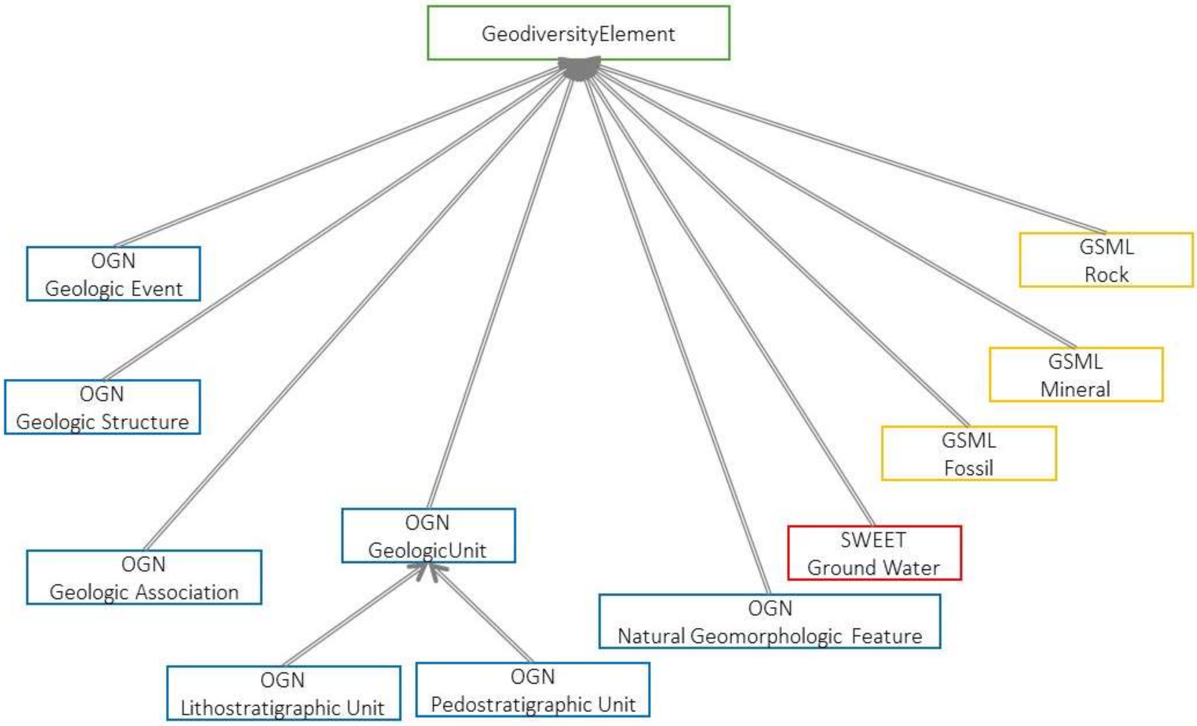

Figure 3.6 - The subclasses of Geodiversity Element in our domain (relation with "subclass of" arrow). The blue squares represent the OntoGeonous classes, in yellow and red the concepts coming from GeoScienceML and SWEET ontology respectively.

Fig. 3.6 represents all the discussed classes. Most of the identified elements come from existing classes in the OntoGeonous ontology (blue in the picture), while some others refer to elements that are not encoded in OntoGeonous, like the Hydrological feature (red in the picture) and the concepts in GeoScienceML (yellow). These classes all come from other ontologies and belong to other taxonomies. However, in the context of our ontology for the representation of the geodiversity and geoheritage elements, these are all subclasses of the Geodiversity Element class.

3.2.3 - Geosite

The third element that is included in the present study is the geosite. To deepen the concept, we selected four definitions, those in Tab. 3.4. These definitions were selected either because they are adopted for national inventories (Wimbledon, 1995, for Italy and García Cortés and Carcavilla, 2013, for Spain), or because they are more recent definitions explicitly reported into research papers concerning geoheritage (Brilha, 2018, and Newsome and Dowling, 2018).
These definitions display one common point, namely the relation of a geosite with its location ("geography" column in Tab. 3.4): namely, geosites are defined areas of land. The distinctive characteristic of the geosites, with respect to other territories, is the importance of that territory, related to attribution of some geological interest or geoheritage values. This aspect, in fact, is the one that causes difficulty of encoding, because of ambiguity. By one side, the first two definitions describe geosites as territories that contain elements of geoheritage: in the definition by Brilha (2018) the

reference to the geoheritage is inferred by the indication of the geodiversity elements with a value of geoheritage, while in the definition by García Cortés and Carcavilla (2013) the reference to geoheritage is explicit in the text. This point of view is in accordance with Brilha's proposal (2016; 2018) of considering geosites only as in-situ occurrences of geoheritage elements. On the other side, the other two definitions consider geosite in relation to the interest: a geosite is a place in which one can find some element that is of geological interest. This is aligned with many national inventories for geosites, that classify the elements based on the geologic interest.
From the latter point of view, we can introduce the concept of interest. According to Díaz-Martínez and Fernández-Martínez (2015), the interest and the values can have a link within the sphere of geoheritage. In fact, it will be clear in the next section, there is a strong connection within these two concepts (i.e., value and interest), and the identification of the interests can bring to the attribution of a value (Perry, 1914, see section 3.3).
The second aspect is that no explicit citation of geologic (or geodiversity) elements is present in this second point of view. However, from a logical point of view, the reference to the geodiversity element seems to be an essential condition for the identification of interests or value (it is the geologic feature in the territory that can be interesting and thus provide interest to the territory).
Hence, the four definitions can be merged to achieve the conditions that define a geosite. Below, we analyse all the elements that will be necessary for the encoding of the class "Geosite".

	Geosite	Geography	Elements	Importance
Brilha (2018)	[...] is usually known as "geosite"	The in-situ occurrence	of geodiversity elements	with high scientific, educational, aesthetic, and cultural value [...]
García Cortés and Carcavilla (2013)	A Geosite, or Site of Geological Interest, is an	area	that is part of the geological heritage of a natural region as constantly shows one or several characteristics that are considered significant in its geological history	
Newsome and Dowling (2018)	[...] are termed geosites	Key localities		of particular geological interest [...]
Wimbledon (1995)	(geosites)	Site location area or territory		in which it is possible to identify a geological or geomorphological interest for conservation

Table 3.4 - Definitions of geosite fragmented in their simplest concepts and mutually compared.

Subclass of

All the definitions agree in stating that geosites are areas, territories, localities… Hence, the class "Geosite" can be considered as a subclass of a class that describes a defined area of land. In the spirit of linked data and semantic web, which is based on exploiting the existing encoded knowledge to describe new features, we should search for a class that describes such an area of the Earth surface, that could be furtherly characterized as a geosite (if it possesses the right attributes, which will be discussed below). This feature can be the “Site”[44] in BFO ontology[45], of which “Geosite” becomes a subclass. An issue to be discussed is scale: in fact, if considered from a cartographic point of view, we will notice that most of the geosites are marked as points, i.e., non-dimensional features. This is a representation issue that depends on the scale of the map. For example, if we look at a national map the scale would be small enough to consider every geosite as points. But at a local scale, most of them will become “big” enough to be represented as areas. For the aim of our work, we will consider that every geosite, even the smallest, cover an area of the Earth surface, and they are thus (very small) Sites. Its formal encoding is distinct from its marking on a map.

Constraints

Geosite is a subclass of Site, as discussed above. What is differentiating a Geosite from a general Site is that a geosite is an area that contains special elements of geodiversity. This information is explicit in some definitions and inferred by the discussion in the others. For the encoding of the Geosite class, the presence of a special element of geodiversity is the necessary condition for a Site to become a geosite. To encode this condition, we need to define two different elements: the type of element that characterizes the Geosite and the relation that holds between that element and the geosite.
First, the relation between a site and its geodiversity elements is realized through the property “has Geodiversity Element” (a specialization of property “Related feature” from GeoScienceML).
Second, we should consider that almost every possible instance of the class Site on the Earth has at least one geodiversity element in it: indeed, elements of geodiversity are everywhere on the Earth. However, this is not enough to make geosites of those Sites: the condition for a Site to be a geosite is that the elements of geodiversity within are outstanding.
Therefore, we need a restriction on the geodiversity elements that are valid for a geosite (i.e. the special ones). This restriction falls in the relation of the geodiversity element with an interest or a value. For what we have discussed until now, if an element of geodiversity is related to a geoheritage value, that it can be classified as an element of geoheritage. If we follow the first two definitions of Tab. 3.4, we will consider geosites as occurrences on the territory of geoheritage. In this case, the element type that restricts the geosites would be elements from `Geoheritage Element` class, or “`Geodiversity Element` AND (*`has Value`* SOME `Geoheritage Value`)”
Other definitions, however, are not so restrictive, as they consider as sufficient the identification of an interest in that area, an aspect that from a logical point of view means that in the area there is an element of geodiversity that is interesting for some reason. As we will discuss in the next section, several philosophical theories establish a direct relation between the interests and the values: i.e., something has value if an interest is satisfied in it. Hence, from our point of view, the attribution of an interest can be the justification for the attribution of a value. We aim at adopting this second type of modelling for the geosites, as it is more inclusive than the restriction with the values. Hence, following the model proposed above, we can state that geosites are Sites in which “`Geodiversity Element` AND (*`fulfils`* SOME `Interest`)” are present. Later, we will discuss the relations between the properties “*`has Value`*” and “*`fulfils`*”.

[44] Link to the class Site in the BFO ontology: http://purl.obolibrary.org/obo/BFO_0000029
[45] Link to the classes of the BFO ontology: https://ontobee.org/ontology/BFO

Axiom

In conclusion of this section, we summarize the conditions for a geosite to be classified as instance of the class Geosite:

```
Geosite
EQUIVALENT TO
Site
AND
hasGeodiversityElement SOME
(GeodiversityElement AND (fulfills SOME Interest))
```

Geomorphosite: sibling or subclass of Geosite?

The definition by Brilha (2018) cites also the concept of Geomorphosite. This concept was first proposed by Panizza (2001), and adopted by other authors; among the others, Reynard (2005), Coratza and Hobléa (2018), Kale (2015); finally, Regolini (2012), who discusses the methods for the cartography of the geomorphosites. It refers to geosites that are characterized by a geomorphological interest. According to Reynard (2009) there is also the geomorphological heritage, which characterize those geomorphological elements of the geodiversity that are of some value. In the definitions reported by Brilha (2018) it seems that geosite and geomorphosite could be considered as siblings, two elements that are subtypes of "Site" and that are distinguished by the element of geodiversity that is interesting in that Site. However, two problems from a logical point of view have to be taken into account:

- If we select the type of geosite based on the geodiversity element type that is in it, we should identify one class for every type of geodiversity element, not only for the geomorphological elements. For example, we should create a "soil-site" class, or a "Fossil-site" class. However, in literature, only Geomorphosites are explicitly cited and defined.
- Sibling or daughter class? If we analyse the axiom that we propose for the geosite, we can say that a geosite contains at least one element of geodiversity with an interest. In our domain of interest, which is the study of geodiversity and geosite, we can say that `Geomorphologic Feature`, which is the necessary condition item for a Geomorphosite, is a subclass of `Geodiversity Element`. Hence, from a logic point of view, also the Geomorphosite should be considered as a subtype of Geosite, and not a sibling as Geomorphologic Feature is not a sibling of Geodiversity Element in our domain.

Hence, willing to integrate the geomorphosites in our encoding, we should first of all consider it as a subclass of geosite, characterized by a specific element of geodiversity (Geomorphologic Feature). Second, if we would create this class, we should also create a subclass for every other type of geodiversity element that is cited in the geodiversity definition (at least, the four main categories: geological elements, geomorphological elements, pedological elements, hydrological elements). However, this characterization of the classes is not carried out in literature (except for the geomorphology).

3.2.4 - Conclusion, general comment on the encoding

This section sums up the concepts of geoheritage, geodiversity, and geosite. We have collected several definitions for each concept and discussed in detail their common and divergent points of view. We propose a fragmented version of the definitions, in order to evaluate the singular aspects and support the encoding of the concepts. During the encoding process, it is important to follow a predefined task: in our case, it is the geological map-based representation of the elements of geoheritage. Hence, the identified classes derived from this point of view: it is possible to guess that with a different task the classes could be different. The result of the encoding, hence, is an ontological representation of geoheritage elements, based on the study of the geodiversity elements that could be considered geoheritage, and completed by the representation of the relations of those elements with their territory (geosites). In line with the Linked data paradigm (Bizer et al., 2009), we have recognized some concepts as possibly equivalent to others that are already encoded in other ontologies. Other concepts, vice versa, were new and thus some new classes, properties and vocabularies were created.

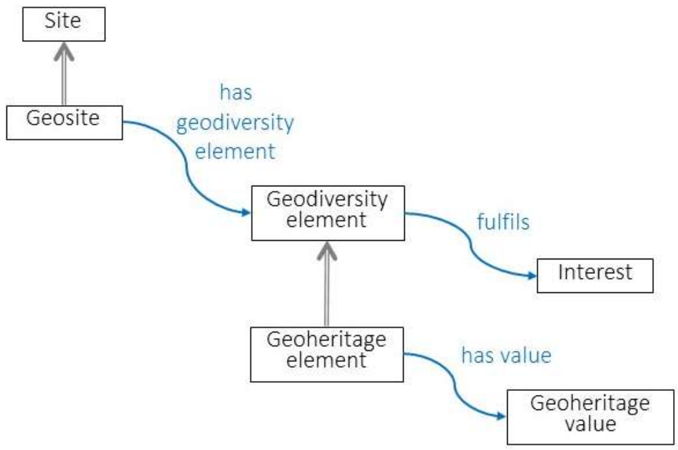

Figure 3.7 - Representation of the encoding of Geodiversity element, Geoheritage element and Geosite.

The relation between the explored concepts is represented in Fig. 3.7. In the picture, the central class is the `Geodiversity Element` (the subtypes are not represented). The class `Geoheritage Element` is a subclass of `Geodiversity Element`, discriminated by the property *`has Value`*. At this point, the encoding of these concepts presents some final issues to point out. First, not all the geodiversity elements have their own encoding. In fact, feature types such as hydrogeological elements, soils or anthropogenic features are not included in the ontologies that we used as a base for the encoding of Geodiversity element subclasses. Consequently, they are not included in the model and in the application that will be the topic of the next chapters. They remain as a hint for future research.
Moreover, it should be considered the nature of some of the types of geodiversity elements that we described. In particular, the Geologic Event is one of the subclasses of Geodiversity element, principally included for the description of the processes that are responsible for the creation and modelling of the rocks and the landforms that we see today. These processes can be both ended in the past or still active today. In the first case, it will be impossible to perceive the process, while in the second case we might see it acting (e.g., river erosion). In both cases, however, it is most likely possible that in a geosite we would see some of the tangible features (e.g., rocks or landforms) on which the processes of the geologic events act, rather than the event itself. This does not influence the attribution of the importance (even events can have interest or value), namely, the event could be the element that gains

the geoheritage status or that makes a site a geosite; according to our model, a site with only one geodiversity element, even of the event class, with an interest, becomes a geosite. However, if at a theoretical level a geosite could be made of even just one event, it should be pointed out that it is improbable to find a geosite without a tangible expression: any site that is possibly delimited on the Earth surface is made of some material, that would be included into one of the geodiversity element subclasses. This aspect deserves further studies, based on the endurant/perdurant theories, which are not integrated in the present work.

Second, the aspects of the values that are fundamental for the classification of the elements of geoheritage. As earlier discussed, the values are presented in several lists that partially overlap. In fact, four values seem to be always present, namely Aesthetic, Cultural, Educational and Scientific values, while others are present only in some lists (e.g., Ecological, or Recreational, and others). To create a model for the representation of geoheritage, we have created a "placeholder" vocabulary for the geoheritage values. The point of having a placeholder vocabulary is that, depending on the task, the vocabulary can be modelled. But, based on the necessity of the various tasks, only some of them can be selected and considered valid for the representation of geoheritage. For example, if the task were the harmonization of all the proposed definitions, a possible sub vocabulary for the geoheritage values could contain the four shared values (Aesthetic, Cultural, Educational and Scientific). The last unsolved issue is the relation between the values and the interests. This issue will be discussed in the next section, mostly based on the theories proposed by Perry (1914), who dealt with the general concept of value.

3.3 - GOING DEEP THE CONCEPT OF VALUE

In the previous section, we identified two different ways to indicate the significance of a geodiversity element: one for the attribution of the geoheritage status, namely the value, one for the definition of a geosite, namely the interest. The hypothesis that we aim at exploring in this section is that through the identification of an interest on an element of geodiversity, we can get to the attribution of a value. This idea is not much explored in the geosciences sphere, even if the use of the interest on the geosites and the values on geoheritage is well rooted. One reference to this work hypothesis is in Díaz-Martínez and Fernández-Martínez (2015). However, we aim to deepen the value-interest relation starting from the general concept of value, which is discussed by Perry (1914), whose theory is here reported and furtherly applied to our topic.

3.3.1 - Perry and the Theory of value

"[…] *value would consist in the fulfillment of bias or interest. An object would be said to possess value in so far as it fulfilled interest or assumed the relation of fulfillment to the term interest, where fulfillment is used in a generalized sense for the consummation of either liking or disliking. Interests may be dispositional or actual, momentary, or permanent, personal, sub-personal, or super-personal, individual or collective, mutually consistent or inconsistent, original or acquired*" (Perry, 1914). The question addressed by the author is the reason for the attribution of a value to some object (concrete or abstract, object or persons, ...). According to the theory, the attribution of a value depends on the satisfaction of an interest: an object possesses a value if at least one interest is satisfied for that object. The concept of interest itself is an extremely variable issue: in fact, there is an uncountable amount of possible interest on a single object, that can change in time and based on the subject that addresses that interest. More recently, some works have been published about the value, mostly devoted to the economic aspects of the value, but the definitions still are similar to the one by Perry. One example is the one by Sanchez-Fernández and Iniesta-Bonillo (2007): "*implies an interaction between a subject (the customer) and an object (the product); it is comparative, personal, and situational (specific to the context); and it embodies a reference judgment*".

For example, we can consider one of the values that are considered for geoheritage, even if only partially shared, which is the "Recreational value". In Aigotti et al. (2004), one of the represented geosites is named "Rocce Montonate di Borgone" (Roches Moutonnée of Borgone), and it is found in the territory of the municipality of Borgone, in the left hydrographic slope of the Susa Valley, NW Italy (more details in section 5.1). This geosite collects several minor sites, among which "Chiampano" and "Rocca Rurà" (which, in the piedmontese dialect, means something similar to "pierced rock"), all set on the Roches moutonnèe that were modelled by the erosion of the Quaternary glaciation in Susa Valley. The history of this site is related to the exploitation of the stone materials: in the area one can find in outcrop a geologic unit named Metagranites of Borgone, made mostly of orthogneiss and lenticular bodies of mica schists within. Both the orthogneiss and the mica schists were quarried: in the locality of Chiampano the orthogneiss were quarried for obtaining building materials, while in Rocca Furà the mica schists were exploited for the extraction of material for the mills. Some of these mills are only partially extracted and are still visible on the walls of the ancient quarry (Fig. 3.8).

Figure 3.8 - The interior of the quarry, visited in February 2024. The mill in the central part of the picture (above the entrance of the quarry) has a diameter around 1,2 m.

These sites are visited by a lot of people, for several different reasons: some of them are hikers that follow one of the several proposed hikes in the low Susa Valley[46] that include the Rocca Furà, some of

[46] One of the proposed paths in the low Susa Valley that include a visit to Rocca Furà: https://visitvaldisusa.it/rocca-fura-un-percorso-ad-anello-tra-leggende-caverne-borgate-ed-antichi-mestieri-della-val-di-susa/

them because of the historical relevance of the site, others because of its final short "via ferrata"[47]. Other users of the area are the climbers, who can choose among the several climbing walls equipped on the abandoned quarry walls, like in Chiampano, or also the multi-pitch historical climbing routes that run on the slopes of Rocca Furà, and get to its top.

From this example, we can see that every singular person might have different interests in the same area: hiking, climbing, and history. Each interest represents a personal inclination demonstrated through the activities chosen during free time on this site: these interests, according to the theory of Perry (1914), are the personal interests that lead to the attribution of a value to this site, namely the Recreational Value. The people that visit this area are not only the local inhabitants. This has an impact on the local economy, as the tourists visit bars for a coffee before their walk, or climbers visiting pubs for a celebrative beer after the climb. Hence, this site is important for the municipality for the earning of the local businesses: Economic Value.

The singular persons, or the institutions of the municipality of Borgone, can be identified as "Actors"; note that the actors may also change their interest in time.

Hence, a key point is to identify this actor of interest: in fact, according to the theory, it is not correct to say that an element has interest. It is the actor that feels an interest that can be satisfied by some object. Finally, the actor satisfies an interest with an object through the presupposition, which expresses a condition that the object must have to satisfy the interest of the agent. For instance, climbers in Turin are familiar with the Borgone walls and multi-pitch, which satisfy their interest in climbing on the Roches Moutonnées of Borgone and give recreational value to the site.

So, if in this system the objects are geodiversity elements and the values are the values of geoheritage, we can have a model to define which elements of geodiversity are geoheritage elements. The issue is hence transposed on the relation that holds between the interests and the values, i.e., which (geologic or geological-related) interests leads to the attribution of which value, and which actor should be engaged to qualify the assessment of the value.

3.3.2 - Encoding of value and interest

From the theory explained and exemplified above, a schema is drawn for the logical representation of the concepts of value and its foundation on the satisfaction of an interest. The issue that we are going to represent is the attribution of a "**`Value`**" to a given "**`Object`**", an action that we are going to name as "**`Value Assignment`**". "Object" is a general concept, that include every instance that can be of interest for someone, including inanimate objects as well as living individuals, such as people or animals. As discussed before, the value assignment depends on the satisfaction of an "**`Interest`**", which we are naming "**`Interest Fulfilment`**". `Value Assignment` and `Interest Fulfilment` are subclasses of a bigger class named "**`Action`**". Its two subclasses are the only defined among the other created classes (axioms in Tab. 3.5). In particular, a general "`Action`" requires three conditions to be classified as an "`Interest Fulfilment`":

A. `Has Actor`, indicating who is having the satisfaction of an interest in some object: the "**`Actor`**"; elsewhere, the Actor is called "Agent", and is defined as a person that can ascribe value

[47] A "via ferrata", that can be translated as "iron path", is an easy climbing route, protected by an iron cable and in which progression is facilitated by the presence of iron steps. It is a facilitated climbing for people who generally hike rather than climb.

to a value object, thereby participating in a value assignment relationship (Andersson et al., 2016);

B. `Has Fulfilled Interest`, indicating the interest that is satisfied;

C. `Has Fulfilling Object`, indicating the object that is satisfying the interest.

The property "C" can be obtained from a property chain that connects the `Interest Fulfilment` to the Object through the Actor, the Interest, the "**`Presupposition`**", and finally to the Object. The Presupposition class represents the reason why a given interest is satisfied by a given object. It might be a condition, or a relation between more than one object. It is also known as "context", i.e., "*any information that can be used to characterize the situation of an entity […] (a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves)*" (Andersson et al., 2016). In general, it represents the idea that the actor has of the object in question, and it is the base of the interest fulfilment. This chain is represented by the properties:

A. `Has Actor`, connecting `Interest Fulfilment` to who is satisfying some interest.

D. `has Interest`, connecting the Actor to the interest.

E. `grounded By`, connecting the interest to the presupposition.

F. `has Object`, connecting the presupposition with the object.

The other defined class is the one regarding the `Value Assignment`, which is dependent on

G. `assigns Value`, connecting the value assignment to the value.

H. `assigns To Object`, connecting the `Value Assignment` to the Object, which must be in time connected with the inverse of the property C, `is Fulfilling Object Of` (J)

The final goal is to connect the Object to the Value. This is attributed by the property has Value (K), which is a chain:

J. `is Fulfilling Object Of`, from the Object to the `Interest Fulfilment` action.

L. implies, relating the `Interest Fulfilment` to the `Value Assignment.`

G. `assigns Value`, connecting the `Value Assignment` to the Value.

These chains converge in the axioms, which are summarized in Tab. 3.5.

Interest Fulfilment	Action and (has Actor some Actor) and (has Fulfilled Interest some Interest) and (has Fulfilling Object some Object)
Value Assignment	Action and (assigns Value some Value) and (assigns To Object some (Object and (is Fulfilling Object Of some Interest Fulfilment)))

Table 3.5 - Axioms of the Action subclasses.

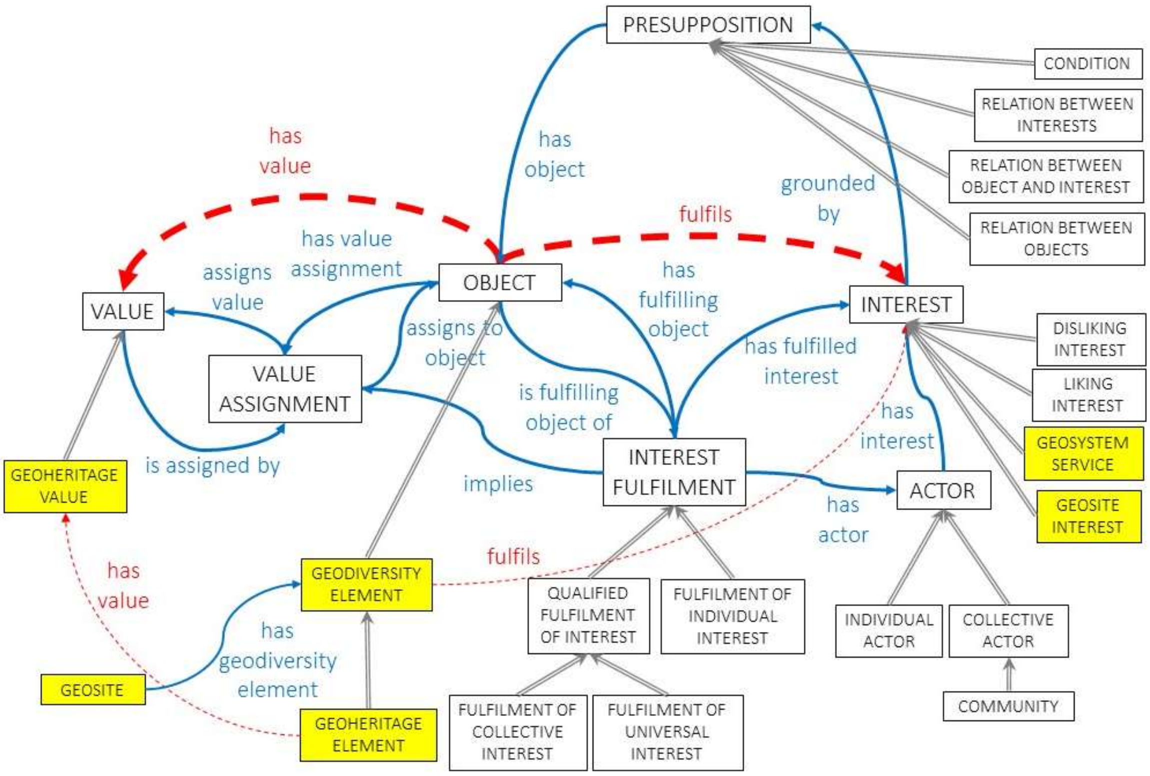

Figure 3.9 - Schematic representation of the connection between value and interest, with the addition of the elements of geoheritage and geodiversity.

Note that the Actor is of very high importance for the process of `Interest Fulfilment`. In fact, according to Perry's theory, there is also the "qualified" interest fulfilment. In particular, an interest fulfilment is qualified when it is either an individual Actor interest that is aware (I know that I am interested in hiking) or if it is an interest from a collective Actor (a community, or an institution like a Geopark, or all of humanity).

This aspect may be of relevance for our study, and for the assessment of values and interests to the objects. For instance, a question that would require some discussion is the limitation of the geoheritage value assignment to those interests that involve collective actors such as Geoparks or Institutions that deal with the conservation of geoheritage.

All the described connections are represented in Fig. 3.9. In the schema, we also introduce the relation with the geoheritage and geosite concepts, in the yellow squares. In this model, `Geodiversity element` becomes a subclass of Object, along with its subclass `Geoheritage element`. Respectively, they relate to `Interest` and **`Geoheritage Value`**. `Geosite` is related to `Geodiversity element` which is related to `Interest`.

3.3.3 - Values and Interest: towards an explicit connection

A question that remains unsolved is which interests fulfil a particular value. The possible connections are almost infinite, limited only by the interests that the actors can have in time towards a single feature. In the field of geoheritage, lists of interests and values have already been created, moreover some connections are already established, like those concerning the interest indicated in the book of

100 geosites (Hilario et al., 2022) towards the Scientific value (Tab. 1.1). From an Italian perspective, we analysed the interests that are used in some regional or local geosite inventories, namely Regions of Friuli Venezia Giulia, Northeast Italy (Cucchi et al., 2009), and Campania, Southern Italy (Aloia and Guida, 2012), and the Provinces of Pavia (Pellegrini and Vercesi, 2005) and Genova (Brancucci, 2004), both in Northern Italy. The interests are also compared with those that are proposed in the inventory form for the Italian geosite by ISPRA.

As represented in Tab. 3.6 (find it at the end of this chapter), there are two main categories of interest, named as "Scientific" and "Context or Other". Mostly, the scientific interests, that may correspond to the Scientific Value, are geology disciplines, like petrography or sedimentology. The Context/Other interests deal with all the other aspects that may regard a natural abiotic element, like the aspect of hiking, or the cultural heritage that can be related to geosites, and that may relate to the other values of geoheritage. It is interesting to note that, in the geosites book by Hilario et al. (2022), it is specified that the collection of geosites only includes sites with high Scientific Value.

Summarizing, there are some proposals of lists of interest for Scientific Value of a geosite. However, in several geosite inventories, also other interests are included, sometimes named "Context" interests, and concern other aspects rather than the scientific one. For this part of the interests, there is no specification in literature of which interest can relate to which value.

However, based on the definitions of the values, we can propose a link between some of the proposed interests and the values. Such a proposal is contained in the second column of Tab. 3.6, in which the values of geoheritage are listed and associated to the possible interests used for the characterization in published geosites inventories.

Another possibility is to search the interest for the geosites among the Geosystem Services (Gray, 2013). In fact, geosites are areas in which elements of geodiversity occur, while geoheritage are elements of geodiversity with special values. Hence, these are elements of geodiversity that could provide some of the Geosystem services. The issue of the relation between Geosystem services and the values of geoheritage, discussed in Mantovani and Lombardo (2022), is represented in Fig. 3.10. The Geosystem services, listed in the central table, are subdivided in their group category (cultural, regulating, etc, listed in the right upper part of the picture); around that table there are the values for geoheritage, represented in the coloured squares with the keywords that are extracted from their definitions. The connections between the values and the services, represented with the arrows, are the result of the analysis of the meaning of the singular values and the description of the services that are reported in the literature, mostly in Gray (2013), in which all the services are described in detail. For example, the Ecological value (yellow in the picture) can be assigned to those elements of geodiversity that have an essential role in the maintenance of the natural ecosystem processes, like some types of processes, as the oceanic processes (the oceanic currents have an essential role in the climate dynamics).

However, associations between the meanings attributed across the papers are subjective and informal. To overcome this subjectivity and establish sound relationships, we conducted a lexicographic study to verify the associations between terms and search for additional relationships. Such a study was performed with the Wordnet resource (Fellbaum, 2005). Each term used for the services and values was analysed to find correspondences. Starting from the list of geosystem services, we analysed each term one by one to discover associations with the values or keywords extracted from their definitions. Unfortunately, this search gave a very limited result. Even those that seemed more likely to be connected, like recreation and leisure did not find any correspondence from a lexical point of view in the Wordnet search engine. As concluded in Mantovani and Lombardo (2022), this issue should be explored by a semantical point of view, supported by empirical studies.

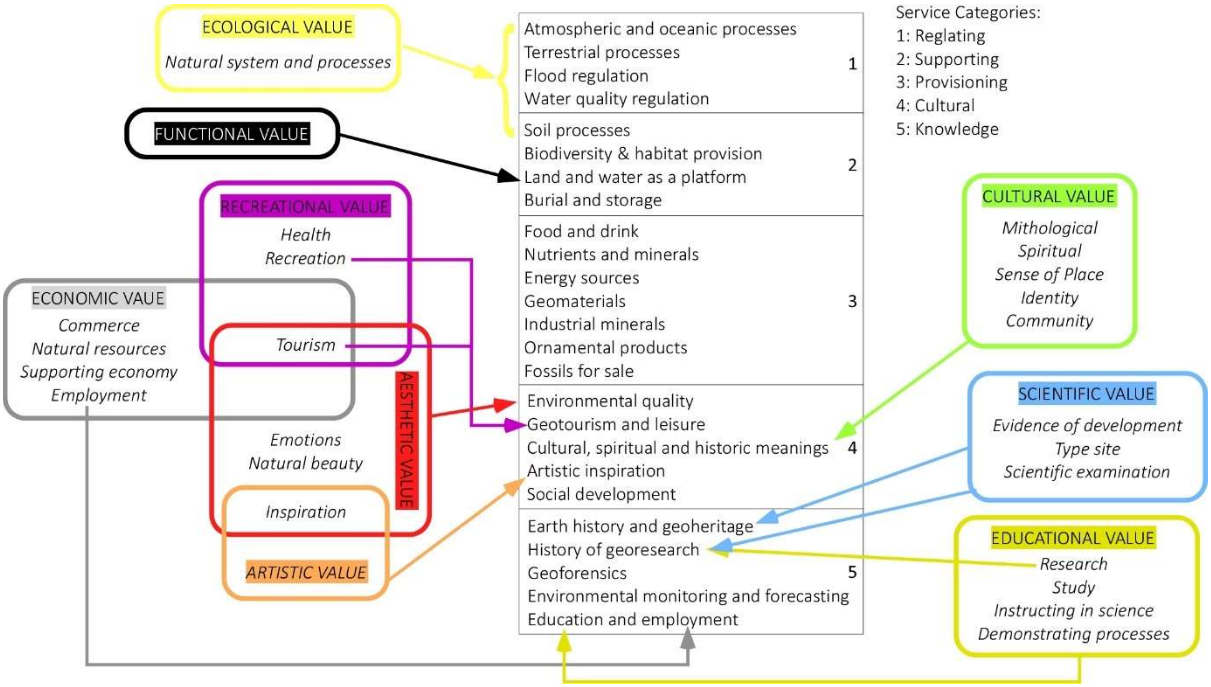

Figure 3.10 - Mapping of geosystem services and values (from Mantovani and Lombardo, 2022).

3.4 - CONCLUSION, GLOBAL MODEL OF THE "GEO" CONCEPTS WITH THE VALUE-INTEREST SYSTEM

In this chapter, we have addressed the concepts of geoheritage, geodiversity and geosite, along with the characterization of their importance, established through the values, the interests, and the geosystem services. Given the analyses of the definitions of these concepts, we have proposed an encoding for the representation of the concepts, composed of classes, properties, and vocabularies. Some of these elements are coming from the semantic web, in line with the principles of the linked data, the encoded knowledge should be "reused" as much as possible: in fact, several classes of our new ontology come from other ontologies, mostly from OntoGeonous ontology for the geological maps. Also, the vocabularies are aligned with the international standard vocabularies, for example, those for the lithology, processes, event, and many others. However, some new concepts are proposed, like the new classes for the geodiversity and geoheritage elements, which are concepts that are hidden in the definitions of geodiversity and geoheritage, but not formally defined. Finally, we have explored the relation between the expressions for the significance of these elements, namely the values, the interests, and the geosystem services. Following a philosophical theory on the concept of value, we have proposed an encoded model for the formal connection between the interests and the value. The grounding concept is that any kind of object (hence, also a geodiversity element) has value if someone is somehow interested in it.
An unsolved question remains the formal attribution of the interests to the value (not that the connection proposed in Fig. 3.9 and in Tab. 3.6 is only hypothetical), as well as the final decision on which are the values for geoheritage. This problem comes from the fact that every author proposing definitions includes a list of values for geoheritage that is different from the other authors. Our proposal, hence, is to include in the ontology placeholder vocabularies for the values and for the interests. Such vocabularies can be modelled depending on the task of the singular use of the ontology

itself: e.g., inventories of geoheritage or geosites of different areas, or for different purposes, could need only a few of these values, or maybe some more. We propose to leave this issue open, proposing full vocabularies (containing all the collected values and interests) and encouraging the use of those that are evaluated as relevant for the task. This is an inclusive proposal, since it leaves the same relevance to theories such as the one by Brilha (2016; 2018), who proposes to consider as geoheritage only the elements with scientific value, as well as others, in which a wider list of values is proposed. However, the structure for the description of the elements and their mutual relations remains the same, in order to allow for an explicit and unambiguous axiomatic definition of the elements of geodiversity that might be or not be considered as geoheritage depending on the chosen list of values. In conclusion, we aim at considering this project of encoding of the concepts of geosite and geoheritage as a reference model that can be modulated based on the necessity of representation of the single case study. Several applications to real case studies can implement and improve the vocabulary of the interests and validate the connections between interests and values. To facilitate the application of the model, we have designed a web-based tool for the collection of geosite data, that will be explored in the next section.

Table 3.6 - Table of the interests in several lists, from local to international level. In the second column, a suggestion for the connection with the values of geoheritage is proposed (next pages)

			Provinces of Italy		Regions of Italy			Nations		International
	Possible association with values		Pavia	Genova	Campania	Friuli-Venezia Giulia	Liguria	ISPRA (Italy)	Portugal	IUGS
Scientific inerests		Applied geology	✓				✓	✓	Geothecnician	Engineering Geology
		Environmental geology				✓				
		Geobiology								✓
		Geochemistry							✓	
		Geochronology								✓
		Geodynamics	✓							
		Geography					✓	✓		
		Geohistory						✓		History of geosciences
		Geology	✓				✓			
		Geomining				✓	✓	✓	✓	
		Geomorphology	✓	✓	✓	✓	✓	✓	✓	Geomorphology and active geological processes
		Geothermal								✓
		Hydrogeology	✓	✓	✓	✓	✓	✓	✓	
		Impact structures and extraterrestrial rocks								✓
		Karst		✓		✓	Karst IPO Karst EPI	✓		
		Marine geology				✓	✓	✓		
		Mineralogy				✓		✓	✓	✓
		Palaeontology	✓	✓	Paleobiological Paleoenvirnmental	✓	✓	✓	✓	✓
		Pedology	✓				✓	✓		
		Petrograpgy		✓			✓	✓	Metamorphic Lithological Petrological	Igneous and metamorphic petrology Petrology
		Sedimentology	✓			✓	✓	✓	✓	Stratigraphy and sedimentology

		Stratigraphy	√	√	√	√	√	√		
		Structural geology	√	√	√	√	√	√	Tectonic-structural	
		Tectonic							√	√
		Volcanology						√		√
Context (other) interests	Socioeconomic	Aetnografic			√					
	Cultural	Architecture						√		
	Cultural	Archaeology			√			√		Geoarchaeology
	Ecological	Botanist	√	√				√		
	Ecological	Geobotanist		√						
	Cultural	Cultural		√		√		√	√	
	Educational Educational	Educational	√	√		√		√	Educational Pedagogical	
	Ecological	Faunistic	√					√		
	Recreational	Geotourism					√	√	√	
	Recreational	Hiking	√	√		√		√		
	Cultural	Historical		√	√	√		√		
	Aesthetic	Landscape	√	√	Panoramic	√		√	√	
	Ecological	Naturalistic	√	√		√				
	Recreational	Turistic	√					√		
	Ecological	"Rare habitats"	√							
		"Representative at a national/local level"	√							

CHAPTER 4

OPERATIVE POINT OF VIEW: DESIGN OF A DATABASE AND OF A DATA COLLECTING TOOL

In the previous chapter we have presented the theoretical framework that articulates the geoheritage, geodiversity and geosite concepts. From the study of the definitions, we have produced an ontological model, and a final encoding in a machine-readable language. However, ontology alone is not a practical tool for data management: for data storage and consultation the relational database format is much more practical. This is the most used tool within the context of geology, geoheritage and geosite (as deepened in Chapters 1 and 2, examples of the national geosite databases). It is a familiar tool for the geoscientists, as any software that manages territorial data, such as GIS, automatically creates a database for every set of data (layer). More practically, to test our model we leaned on the Oneka-S CMS, a user-friendly tool on which we created the data fill in forms, furtherly tested by general users, that is based on the creation of relational databases.

Ontologies, however, can be a useful ally to design a database structure (Bellatreche et al., 2011; Mbaiossoum, 2014). Several examples are present in different fields, among which the geosciences. For example, Mantovani et al. (2020 a, b) designed an ontology driven geodatabase for the data represented in the geological maps; the base was the OntoGeonous ontology for the geological

mapping data (Lombardo et al., 2016, 2017, 2018). The database of the Geological Map of Piemonte (Piana et al., 2017a, b)[48] is designed following the same criteria.
In this chapter, we aim to present the application of the ontology for geodiversity and geoheritage to the design of a database for the collection of data about geosite and geoheritage elements.
The database comprises multiple tables containing interrelated information. We designed the tables to contain the different geodiversity element types and to contain the information that is crucial for the classification of geosites and geoheritage elements (namely, interests and values). In order to support a complete description of the items, in particular the geosites, we took inspiration from the description of the geological data in some national geosite databases. Moreover, we created an interface to ease the filling-in process.
The aim of this work is to improve data interoperability by applying explicit connections encoded in the ontology to geosite and geoheritage data. This will support the connection and comparability of data related to geoheritage and geosite. Furthermore, we propose a tool that promotes transparency and reproducibility in the decision-making process when establishing a geosite or geoheritage element (since this requires the declaration of any relevant interests or values).
Before starting with the presentation of the applicative tools, one aspect should be discussed. For a complete description of a geosite, much information must be taken into account besides geology, such as, e.g., the accessibility information for tourists, or the conservation status and actions. These aspects, however, are not included in the present work, which is dedicated to the description of the geological aspects of the geosites (as already stated in the introduction). Hence, the tables that are described below should not be considered as a complete descriptive form for the geosites, but they are a section (dedicated to geology) of a wider form. Finally, for what concern geological data, our survey was limited by the preexisting encoded data in OntoGeonous, on which we modelled the database. This causes a limitation of the types of geodiversity elements that are described (e.g., hydrogeology, soil or human factors such as quarries). Our model is a prototype of a possible management of geological data for geosites that can be improved in presence of new encoded knowledge.

In the next sections, we are going to present the design of the ontology-driven database (section 4.1), which can be found in the Zenodo repository in a GIS format[49]; thereafter, we will present the guided procedures for the filling in of the data (section 4.2); finally, we summarize the operational workflow (section 4.3), which we will apply to real case studies in the next Chapter 5.

[48] Web application for the visualization of the Geological Map of Piemonte: https://webgis.arpa.piemonte.it/agportal/apps/webappviewer/index.html?id=6ea1e38603d6469298333c2efbc76c72
[49] Link to the repository (V2): https://doi.org/10.5281/zenodo.12591979, Mantovani (2024)

4.1 - DESIGN OF THE DATABASE

For the design of an ontology-driven database, we lean on the structure of OntoGeoBase, presented in Mantovani et al. (2020 a, b), briefly recapped in the next subsections. Once we analyse the existing tables for the description of the partial geodiversity elements, we propose new tables for widening the geodiversity universe and, finally, to encode the geosites.

4.1.1 - Tables for the geodiversity elements

As presented in Mantovani et al. (2020 a,b), OntoGeoBase focuses on the elements that are normally represented in a geological map of the bedrock. In fact, the tables that are proposed in the paper are related to the geologic structures and to lithostratigraphic and lithotectonic units (subtypes of Geologic Unit). It is an ontology-driven database, namely, the design of the columns reflects the properties that are included in the ontology axioms. In the tables some section are present:

- taxonomy columns, for the classification of the element into the subclasses of the geologic structures (the classification is more and more deep in the taxonomy);
- definitory columns, that represent the property that are necessary for the classification into a given subclass. For example, the Lithostratigraphic unit that we used as an example in the previous chapter, needs the lithology field (that comes from the *has Lithology* property) and the stratigraphic role field (*has Role*);
- Other columns collect information that correspond to properties of the ontology, but that are not fundamental for the classification (e.g., has Named Age or is Metamorphic)
- Not encoded concepts report information that still do not have an encoding in the ontology, like the paleogeographic domain[50]

As an example for the procedure of creation of the database, let's take the Geologic structure table (Tab. 4.1), presented in Mantovani et al. (2020a) and adopted in this work. The First group are the "Name + taxonomy" columns of the database. The name is the proper name of the structure that we are describing, that identifies that precise element. The taxonomy columns are those that describe the type of structure. In particular, the item in the table, that is Karkonosze intrusive contact, has enough information to be classified, step by step, as a Contact. The criteria for the classification into this class/column are listed in the second group of the table, which are called the "Definitory columns" which collect all the information required for the classification of all the geologic structures. Hence, to be classified as a Contact, an item should be a planar feature (Geometrical Object -> plane), with no record of a displacement along the surface (Movement -> False). Moreover, to be a Contact, I must bound at least two Geologic Units (in this case, the Karkonosze Granites and the Metamorphic Aureola-Jizera Massif). Finally, for the contact it is required the indication of the presence of absence of a hiatus in deposition (False, in this case).

[50] The paleogeographic domain refers to the environmental conditions during the formation of a given geologic unit. For example, the item in the table, the geologic unit named Marne di Monte Piano, were deposited in the context of the BTP (Tertiary Piedmont Basin), which was interpreted as a sedimentation basin coeval with the alpine orogenesis.

The section “other columns” represents information (either encoded or not) that are important for the description of the feature, but that is not fundamental for the classification into one of the classes of the ontology. For example, the Age is a very important data for geological interpretation, but it is not influential for the classification of the item into one of the classes of the ontology. Going back to the example of the classification of the contact, the mandatory information cited above describe the geometry and the bounding geologic units. The information about the age doesn’t influence the classification of the contact, namely, a contact is a contact independently from its age (Mantovani et al., 2020a).

Name + taxonomy columns	Structure name	Structure type	Structure subclass 1	Structure subclass 2
	Proper name of the structure	List of structure types	List of structure types	List of structure types
	Karkonosze intrusive contact	Contact	Magmatic intrusive contact	

Definitory columns	Bounding unit	Bounding unit	Geometrical object	Movement	Deformation style	Hiatus	Movement type	Dip	Event
	Name of bounded Geologic Unit	Name of bounded Geologic Unit	SWEET - geometrical object	Boolean (True or False)	CGI Vocabulary Deformation style[51]	Boolean (True or False)	CGI Vocabulary Movement Sense[52] or Type[53]	Angle of dip	Name of genetic Event
	Karkonosze Granite	Metamorphic Aureola-Jizera Massif	Plane	False	null	False	null		Karkonosze intrusive event

Other Columns	Age	Source	Observation method
	Geologic Time Scale	Bibliographic source	CGI Vocabulary of Observation Method[54]
	Carboniferous	http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4472	Surface data observation

Table 4.1 - Table for Geologic structure in OntoGeoBase modified from Mantovani et al., 2020a, with an example from the case studies in Chapter 5. The purple writings indicate the information that is original from this table, in blue the information from the Geologic unit table and in red from the geologic event table (Tab. 4.2 and 4.3 respectively)

[51] Vocabulary of Deformation Style: https://resource.geosciml.org/classifier/cgi/deformationstyle
[52] Vocabulary of Movement Sense: https://resource.geosciml.org/classifier/cgi/faultmovementsense
[53] Vocabulary of Movement Sense: https://resource.geosciml.org/classifier/cgi/faultmovementsense
[54] Vocabulary of Observation Method: https://resource.geosciml.org/classifier/cgi/featureobservationmethod

Name + definitory columns	Lithostratigraphic unit name	Lihtology	Stratigraphic Role
	Proper name of the unit	List of structure types	List of structure types
	Borgone Metagranite	Orthogneiss	Only part

Other columns	Geologic Unit 1	Geologic Unit 2	Age	Metamorphic	Source	Observation method	Description
	Name of wider Geologic Unit	Name of wider Geologic Unit	Geologic Time Scale	Boolean (True or False)	Bibliographic source	CGI Vocabulary of Observation Method[55]	Textual description of the unit
	Dora Maira		Permian	True	Cadoppi et al. (2002)	Surface data observation	

Table 4.2 - Table for Lithostratigraphic Unit in OntoGeoBase modified from Mantovani et al., 2020a, with an example from the case studies in Chapter 5. The blue writings indicate the information that is original from this table, in red the information from the geologic event table (Tab. 4.3)

As discussed in the previous chapter, there are several elements that are included in the group of the geosite elements; geologic structures are part of these features, as well as geologic units. The latter, in the organization of OntoGeoBase, is better represented by the Lithostratigraphic unit table, which is meant to describe the geologic units through their lithology and their role in a stratigraphic section (the two definitory columns in Tab. 4.2).

Other elements of geodiversity, however, do not have a table within OntoGeoBase. For our task, we need a table for each of the existing types of geodiversity element. For the aim of our case studies and to test the system, we have created a few of these tables, namely the one for the Natural geomorphologic features and the one for the Geologic events. In fact, these four types of elements are sufficient to describe the majority of the geosite, because they are related to the most commonly reported information, like lithology, morphology, origin and age. In the next subsection we are going to present these tables, discussing their organization and the properties that inspire their columns.

For the purposes of our work, which is the representation of the geodiversity and geoheritage elements and of the geosites data based on the use of geological maps, we developed two new tables for the description of the geodiversity element, namely the Natural geomorphological features, for the description of the landforms, and the Geologic events, intangible feature that constitute the link to any geological feature to its genetic event, with the specification of age, geologic process and environment. Geologic events can be both in the past (processes that already ended) or in the present time (processes that are still active).

[55] Vocabulary of Observation Method: https://resource.geosciml.org/classifier/cgi/featureobservationmethod

Geologic Event table

According to GeoScienceML, a Geologic Event is an identifiable event during which one or more geological processes act to modify geological entities. It may have a specified geologic age (numeric age or Geocholigic Era Term) and may have specified environments and processes.[56]

Hence, for the description of a geologic event (Tab 4.3) the required information is the following:

- the Age, to which is related the Geologic Time Scale vocabulary, through the properties has (younger/older) Named Age, or a numerical value, through the properties has (younger/older) Numeric Age. In both the cases, it is possible to use either one type of property (named/numeric) both as a range (using younger and older) or as a singular data;
- the event process, to which is connected the CGI vocabulary[57] (e.g., eruption or deposition);
- the event environment, to which is connected the CGI vocabulary[58] (e.g., marine settings or earth surface settings).

Event Name	Younger Named Age	Older Named Age	Younger Numeric Age	Older Numeric Age	Event Process	Event Environment
Proper name of the event	Geologic Time Scale		Numeric value		CGI Event Process Vocabulary[50]	CGI Event Environment Vocabulary[51]
Susa Valley Glaciation	Pleistocene				- Ice erosion[59] - Deposition[60]	Glacier Related setting[61]

Table 4.3 - Geologic Event table with an example from the case studies in Chapter 5. Each element needs its proper name, plus information about the age, the process and the environment.

Natural geomorphologic feature table

According to GeoScienceML, a Geomorphologic feature describes the shape and nature of the Earth's land surface (i.e., a landform)[62]. Since we deal with the Natural Geomorphological features, we consider only those that are created by natural Earth processes, leaving apart those that are derived from human activity (e.g., dredged channel, reclaimed land, mine waste dumps).

[56] GeoScienceML, Geologic Event: https://docs.ogc.org/is/16-008/16-008.html#71
[57] CGI vocabulary for event process: http://resource.geosciml.org/classifier/cgi/eventprocess
[58] CGI vocabulary for event environment: http://resource.geosciml.org/classifier/cgi/eventenvironment
[59] Defintion of ice erosion: http://resource.geosciml.org/classifier/cgi/eventprocess/ice_erosion
[60] Defintion of deposition: http://resource.geosciml.org/classifier/cgi/eventprocess/deposition
[61] Definition of glacial related setting: http://resource.geosciml.org/classifier/cgi/eventenvironment/glacier_related_setting
[62] GeoScienceML, Geomorphologic Feature: http://docs.opengeospatial.org/is/16-008/16-008.html#97

Landform name	Landform type
Proper name of the landform	Vocabulary of Polish landforms
Castellazzo Erratic Boulder	Erratic boulder

Geologic unit	Lithology
Name of an instance from the unit table	CGI Simple Lithology vocabulary
Borgone Metagranite	Orthogneiss

Event Name	Younger Named Age	Older Named Age	Younger Numeric Age	Older Numeric Age	Event Process	Event Environment
Item from the geologic event table	Geologic Time Scale		Numeric value		CGI Event Process Vocabulary	CGI Event Environment Vocabulary
Susa Valley Glaciation	Pleistocene				- Ice erosion - Deposition	Glacier Related setting

Table 4.4 - Natural Geomorphologic Feature table in the database with an example from the case studies in Chapter 5. The green writings indicate the information that is original from this table, in blue the information from the Geologic unit table and in red from the geologic event table (Tab. 4.2 and 4.3 respectively)

In the analysis of the concepts that was conducted for the representation in OntoGeonous of the `Geomorphologic Feature` class, some information was required, among which the relation with a vocabulary of Shapes, for the description of the representative cartographic element (line, point, area) and with the genetic process, which must be a natural process, in case of Natural Geomorphologic Feature. Below the `Natural Geomorphologic Feature` class there is the subdivision of the type of features, which is currently based on a mixed criteria of process and environment. Indeed, the `Geomorphologic Feature` class and taxonomy is still work in progress within OntoGeonous, and no reviewed axioms are present. Hence, for the Geomorphologic feature table in our database (Tab 4.4) we will lean on the definition and properties by GeoScienceML.

- Description of the landform type: a column indicates the landform type (first section in Tab. 4.4). As a vocabulary, we adopted the one proposed for the Digital Geomorphological Map of Poland (Rączkowska and Zwoliński, 2015). This vocabulary groups the concepts based on the processes (aeolian, glacial, …), with several different features for each type, for a total amount of 97 terms. The distinction of the terms in genetic-related groups is very suitable to the connection with other used vocabularies, such as the event process and environment. The one proposed by INSPIRE[63] has 38 terms that in part describe topological elements (e.g., mountain top) mixed with terms that have a process derivation (e.g., glacial). This vocabulary can be used as an alternative to the one of the Digital Geomorphological Map of Poland, if it is considered as more suitable for the task.

[63] A full list at the link: http://inspire.ec.europa.eu/codelist/NaturalGeomorphologicFeatureTypeValue

- The information about process, environment and age are related to the genetic event (second section in Tab. 4.4): the full description of the Geologic event that is responsible for the generation of the landform in the proper table, should guide the filling of all the other columns of the group (process, environment, age), based on the above discussed properties. The relation with the event is very important for the attribution of process and environment following the GeoScienceML proposals, as those properties are only connected with the event. Consequently, the attribution of this information to other geological features should pass through the relation with a geologic event.
- The material of the landform (third section in Tab. 4.5): the landforms are the description of the geometries of the Earth surface, made of some material: this aspect is described by the property "unit Description"[64], which is meant to relate the `Geomorphologic Feature` to a Geologic Unit that composes it, and that consequently acts as a link for the description of the lithology (CGI Simple Lithology vocabulary).

For a test of the system of description of the elements of geodiversity we selected four main types of geodiversity elements, to which ontology driven tables are related. These tables are meant to collect real items that occur in the natural environment and, mostly, that can be represented on a geological map. These tables are mutually related, as the elements that are described within can be foreign keys in any of the other tables.
As we will discuss in the section devoted to the case studies (5.1), the use of pre-described elements for the description of new items has several advantages, among which the possibility of a direct relation among the elements. For example, if we look at a contact between two geologic units represented on a map, we can understand the precise meaning of this graphical representation and the relation that holds between these elements. If we describe these elements in the structure described for the database, the relation becomes explicit also at a database level, besides the graphics.
In the next section we will present the complete database schema for the representation of the geosite information, integrating all the data that are described in the tables that we presented above.

4.1.2 - Tables for the geosite data representation

As for the tables for the representation of the data about the geodiversity elements, in which some of the columns are related to properties (either definitory or not) and other columns that contain not encoded concepts, also for the geosite database a mixed approach should be adopted. Note that this analysis concerns the representation of the geological data of the geosite: in fact, a complete database for the geosite contains management data, access data, specific geographic information and many other aspects. These data will not be included in the discussion and in the building of the table, as our task is the representation of the geological information about geosites.

Definitory columns

As discussed in the previous chapter, the selection criteria for a geosite require the presence of at least one element of geodiversity in the territory under consideration. Moreover, it is necessary that this element fulfils an interest. Note that it is usual (but not mandatory) for a geosite to have more than one recognized geodiversity element in it (for example, a geomorphological element and its composing

[64] GeoScienceML, Natural Geomorphologic Feature: https://docs.ogc.org/is/16-008/16-008.html#98

geologic unit). However, to satisfy the necessary condition, it is sufficient that even just one of the elements fulfils an interest to make that area a geosite. From this analysis, the consequence is that to represent a geosite in an ontology driven database, the definitory columns should contain the reference to one instance coming from one of the tables of the geodiversity elements and the column of the interest that the selected element fulfils.
This module of Geodiversity element-interest can be repeated based on the number of interesting elements (a basic representation in Tab. 4.5).

Geosite name	Geodiversity element	Interest
Castellazzo hump	Castellazzo Erratic Boulder	Geomorphology

Table 4.5 - Basic representation of the main structure of the table for the geosites. Following the ontology property, it is mandatory to indicate at least one element of geodiversity that fulfils at least one interest. In the table, the example of Castellazzo Geosite (see details in section 5.1.1)

The database structure represented in Tab. 4.5, however, is not enough to describe a geosite, and deeply different from the normally used database structures. To display a complete geological framework about the geosites, and to align our database with some of the national databases, we analysed them and added some columns. In particular, we analysed the Italian and Polish databases, represented in Fig. 4.2, in which the sections for the geological information are represented.

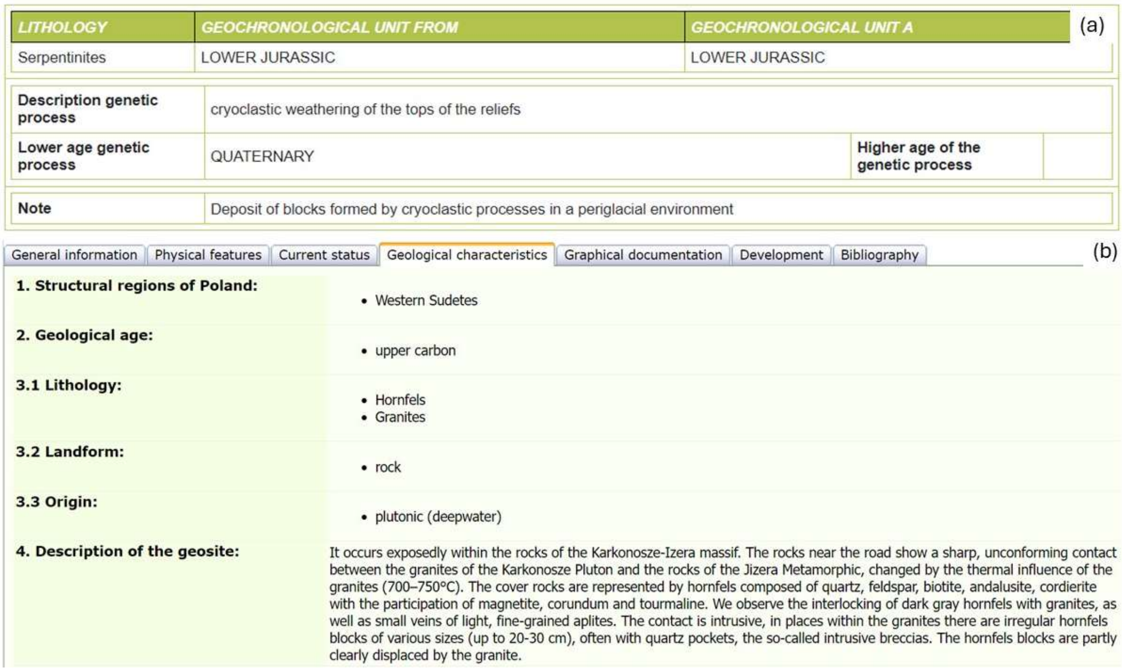

Figure 4.1 - Geological data from the Italian[65] (a) and Polish[66] (b) form for the description of the geosites

[65] Descriptive form in the ISPRA website (a free registration is necessary to access): https://sgi.isprambiente.it/GeositiWeb/scheda_geosito.aspx?id_geosito_x=876&token=E19ED0809598AF379CE0257A
[66] Descriptive form in the Polish website for the geosites: https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4472

Picture 4.1 reports two examples from the Italian (a) and Polish (b) geosite databases. The Italian geosite is the "Pian del Fretto Blockfields", in the municipality of Sassello, Liguria Region (Northern Italy). It consists of deposits of blocks of Jurassic rocks which were disaggregated and deposited during the Quaternary in a periglacial environment. The Polish geosite is the Zakręt Śmierci geosite (Szklarska Poręba municipality, southwest Poland), that shows the contact between the granites of the Karkonosze pluton and the encasing rocks of the Jizera Massif (more detail in section 5.1.2).
In both the form we can notice that there are several data, that we can summarize as follows:

- Lithology: in both the forms there is a field with the indication of the lithology (serpentinites in the Italian geosite, granites and hornfels in the Polish one);
- Origin: displayed in both the forms, but referring more to the process in the Italian form and more to the environment in the Polish one;
- Geologic age: in the Polish form there it is indicated the Upper Carbon age, corresponding to the age of the main event occurred in the geosite (the intrusion of the pluton, with the consequent formation of the granite and metamorphic processes that created the hornfels); in the Italian form, differently, there is the reference to the age of the rock and the age of the genetic process, that in this case is very different (Jurassic, 200-150 My, and Quaternary, 2,5 My-present day);
- Landform: only occurring in the Polish form, describes the morphological aspects of the geosite;
- Structural Region of Poland: referring to a wider geological domain. This element can be classified similarly as in Fig. 4.1 (b), in which a number of columns were included for the description of the geologic unit hierarchy;
- Notes field, or description of the geosite, occurs in both the forms.

The Polish form is richer in information, as it includes a reference to the geologic domain and a reference to the landforms. Moreover, the format of the information is comparable to a controlled vocabulary filling-in. This is different from the Italian form (Fig. 4.1a): the description of the geological process is in a textual format, as well as the lithology field. However, in the Italian form there is the specification of the age of the lithological part and of the process part (information that is "mixed" in the Polish form).
In our system, we based the description of the geosites on the elements of geodiversity that compose the geosite. However, if for every geosite we would describe all the features that are present, the table would become very difficult to manage and read. The ontology driven relational database allows for a complete description of the relevant information about the geosite, with a connection with the geodiversity elements that are involved. Hence, all the knowledge that describes the geosite is related to the element that brings to the geosite that specific characteristics. For example, the geosite that is described in the Italian form in Fig. 4.1a has an age for the rock (Early Jurassic) and another age for the process (Quaternary). Our intent is to organize the table in order to include all the geodiversity elements that are included in the geosite, with the salient information for the description of the geosite and the reference to the interest that the elements fulfil. Every element that is included, however, may have a wider set of information besides that included in the geosite table. Through the reference to the precise item, it is possible to access all the information in the table of the singular geodiversity element.
The final schema of the table that we proposed is based on the main criteria for the definition of a geosite, namely the presence of at least one element that fulfils an interest. We add the relevant information coming from the single elements, like, e.g., the lithology from the geologic unit.

In Tab. 4.6, there is a representation of the table format, organized in four sections (but they stand in a unique record). These are “thematic groups” in which the involved geodiversity element is indicated with the information and the interest. The sections are listed as:

- geologic units for the description of the lithology;
- geomorphologic features for the description of the landforms;
- geologic events for the description of process, environment and age;
- geologic structures for the description of the geometry;
- A final field is included for the textual description of the site.

In Tab. 4.6 is described one of the geosites that will be explored in Chapter 5, the Castellazzo Hump. In the geosite there is a type of landform that provides the interest to the geosite, namely the geomorphological interest. The Erratic boulder is the element that allows the area to become a geosite. In the geosite occur two geologic units (see details in the next chapter) and the main feature (the boulder) is related to the Susa Valley glaciation event. The repetition of the column for the interest depends on the possibility that every element of geodiversity can be the one that satisfies the condition of the fulfilment of an interest and thus allows the proper classification of the geosite; moreover, more than one element can be related to an interest. In the case of the example, only one element brings the interest (the boulder). Every single “section” can be repeated multiple times, in the case of the coexistence of more than one element belonging to the same class (in Tab. 4.6, for example, occur two items of the geologic unit class/table).

Finally, this model is designed after the limited analysis of the geodiversity elements that was performed in the context of the present work, oriented at supporting testing on case studies and based on the geological mapping process task. Hence, it could be implemented with other elements of geodiversity, by the addition of more groups devoted to new types of geodiversity elements.

Geosite name	Description
Proper name of the geosite	Notes, open text format
Castellazzo Hump	*It is a large sub-rounded rocky block that lies on the grassy clearing enclosed by the ruins of the medieval 'Castrum Capriarum', on the top of a rocky hump that emerges some twenty metres from the alluvial plain of the Dora Riparia, on the border between the municipalities of Condove and Caprie in the Castellazzo region (Susa Valley)*

Lithology thematic group	Geologic unit	Lithology	Interest
	Item from the Geologic Unit table	Info from the item/ CGI Simple Lithology vocabulary	Vocabulary of interests
	Borgone Metagranite	Orthogneiss	
	Low Susa Valley Serpentinites and Peridotites	Serpentinites	

Morphology thematic group	Geomorphologic feature	Type of landform	Interest
	Item from the geomorphologic table	Info from the item/ vocabulary of landforms	Vocabulary of interests
	Castellazzo Erratic Boulder	Erratic boulder	Geomorphology

Event thematic group	*Geologic event*	Event process	Event environment	Age	Interest
	Item from the geologic event table	Info from the item/CGI Event Process vocabulary	Info from the item/CGI Event Environment vocabulary	*(here, 4 columns with named and numeric age)*	Vocabulary of interests
	Susa Valley Glaciation	Deposition	Glacier Related setting	Pleistocene	

Structural thematic group	Geologic structure	Structure type	Age	Interest
	Item from the geologic structure table	Info from the item	*(here, 4 columns with named and numeric age)*	Vocabulary of interests

Table 4.6 - Table for the geosite; the example is the Castellazzo Hump. The information is coloured in base of the source of data: blue for the units (Tab. 4.2), green for the landforms (Tab. 4.4), red for the event (Tab. 4.3)

4.1.3 - Expected impact on the interoperability of data

In the previous sections we presented the tables for the database of the geosite and of the geodiversity elements. Every table is connected with the other, through the explicit reference to specific items coming from other tables that enrich the description of the new items. From the point of view of the geosite, the geological data comprehensively rely on the geodiversity elements that compose it, namely the materials (i.e. the rocks, conveyed by the geologic units), the geometry (geomorphology and structures) and the geologic history (events). Every descriptive item brings to the geosite some information and possibly an interest. Note that just one element with an interest can be included to consider a Site as a geosite, that can thus have no other geosite elements, or other geosite elements with no indication of interest. The explicit relation of these elements among the tables of the database, enforced by the ontological base of the database, is reflected in the interoperability of data. In fact, every element holds in relation with other elements. The organization of the table columns, supported by the ontology properties, expresses the explicit relation between the elements. The relations can be multiple, for example, more than one item can hold in relation with the same geologic event.
Hence, these ontology-based relations create a network between the elements, enhancing the possibility of interoperability of data. In general, if we compare our system with some national databases and descriptive forms (Italian and Polish), we can summarize our method highlighting two aspects that impact on the interoperability of data:

- the description of the characteristics through controlled vocabularies. In the Italian form, the information concerns the process and the lithology. Analysing several examples, these fields are managed in a textual format, with no connection with a controlled vocabulary. Vice versa, the Polish form shows the presence of internal controlled vocabularies[67] for the structural region of Poland, age, lithology, form of terrain and origin. International standard vocabularies have shared and publicly accessible links and definitions. This has a consequence on the interoperability of data, especially at an international level, for the understanding of the terms, overcoming translation problems. For example, the "origin" field in the geosite in Fig. 4.1: the term in Polish is "plutoniczna (głębionowa)"; checking two translators (google and DeepL), in English it turns in "plutonic (deep sea/deep water)". The translation in English is incoherent with the typical environment of generation of a pluton, which is deep/medium crust. Only searching on the Oxford Polish-English vocabulary (Linde-Usiekniewicz, 2002, p.264) we found a proper translation, with the reference to "skała głębionowa" and the translation as an intrusive rock. Hence, for a foreign reader, the lack of precision within the scientific terminology of the translators may lead to big misunderstandings: if we connect a vocabulary with definitions, the correct interpretation of given terms can bypass these issues.
- The introduction of the connection with the geodiversity elements that compose the geosite. We see the geosites as global features that, however, derive from the sum of several features (the geodiversity elements). Geodiversity elements are referred in the records of the geosites and these concern both material element as rocks and landforms and immaterial elements as the processes. This approach in the description supports several tasks. From the user point of view, the description

[67] For example, "*Gravelly sands (sands and gravels, sands with gravels)*" is one of the used sentences in the Lithology field, repeated in several geosites, among which those at the links:
https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1384
https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1437

of the single elements increases the precision in the geosite searches (see case studies in the next chapter). From the point of view of the operator that is in charge of the data uploading, the possibility of extracting data from previously described geodiversity elements reduces the time and the possibility of human mistakes.

- Finally, textual descriptions of geosites contain a variable amount of information, concerning the context of the geosite, its geological history, and the acting processes, that directly address the "human reader". Though Large Language Models can extract significant information to fill the database entries, they need organized databases such as ours to train the models correctly. The tests reported in this work have seen scientists and students filling the database with rigorousness, explicitness and ambiguity limitation, after a training phase; we believe that this content will be useful in the future for Large Language Models training. This aspect will be exemplified in the case studies in the next chapter.

As a proof of concept, we designed an application for the filling in of the information, and for the subsequent visualization and analysis. This will be the topic of the next section, while in the next chapter we will apply the database and the interface to case studies in Italy and Poland.

4.2 - DESIGN OF AN INTERFACE

The method discussed in the previous section finds its operative approach in a prototype of application, developed with the Omeka-S software. Such application has two goals: first, the representation of the descriptive forms that derive from the proposed organization of the database and the testing of the interoperability of data; second, the testing of the system itself, which was submitted by several groups of international volunteers. The final product is a website to which a generic user can access to visualize geosite data (organized in a descriptive form format) and upload new geosite data through dedicated collecting forms. In the next sections we are going to describe the theoretical base of this application and we will present the collecting form for the guided filling in of the information.

4.2.1 - Theoretical base of the project and private interface design (back-end level)

Omeka-S is a CMS, Content Management System, designed to easily manage data and their representation in a flexible environment. In this section we are going to analyse the basis of the project, namely the steps in the back end, to which only authorized users can access. The description of this restricted visualization is fundamental for following the description of the publicly accessible pages. In fact, on the base of the work in the back end we could model the public page.

The software Omeka-s allows to upload vocabularies in several formats (including. OWL) or create them manually. For our project, we uploaded all the ontologies described in the previous chapter and all the cited vocabularies (CGI, plus the Polish landforms vocabulary). We uploaded the ontologies in their original .OWL format: the Omeka-S system imports the classes and the properties, along with all its annotations, like labels or comments, but does not consider the constraints in the axioms. For what concerns the vocabularies, we needed to create them manually, by importing lists of terms coming from the original sources. These types of vocabularies are called "custom vocabularies".

From the back end of the Omeka-S system it is possible to add new items, which are the representation of the elements that we want to describe (e.g., one geologic unit, one geosite, …). They can be considered as similar to the instances of an ontology. When starting the description of a new item, only two properties appear, related to the name and the description of the feature. The user can manually select the useful properties for describing the feature from a list of properties uploaded with the .owl files. However, it is possible to create models for describing specific types of elements. These models are called Resource Templates and consist of predefined lists of properties that are relevant for describing a particular type of item. Hence, when stating the description of a new item, the user can select the proper resource template from a drop-down menu: the field of the "class" will be automatically filled, and the predefined properties will appear in the form that will be ready for the completion. To create a resource template, we select the properties from the uploaded .owl files. After the selection of a property, it is possible to leave it in its original format, coming from the ontology, or to model it, through the addition of ad-hoc labels or comments to facilitate the further use. Moreover, it is possible to specify the filling in method for the properties, for example, to the property "has event process" or "has lithology" we connected the related CGI vocabularies.

Resource templates are model that mean to inspire the description of the items: in fact, when selected a resource template, the properties that are not signed as mandatory can be skipped; vice versa, other properties that are not included in the template but that are considered relevant in that specific case can be selected from the list and added to the predefined properties.

During the description of the items, other information can be added, in addition to those related to the properties. In particular, it is possible to locate the item in a map, or to indicate the inclusion in an item set. The item sets are important for the building of the vocabularies. In fact, one type of custom vocabulary is the one related to the item sets. In our case, in which for the description of many items is necessary to lean on previously described items it is very important to have a list of precise types of elements. For example, we exploit this feature for the collection of geologic units that are reported in different items, e.g. geologic structures. Every new item that will be included in the item set will automatically be included also in the vocabulary. This vocabulary is connected to the resource template for the description of the geosite, in correspondence to the property that relates the geosite to this type of geodiversity element. Hence, when describing a new geosite, we can select the previously described geologic unit from the list: in this way an explicit link is created between the "new" and the "old" item. This aspect is of crucial importance for our goal, which is the enhancement of the interoperability of data.

Moreover, the organization of the items into item sets is important for the organization of the public access website pages. In fact, the back end is a working level, in which authorized users can test and model the final interface and organization of the data collecting. The final product is the website in which the collected elements are visible by the public, who can also check the connections between the collected elements. The idea is to create a showcase of items that a user can explore to get data about a single geosites and of similar geosite. The similarity is underlined not only using the same terms for the description of the elements (the use of the controlled vocabularies that is mandatory for the data filling in) but mostly important by the explicit connection of the described item (easy to explore through the links in the pages of the website).

The description of this system, named GeOntoLogicSite, will be the topic of the next section.

4.2.2 - Design of the public interface (front-end level)

The output of the data organization is the publicly accessible website[68], created on the base of the structure modelled in Omeka-S. From the pages of the site, a generic user can search and consult the uploaded geosites or geodiversity elements, and also upload new elements in the system through the collecting forms.

Consultation of the geosites

The uploaded elements can be displayed in the pages of the website. Two themes are selected for the representation of the items: in one page, there is the showcase of the geosites, supported by a map representation of their localization. In another group of pages, all the types of geosite elements are represented, grouped by class.

With a user-friendly research tool, identified with the symbol of a lens, it is possible to search for specific items in the system, finding all the items that are connected to the searched item. In the case study section, we will see some examples of this process and how this is relevant for the enhancement of the interoperability of data.

Filling in of the geosite data: collecting forms and guided procedure

A very important part of the system is the final interface for the data collecting. This interface was created mostly to practically represent the system and for allowing its usability test (which was submitted to international groups of volunteers, see in the next chapter).

For the creation of the guided procedure[69], the first step is the creation of dedicated collecting forms. Collecting forms are the public version of the resource templates. They are based on the same properties that model the resource template, that can be equipped with specific labels and comments for better explaining the required information type and can be connected with different data types (e.g., text or controlled vocabularies). The difference between the collecting forms and the resource templates is that the first are rigid structures that support one value for every property, while in a resource template the same property can have multiple values even in a different format (e.g., one value from a vocabulary, one from a text string). This influenced the creation of the collecting forms, making it necessary to foresee how many values could be necessary for a good description of the mean of the elements. For example, we can consider the case of the description the lithology of a geologic unit. Depending on the scale on which we are describing the geologic unit, one field for the lithology might not be enough: some geologic units are massive strata of limestone (e.g., the Triassic Dolomites in the Eastern Alps), but other are frequent alternation of thin layers of coarser and thinner sediments (e.g., the Varvite Park in Brazil, Guimarães et al., 2018) that require more than one term for the description of the lithologies. Moreover, to test the adequacy of the vocabularies, one free text field was included for each property that ought to be filled with controlled vocabulary, to leave the possibility of proposing new terms in case of missing a proper term.

For each one of the explored elements of geodiversity, namely geologic unit, structure, event and geomorphologic feature, and also for the geosite description, we created a specific collecting form. In each of them, there is a setting that includes every uploaded item in the related item set, thus

[68] Homepage of our website: https://bearchaeo.di.unito.it/exercise/s/geontologicsite/page/homepage
[69] Link to the guided procedure: https://bearchaeo.di.unito.it/exercise/s/geontologicsite/page/geosite-collecting-form-introduction

automatically refreshing the item set vocabulary type, allowing to use the newly uploaded element in the further description. In fact, as discussed for the encodings and for the databases, the description of the elements is mutually dependent. For example, the items from the geologic event table that are foreign keys for the description of the items in every other table, geologic units are foreign keys in the geomorphologic feature and the structure tables, as Fig. 4.2 represents (orange and red arrows respectively); all the tables (identified with blue labels) are foreign keys in the geosite table (identified with the purple label). For this reason, the system is organized into a well precise path of description, described by the thick green arrows in Fig. 4.2.

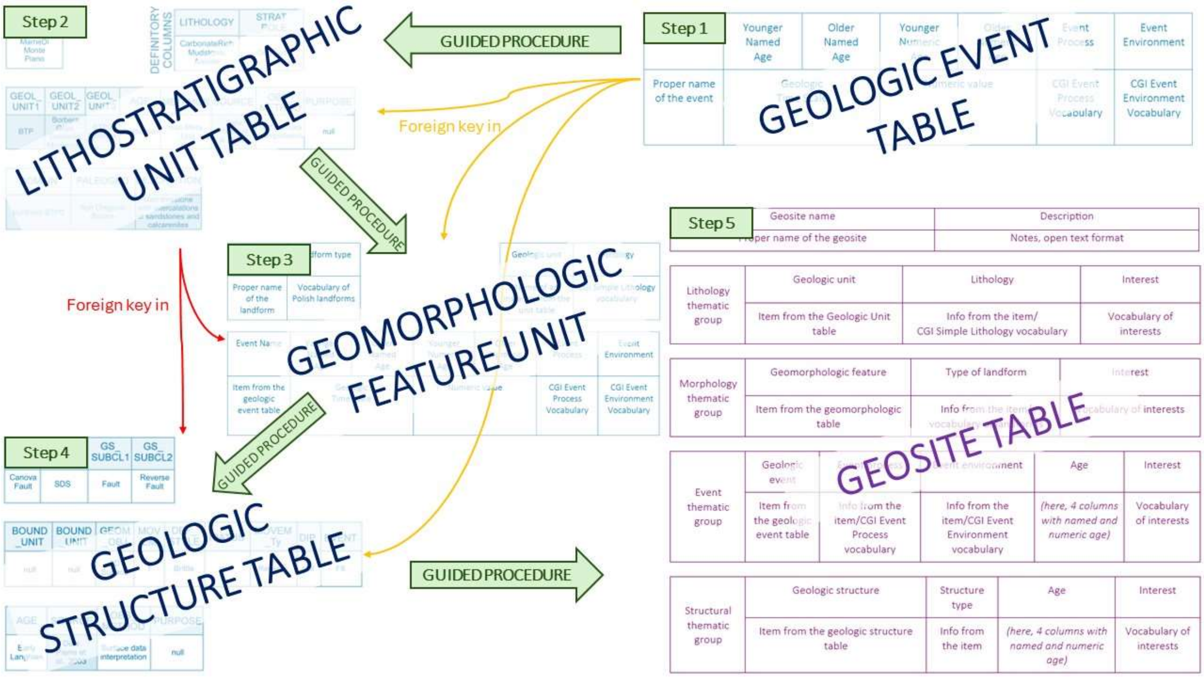

Figure 4.2 - Workflow of compilation of data in the guided procedure. The green arrows describe the order of description of the items (event, units, geomorphology, structure, geosite). The orange and red arrows indicate the tables in which events and units respectively are foreign keys.

Hence, we foresee five steps; four of them focus on one specific geosite element type, while the last one focus on the final and complete description of the geosite. The first four steps are subdivided into two parts that are differentiated by a specific question, whose aim is to guide the user on the process of analysis of the needed information and descriptions. For example, the first step is devoted to the analysis of the possibly needed geologic event in the process of description of the geosite. In step 1a (Fig. 4.3a) the question in the yellow square invites the user to decide whether if a geological event is necessary for the further description of the geosite; the answers yes or no, also highlighted by red and green colours, are links that lead to two different paths:

- If NO, meaning that no geologic event is relevant (or known) for the description of the geosite or the further geodiversity elements, the link brings to the second step of the procedure (that, in this case, is dedicated to the geologic units)
- If YES, meaning that at least one event is relevant for the geosite description or the further geodiversity elements, the link brings to step 1b (Fig. 4.3b). The relevance of this step is to avoid repetition in the described items. In particular, once identified the geologic event that is needed for the description (step 1a), it is necessary to check if an item (sensu Omeka-S) for such an event is present in the system. This is the question that is asked in the yellow square of step 1b; the red

link in the same square invites the user to check if the identified event has already been described in the system (the link opens a pop-up window that shows the page for the geologic event items).

- If it was present among the uploaded items, the link YES brings to the following step of the procedure (geologic units in this case)
- If it was not present, then the link NO brings to the page with the collecting form for the geologic event, in which the user can fill-in all the information through drop-down menus or text fields. Once submitted, a success text invites the user to restart the collecting form in case of the necessity of uploading a second item, or to go back to the guided procedure. Once every item related to that class is in the system, the link YES brings the user ahead in the procedure.

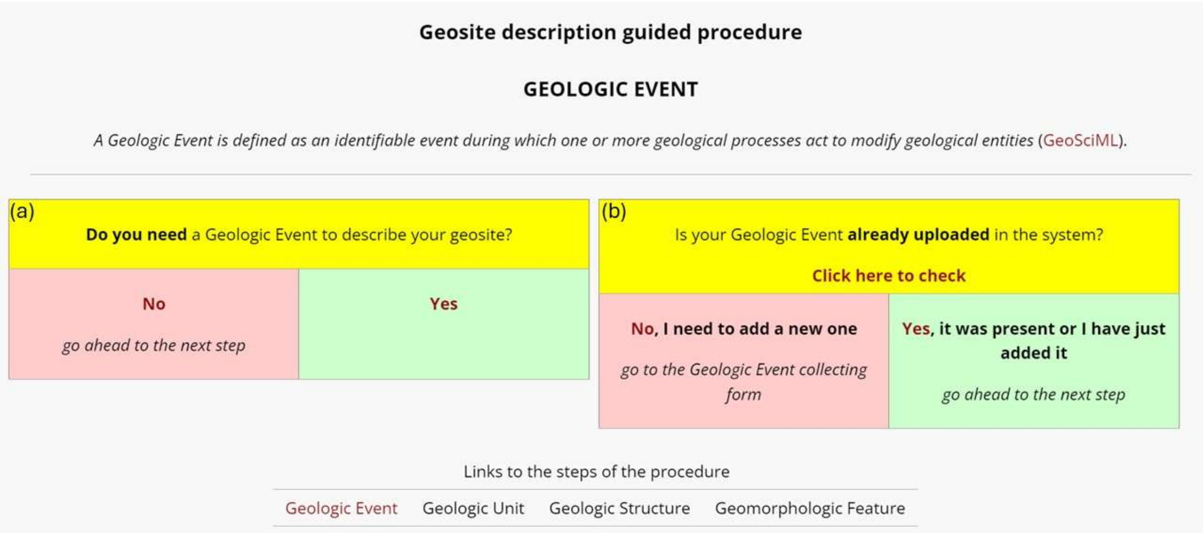

Figure 4.3 - The first step of the guided procedure, related to the geologic event. Note that the two tables are displayed in two sequential pages, represented in (a) and (b) respectively.

This schema is repeated for every geosite element, till the final step in which the geosite is described leaning on the previously described elements. In the final geosite form, as well as in the collecting forms for the elements, the fields to fill are those that are presented in the database that is described in the previous section.
In particular, the collecting form for the geosites is organized into defined sections, those that are represented in Tab. 4.4. For example, in the section dedicated to the description of the lithological aspect of the geosites (Fig. 4.4), it is required to indicate the main geologic units that are outcropping in the geosite, along with the terms describing the lithology from the controlled vocabularies and also through the use of free text fields, in case of complex descriptions, or inadequate vocabularies. At the end of the section, it is required the interest that the element fulfils within the geosite. The filling in of every single section is explained in green squares, in which the links to the sources of the vocabularies are added.

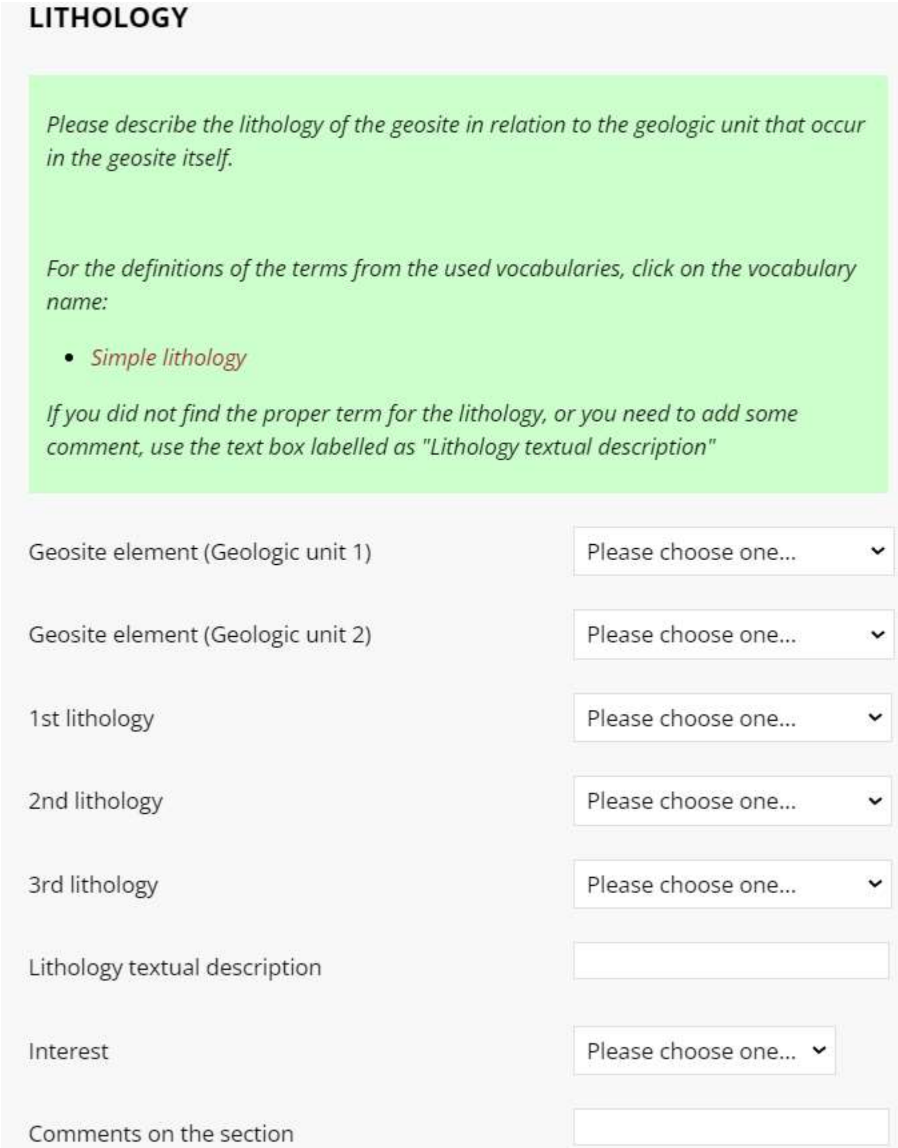

Figure 4.4 - Lithology section in the geosite description form

The result of the procedure is the uploading of one new geosite in the system, along with all the geodiversity elements that occur (either physically or not) in the geosite itself. The main goal of this application on the public interface of Omeka-S was to test the usability of the database, while aiding its filling through the guided procedure.

The procedure that is summarized in this section is the final results of several versions that were modified as a consequence of comments and discussion after the tests with the groups of volunteers. The tests (and the modification to the system) will be discussed in detail in chapter 5.

4.3 - SUMMARY OF THE METHOD

The final goal of the method of representation of geosite data that is presented in Chapters 3 and 4 of the present thesis is the enhancement of the interoperability of data.

The theoretical base grounds on the ontological representation of the concepts, in order to organize real data on a coherent and unambiguous structure. In fact, we analysed the main concepts from a theoretical point of view, and encoded them into ontology classes, provided with systems of taxonomies, axioms and properties that describe their mutual relations (see chapter 3). All these connections are in accordance with the Linked Data paradigm (Bizer et al., 2009): in fact, we exploited pre-encoded ontologies and concepts for the geosciences while encoding the concepts of geodiversity, geoheritage and geosite.

In order to practically exploit this encoded structure of the knowledge, the ontology rules inspired the modelling of an ontology driven database, composed by a system of tables that are organized for the description of the different types of geodiversity elements and one for the description of the geosites in their globality. Each table is related to the other table through the property of the ontology: in fact, the geodiversity elements described in some tables can support the description of geodiversity elements in other tables, while every one of those supports the description of the geosites.

To represent and test the filling in of this database, we designed an interface with the software Oneka-S that guides the user in the compilation of data, proposing a defined set of required data (referred to ontology properties to which connect instances from controlled vocabularies) and through a reasoned path of entry of items.

The final act is the compilation of the database with the data of the geosites and of the geodiversity elements that compose them. The database information is displayed in a user-friendly interface in a publicly accessible website; every geosite has its dedicated page, with all the reported information, either described with controlled vocabularies and in a textual format, to support by the one hand the efficiency of the search tools and by the other hand the understanding of a human reader. In each geosite description there is the explicit reference to the geodiversity elements that compose it (either physically, like the geologic units, or not, like the geologic events). In the web pages, the items are in a link format, from which the user can view the full information (besides that displayed in the geosite page). This is the most relevant novelty proposed by this method, as this explicit representation aims at the improvement of the interoperability of data, acting on the accuracy in the geosite information search and comparison, allowing also to exploit the data that are usually “hidden” in the textual descriptions.

CHAPTER 5

CASE STUDIES AND TESTS ON THE GeOntoLOGIC SITE SYSTEM

In this chapter, we discuss the tests on the system. In particular, we selected several geosites from Italy and Poland to test the data collecting method, both from the back end (point of view of the "insider") and from the front-end (tests with volunteers). In the first section of this chapter, we present the case studies from Italy and Poland, provided with a brief geological framework. Among the amount of visited and studied geosites, we selected some of them to show the final representation in the system (database and website), and to prove the enhancement of interoperability and searching accuracy.
As introduced in the previous Chapter, we tested the system with some groups of volunteers that experimented with the geosite description. To evaluate the result of the test, they were asked to fill in a final questionnaire to evaluate their experience. This will be the topic of section 5.3.

5.1 - INTRODUCTION TO THE CASE STUDIES

To test the database and the data filling, we selected several case studies. The main goal of the case studies is to test the method and showcase the improved possibilities of data search and comparison at a local and international level. For this reason, we selected some geosites (for a total amount of 12 sites) from three areas in two countries, namely Italy and Poland, to showcase different types and combinations of geosites and to test the data comparison after the description. The criterion of choice of the geosites were the similarity of processes and the most complete retrieved information. In fact, the chosen geosites represent different aspects related to two main groups of processes, namely the glacial processes and the magmatic processes. Moreover, the events that created the geological element in these geosites are somehow related, as they refer to the Variscan orogenesis for the magmatic related geosite, and to the Pleistocene glaciations for the glacier related geosites.
In the next sections there will be a brief introduction of the case study areas and geosites. All the original bibliographic material for the geosites (both Polish and Italian) are found in Appendix 3.

5.1.1 - Italian case studies

The case studies for Italy are located in two main areas of the Piemonte Region, highlighted in Fig. 5.1 by the coloured circles. The light blue circle, in the northeastern part of the region, show the location of the geosites in the Sesia Val Grande UNESCO Global Geopark (described in section 5.1.1.1), related to magmatic activity during the Permian age. The light green circle, in the central western part of the region, indicates the low Susa Valley, in which are found the two geosites related to glacial processes that we describe in section 5.1.1.2.

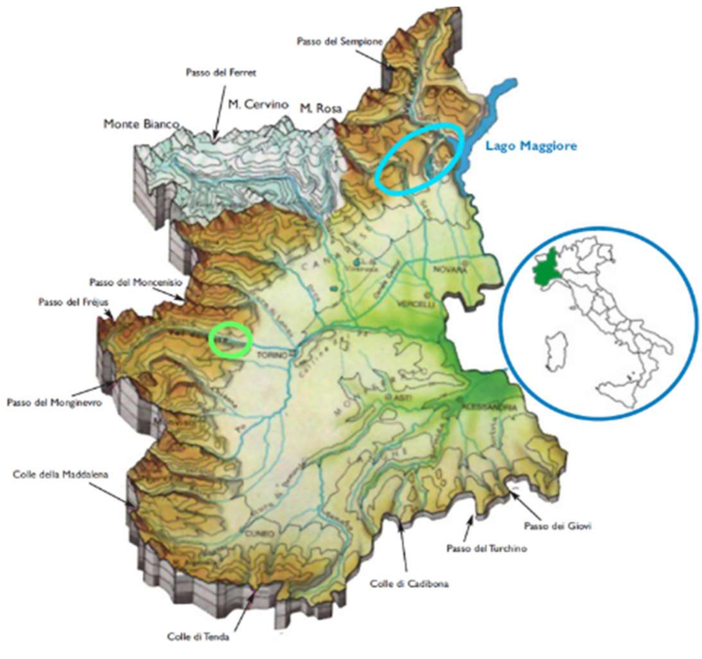

Figure 5.1 - Location of the geosites in Piemonte Region, NW Italy. In yellow the area of low Susa Valley, in red the geosites of the Supervolcano complex and in Orange the geosite of Montorfano. Modified from https://www.cosepercrescere.it/cartina-fisica-del-piemonte/

5.1.1.1 - The South Alpine domain and the Permian Magmatic System (Sesia Val Grande UNESCO Global Geopark)

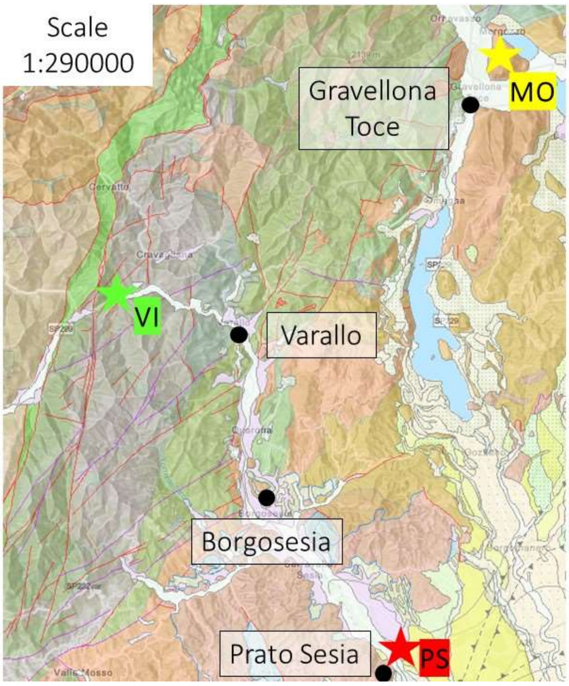

Figure 5.2 - Position of the geosites of Sesia Val Grande UNESCO Global geopark: Vocca Island (VI, green); Montorfano (MO, yellow); Prato Sesia (PS, red), on the Geological Map of Piemonte base (Piana et al., 2017b).

Sesia Val Grande UNESCO Global Geopark (SVUGGp) is a wide and geodiverse area in the northern part of the Piemonte Region (North-West Italy, Fig. 5.1 blue area). Its territory ranges to the plain, fluvial, and lacustrine environments around Lake Maggiore (200 m a.s.l.) to the high glaciated mountains of the Monte Rosa Massif (Punta Gnifetti, 4554 m a.s.l). From a geological point of view, a cross section of the Pennine, Austroalpine and South Alpine domains is outcropping, highlighting a highly diverse geological and geomorphological framework.

In the whole territory, numerous geosites are recorded and several thematic field trips are organized (Perotti et al., 2020). One example, among those presented in the ProGeo Piemonte project (Perotti et al., 2019), concerns the thematic of the Permian magmatic System in the South Alpine Domain (Mazzucchelli et al., 2014). In fact, relevant magmatic processes occurred in the area of the Geopark, generating different rocks and associations. In particular, a bimodal magmatism occurred, generating on the one hand granitic intrusion within the “Serie Dei Laghi” geologic unit (upper crust), on the other hand intrusion of mantle-derived mafic melts of the Mafic Complex in the Ivrea-Verbano Zone (deep crust). This series, grouped in the “Permian Magmatic System”, comprises also evidence of volcanic activity with rhyolites and the Megabreccia, the latter related to the collapse of the caldera system of the Sesia Supervolcano (Sinigoi et al., 2010). The three geosites described below are examples of the different magmatism, i.e., ultrabasic in the deep crust (see Vocca Island), sialic in the upper crust (see Montorfano) and paroxysmal activity (see Prato Sesia). The information about the geosites mainly come from the description in ProGeo Piemonte website[70] (Giardino et al., 2014); the descriptive files also

[70] Webpage in ProGeoPiemonte for the Valsesia geosites: https://www.progeopiemonte.it/path/valsesia.html

contain pictures of the geosites. The geosites are located as shown in Fig. 5.2, while the encoding into items is represented in the schemas of Fig. 5.3.

Vocca Island[71]

This geosite is in the Mafic Complex of the Ivrea Verbano Zone. The main lithology in the area is the gabbro; the rocks show evidence of a very high temperature of the primary melted material (around 1200°C), the highest that was reached by the Sesia Magmatic System. Some zones of accumulation of minerals are visible in the geosite, like a black lens within the gabbros, composed of olivine pyroxenite. The gabbros show evidence of deformation that is interpreted as related to the extensions of the crust due to the multiphase intrusion of magma.

Montorfano granite

In the southern and eastern part of the SVUGGp territory there are bodies of granites that intruded the Hercynian basement of the South Alpine Domain during the late Vasiscan phase. The age of the rock is estimated around 282 My (Schaltegger and Brack, 2007). From some of these bodies are extracted ornamental stones, for example "Bianco di Montorfano" and "Rosa di Baveno" (Dino et al., 2020), a white and rose type of granite respectively.

Prato Sesia[72]

In this geosite, along the Sesia River, the result of the final event of the activity of the Sesia Magmatic System: the collapse of the caldera and the eruption of the so-called Supervolcano (282 My). The evidence of this event in the rocks is called Megabreccia. It is an ignimbrite, formed by the eruptive tufts and lapilli, with a very rich sampler of rocks within. Blocks of various dimensions of all the parts of the complex of the Supervolcano are found within, among which the Laghi Shales, rocks from the ancient crust.

[71] Webpage in ProGeoPiemonte for the Vocca Island geosite: https://www.progeopiemonte.it/path/valsesia/stop4.pdf

[72] Webpage in ProGeoPiemonte for the Prato Sesia geosite: https://www.progeopiemonte.it/path/valsesia/stop10.pdf

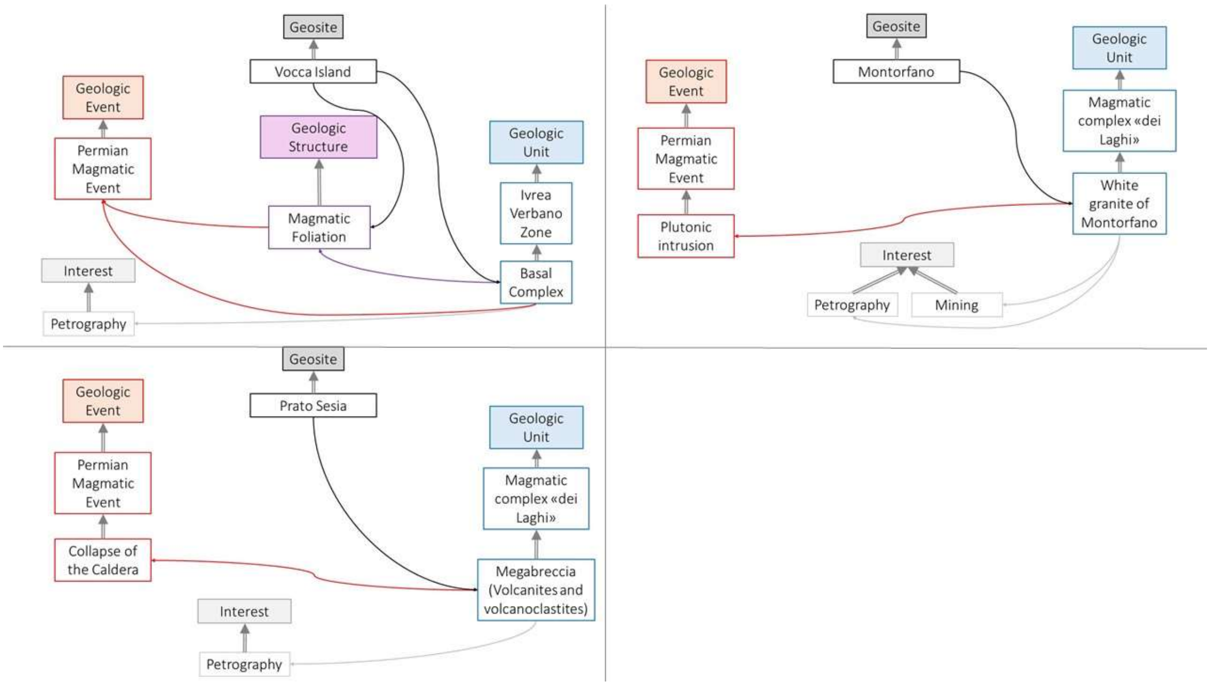

Figure 5.3 - Schematic representation of the three geosites discussed in the section: Vocca Island, Montorfano and Prato Sesia (dark grey squares). In red the events, in blue the units, in purple the structures and in light grey the interests.

5.1.1.2 - Susa Valley glacial evidence

Susa Valley is a long alpine valley that crosses the Western Alps in the middle part of the Piemonte Region, in a western position with respect to the city of Turin (Fig. 5.1, green). Its territory is related to the basin of the Dora Riparia River and is extended approximately in a E-W direction, with an altimetric range from 300 m a.s.l. (at the contact point between the morainic amphitheatre and the deposits of the Po plain) and 3535 m a.s.l. (Mount Rocciamelone). From a geological point of view, the bedrock is composed of geologic units belonging to the Pennine Domain. According to Cadoppi et al. (2002), two main types of units are outcropping, as witnesses of different paleoenvironments: Continental Margin Domain, with continental crust units and Mesozoic covers, and Oceanic Domains, with ophiolites and oceanic crust rocks. From a geomorphological point of view, glacial-related Pleistocene processes (Petrucci, 1970; Nicolussi Rossi, 1992) had a great impact on the general morphology of the valley, furtherly elaborated by gravitational and fluvial related processes. Glacial evidence is both erosional and depositional features. For example, the U-shape of the valley, or the abrasion on the slopes of the mountains (Roches moutonnées) for the erosional features; the morainic amphitheatre of Rivoli-Avigliana and numerous erratic boulders for the depositional features. Fig. 5.4 represents the localization of the two geosites that are described below, while in Fig. 5.5 the items are represented in schema.

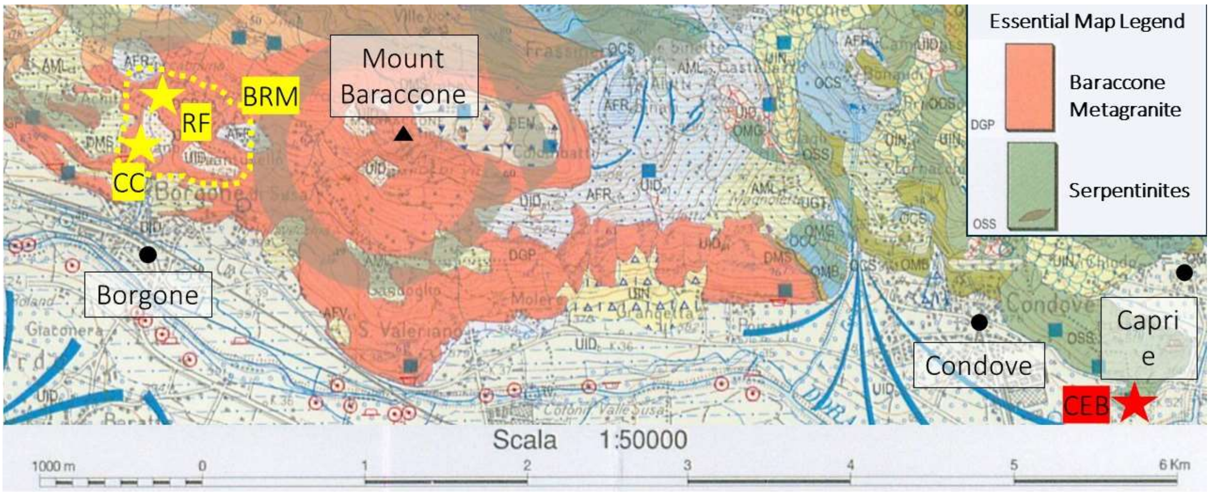

Figure 5.4 - Slice of the Susa Sheet of the Geological Map of Italy (CARG). In yellow, the geosites related to the Borgone Roches Moutonnée (BRM), with the Cava Chiampano (CC) and Rocca Furà (RF). In Red the Castellazzo Erratic Boulder (CEB) geosite.

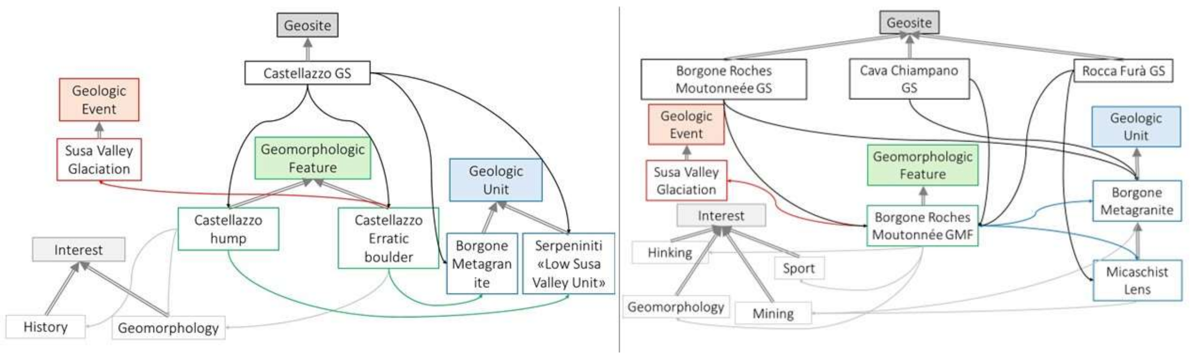

Figure 5.5 - Schematic representation of the three geosites discussed in the section: Borgone Roches Moutonnées, Cava Chiampano, Rocca Furà, Castellazzo Erratic Boulder (dark grey squares). In red the events, in blue the units, in green the landforms and in light grey the interests.

Borgone Roches moutonnées and the Borgone quarries

This complex includes three geosites that are present in the Borgone territory, in the left flank of the Susa Valley. As reported in the description by Aigotti et al. (2004), the main features that are common for the geosites are the morphology, derived from the action of the quaternary glacier, and the rock body, represented by the Borgone Metagranite geologic unit. The three included geosites represent different interests. One of the sites is devoted to the representation of the morphology of the feature, namely the Roches moutonnées, and it has the widest area. The other two are the quarries for the stone materials, namely the Chiampano Quarry for the Metagranite used as ornamental materials, the other is Rocca Furà, in which the micaschists were extracted for creating the mills (already shown in Chapter 3, Fig. 3.7).

Castellazzo erratic boulder

A few kilometres eastwards with respect to the Borgone geosites (around 6 km), there is another site located in the municipality of Caprie. The site is located on the top of a rock hump (391 m a.s.l.), where it is possible to find the ruins of an ancient military fortress known as “Castellazzo” or “Castello del Conte Verde” (literally, “Count verde's castle”). Within the remains of the walls, a boulder stands, as a key element of the geosite (Fig. 5.6a). In fact, the lithology of the boulder is strongly different with respect to the rocks that compose the hump on which it lies, or the mountains around the sites. The surrounding geologic units are mostly made of serpentinite, peridotite, metagabbros, and are interpreted as Oceanic Units (Fig. 5.6c). Differently, the Erratic boulder is composed of an Orthogneiss (Fig. 5.6b) whose petrography is very similar to those outcropping around the Borgone area. In particular, this rock type seems to come from the Mount Baraccone slopes. Hence, how the schemata in Appendix 3 shows, this boulder fell on the glacier of Susa Valley due to a landslide from Mount Baraccone (above the Borgone municipality). The flowing of the glacier transported and modelled this boulder from the area around the present day Borgone town to the area around the present day Caprie. Finally, when the ice melted down due to the glacial retreat, the boulder found its place on the top of the Castellazzo hump (Aigotti et al., 2004).

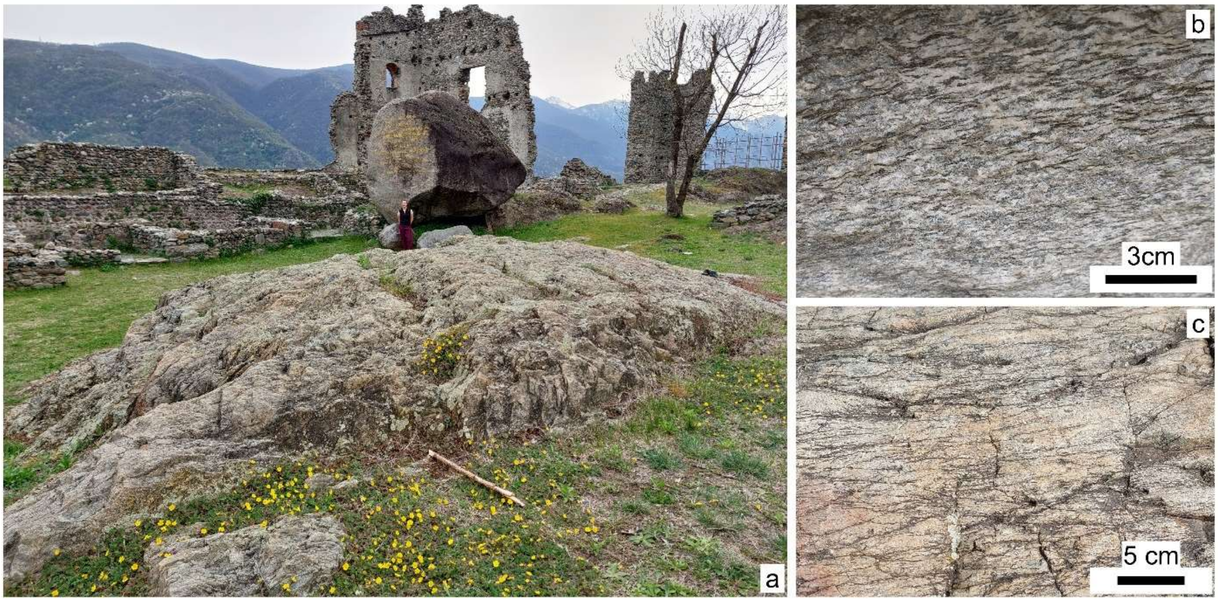

Figure 5.6 - Castellazzo Erratic Boulder. (a) general view of the site, with outcropping serpentines in foreground and the erratic boulder in background, surrounded by the ruins of the castle around. Detail of the orthogneiss of the boulder (b) and of the serpentinites of the bedrock (c)

5.1.1.3 - Conclusion on the Italian case studies

In this section, we have described two groups of geosites in the Piemonte Region in Italy. The geosites show two different types of features, on the one hand magmatic-related features, with environments from the deep levels of the Earth crust to the evidence on the surface (SVUGGp), on the other hand the evidence of the action of an alpine glacier. In the next section, we will present some case studies in Poland, characterized by similar types of processes and environments.

5.1.2 - Polish case studies

The case studies selected among the Polish geosites are located in three main areas related to three National parks (Fig. 5.7). As mentioned earlier, we will see some glacier related and magmatic related geosites. The glacier related geosites are in the Wielkopolski National Park (yellow), located in the centre-western part of Poland, near the city of Poznań, and in Wolin National Park (blue), located in the north-western part of Poland, facing the Baltic Sea and the boundary with Germany. These areas are the topic of sections 5.1.2.1 and 5.1.2.2 respectively. The geosites related to the magmatic processes are found within the Karkonosze Jizera Massif, in an area surrounding the Karkonosze National Park (red), in the south-western part of Poland, next to the boundary with the Czech Republic (see section 5.1.2.3).

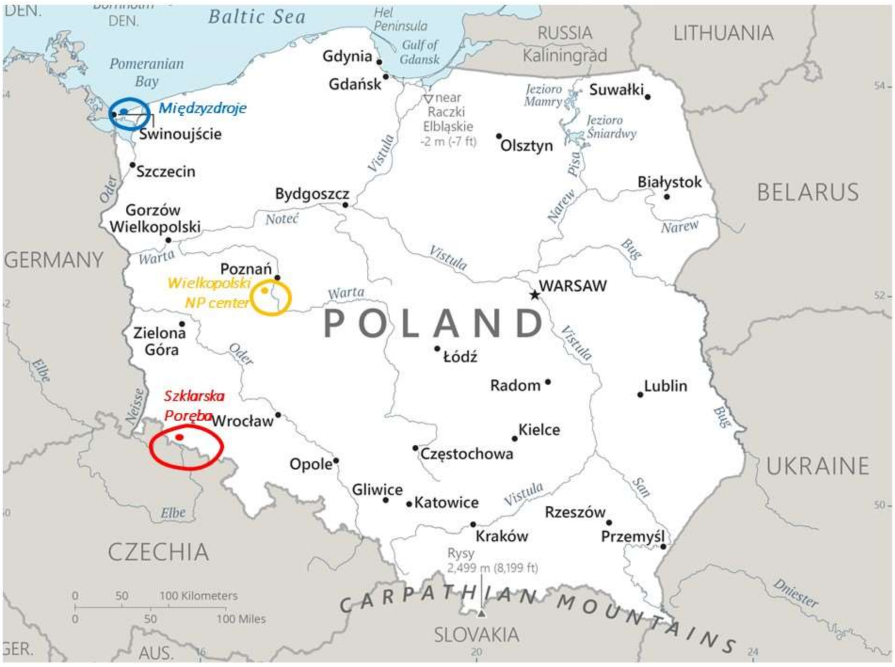

Figure 5.7 - Map of Poland[73] with the location of the areas: in Yellow the location of the Wielkopolski National Park; in green the location of the Wolin National Park and in red the Karkonosze National Park.

5.1.2.1 - Wielkopolski National Park

Wielkopolska (Great Poland) is a region situated in the Central-Western area of Poland (Fig. 5.7, yellow), comprising the areas around the Warta River and its tributaries. From a geomorphological point of view, it is classified as a lowland area, with a geomorphological setting mostly related to the action of the Scandinavian ice sheet (Vistulian Glaciation, Kozarski 1995), that modelled the hilly surface of the area around the city of Poznań and of the Wielkopolski National Park, that ranges around the 60 m a.s.l. of the Warta River incision and the 153 m a.s.l. of the Góra Moraska. The area around the city of Poznań is very rich in geosites that witness the glacial history of the area, plus the meteorite reserve in Morasko, North of Poznań (Zwoliński et al., 2017). The two analysed geosites of this area are represented in Fig. 5.8, while the schema of the items are in Fig. 5.9.

[73] https://www.cia.gov/the-world-factbook/countries/poland/map/

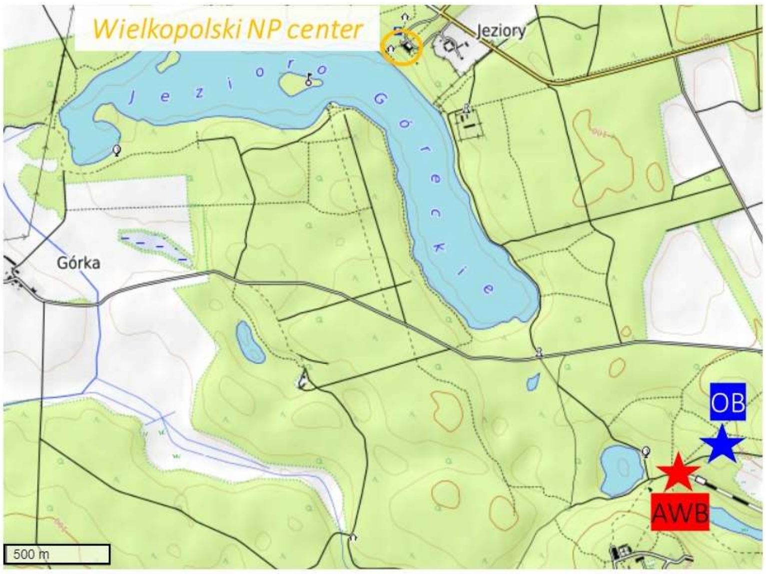

Figure 5.8 - Localization of the Wielkopolski National Park (its centre is marked in orange): Wodziczko boulder (AWB) in red, and Bukowsko-Mosiński esker (OB) in blue, over a OpenTopoMap base[74].

Professor's A. Wodziczko boulder[75]

The geosite represents one of the numerous pieces of evidence of the glacial processes that involved the region. This is an erratic boulder of which petrographic studies confirmed a Scandinavian provenience; in particular, this is a Jareda Granite, coming from Smaland, Sweden. The information about the geosite come from the Polish database and from the panel that is found in-situ (picture in Appendix 3). Crossing the information in the sources, we learn that the boulder arrived during a glacial phase that occurred around 20000 years ago and brought to Poland several boulders from Scandinavia and from the region that is now occupied by the Baltic Sea. This particular boulder is made of Jareda granite, coming from the Smaland territory. According to Zabielska (2023) this part of the present-day Swedish territory is a plutonic intrusive rock that formed in the context of the Svekofen orogeny and dated between 1.96 and 1.75 billion years ago (Korja and Heikkinen, 2005; Gaál and Gorbatschev, 1987; Gorbatschev and Bogdanova, 1993; Bogdanova et al., 2008; Lahtinen et al., 2008). The numeric age is partially comparable to the one reported in the national inventory (Precambrian; according to the geologic time scale, the indicated age can be included in the Paleoproterozoic, older than Noeproterozoic). The origin of the geosite is glacial transport and deposition. It was dedicated to the professor Wodziczki, a botanical biologist from the University of Poznań[76].

Bukowsko-Mosiński esker[77]

This geosite is found at the terminal section of a kilometric elongated landform, namely an esker. This geomorphologic feature type is generated within the context of ice caps, like the one that covered the Polish territories in Upper Pleistocene and Holocene. Within the ice, some crevasse with flowing water

[74] Link to OpenTopoMap: https://opentopomap.org/

[75] Descriptive form for the Professor's A. Wodziczko boulder in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1248

[76] Wikipedia webpage for Adam Wodziczko: https://pl.wikipedia.org/wiki/Adam_Wodziczko

[77] Descriptive form for the Bukowsko-Mosiński esker in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1384

could be found: with the water, gravelly sands and clay sediments were transported and deposited at the base of the glacial mass. After the ice melting, the sediments created this elongated hill, which is 37 km long, 80-300 m wide and up to 40 m of maximum elevation from the plane. According to the panels in the Wielkopolski National Park, the Bukowsko-Mosiński esker is the longest in Poland and one of the longest in the Central Europe Lowlands.

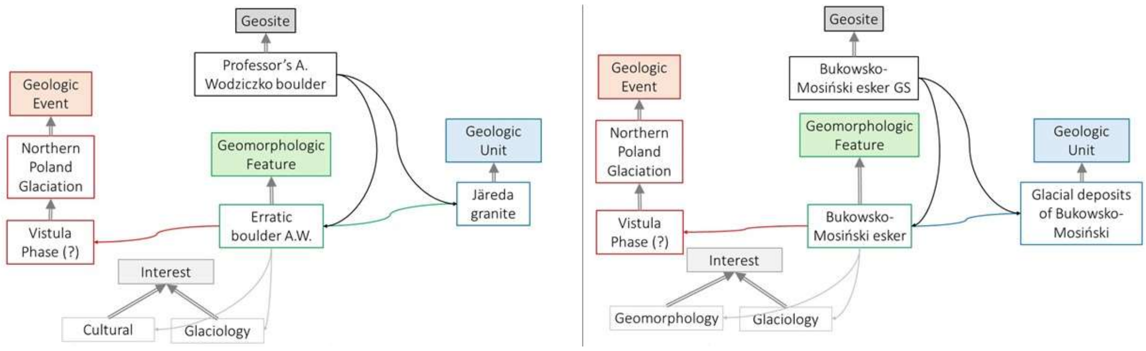

Figure 5.9 - Schematic representation of the geosites in Wielkoploski National Park (dark grey squares). In red the events, in blue the units, in green the landforms and in light grey the interests.

5.1.2.2 - Wolin National Park

The Wolin National Park is in the North-Western part of Poland, next to Germany and the Szczecin Lagoon, at the shoreline of the Baltic Sea (Fig. 5.7, blue). The territory ranges from the sea level to Mount Grzywacz (116 m a.s.l.). The geomorphological setting of the area is influenced by the Gardno Phase of the Weichselian Glaciation. Quaternary mostly glacial related sediments (tills, glaciofluvial sands and gravels, aeolian sands, Borówka et al., 1986; Ryszard et al., 2008) cover a Mesozoic bedrock (Alexandrowicz, 1967). In Fig. 5.10 there is the map of the geosite, and the schematic representation is in Fig. 5.11.

Figure 5.10 - The Międzyzdroje-Wisełka cliff runs along the coast for 11 km; the cliff is in red in the picture (OpenTopoMap base[68])

Międzyzdroje-Wisełka cliff[78]

According to Najwer et al. (2022), the 15 km long Wolin cliffs, formed by multiple glacial phases and processes, is the main abiotic element of nature conservation within the Park. With its highest elevation point corresponding to Mount Gosań, 95 m a.s.l., this landform represents the highest cliff on the Polish coast. It is a composite landform, in which four different types of deposits, with different genesis. The lowest, hence older, and thicker (around an average of 40 m) level is made of grey clays, deposited in occurrence of the Warta Glaciation (210000 years ago). The second level (3m thick) is made of yellowish clays, attributed to the Vistula Glaciatiation (14-12000 years ago), the latest advance of the ice cap in this area (in Fig. 5.12e, the greyish clays compose the majority of the wall, while the yellowish are in the highest part). After the ice cap retreatment, a fluvioglacial environment developed in the area, as witnessed by the sandy-gravel fluvio-glacial deposits, occurring on the older formations in a layer of variable thickness. Finally, a 2-15m level of aeolian sands cover the older deposits.

This complex landform is witness to several glacial phases and different palaeoenvironments. However, it is also a matter of interest that the present-day processes that act to modify the morphology of this cliff. In particular, it is subject to the action of the wind and of the sea waves, especially during storms (Terefenko et al., 2018; Winowski et al., 2022; Tylkowski et al., 2023). These phenomena act with variable intensity every day, operating a continuous foot erosion of the cliff. The consequence is the continuous change of the landform and on the beach below. The blocks and boulders that are included in the clays (Fig. 5.12a) are brought to light and finally fall on the beach (Fig. 5.12b, e).

Moreover, landslides involving sediments and trees occur on the beach (Fig. 5.12d) and flows of sediments coming from the highest levels of the cliff feed cones of sands (Fig. 5.12c).

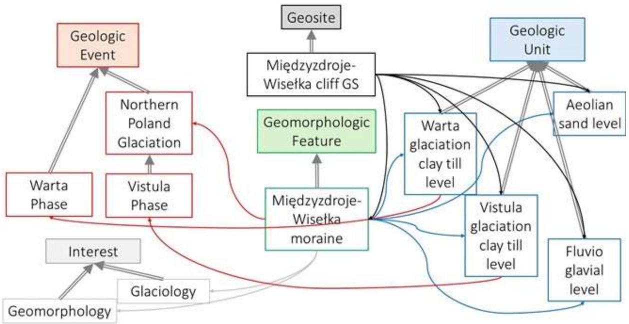

Figure 5.11 - Schematic representation of the geosites in Wolin National Park (dark grey square). In red the events, in blue the units, in green the landforms and in light grey the interests.

78 Descriptive form for the Międzyzdroje-Wisełka cliff in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=3723

Figure 5.12 - Details of the Międzyzdroje-Wisełka cliff, 20/05/2023. (a) one of the blocks (this is a flint fragment) that are deposited within the clays; (b) the blocks of various size included in the clays fall on the beach after the erosion, leaving these deposits; active processes on the cliff: (c) cones of sands flowing from the top of the landform and (d) landslides; (e) view of the levels of the cliff, with the grey and yellow clays visible.

5.1.2.3 - Karkonosze Jizera Massif (nearby Karkonosze National Park)

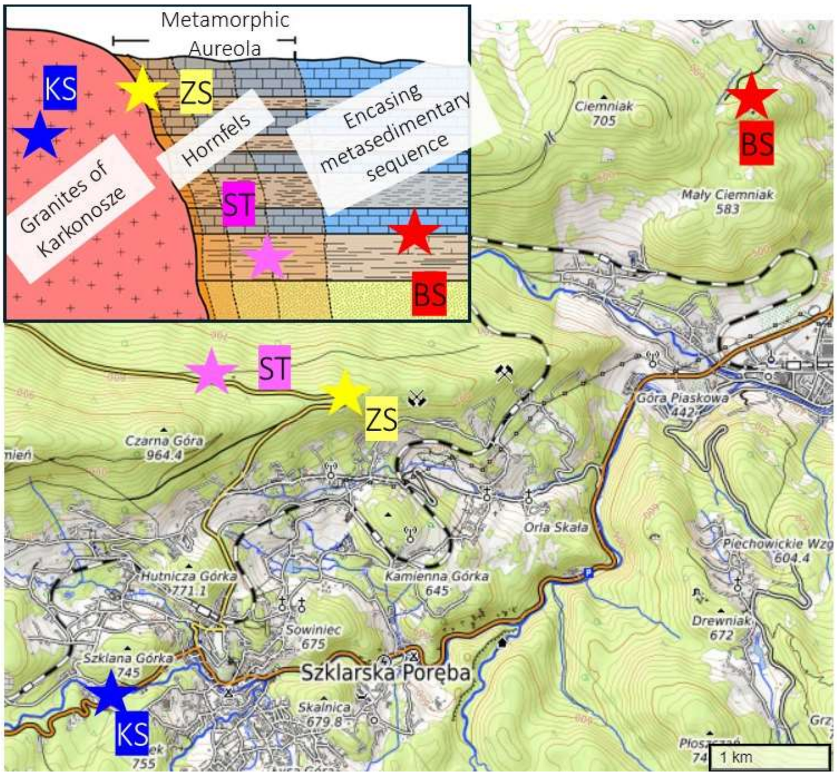

Figure 5.13 - Map of the geosites on OpenTopoMap base[68]. The geosites are also marked in the schema representing an example of intrusive mass within a sedimentary section, with the formation of the metamorphic aureole, weaker and weaker with the distance from the cooling mass. In the stars the indicated the geosites (KS) Krucze Skały; (ZS) Zakręt Śmierci; (ST) Skałka Teściowej; (BS) Bobrowe Skały.

Karkonosze National Park is found along the Polish-Czech border, on the Sudetes mountains (Fig. 5.7, red). The highest peak is the mount Śnieżka (1603 m a.s.l.). The nature of the bedrock influences the geological and geomorphological assets of the area: the core stands in the Karkonosze-Izera Massif, containing the biggest granitoid body in the Sudety Mountains, the Karkonosze pluton (Kusiak et al., 2014; Knapik and Migoń, 2011; Najwer et al., 2022). The Karkonosze pluton is a granitic body composed of a variety of lithotypes, from lamprophyre to leucogranite (Słaby and Martin, 2008), dated around 312 My (Słaby and Martin, 2008, Kusiak et al., 2014). This pluton intrudes a metasedimentary section whose protolite are interpreted as Late Precambrian age (Mazur et al., 2006), while the age of the metamorphism is interpreted around Late Devonian to Early Carboniferous (Mazur and Aleksandrowski, 2001). At the contact between the granitic intrusive rocks and the metasedimentary rocks, because of the heat coming from the cooling magma, a metamorphic contact crown is created at expense of the encasing schists and gneisses. The following four geosites represent different parts of this story, from the intrusive granite to the encasing rocks, showing the contact between them and the metamorphic aureole, as represented in Fig. 5.13. Finally, the schemata of the geosites are in Fig. 5.15.

Krucze Skały (Raven Rock), Szklarska Poręba[79]

This site represents an outcrop of the typical Granite of Karkonosze, with a grey-pink colour, with variable mineral size dimension, and an isotropic texture, a view of the inner part of the Karkonosze pluton (Fig. 5.13, KS element). The rocky mass is affected by a system of fractures, oriented NNW-SSE.

Zakręt Śmierci (Death Bend), Szklarska Poręba[80]

Here we can find in outcrop the contact between the intrusive Granites of Karkonosze and the rocks composing the encasing rocks from the Jizera Massif (Fig. 5.13, ZS element, Fig. 5.14a). The encasing rocks changed by the heat and the thermal processes due to the melted rock intrusion, becoming "Hornfels", composed of quartz, feldspar, biotite, andalusite, cordierite, plus magnetite, corundum, and tourmaline (Fig. 5.14c). In the Hornfels, some aplitic veins are visible. The granite shows a texture oriented parallel to the contact (Fig. 5.14b), different from the isotropic texture of the main mass of Granites.

Skałka Teściowej (Mother In-Law's Rock), Szklarska Poręba[81]

Due to the heat coming from the cooling magma, the slates of the Jizera Massif, at the contact with the intrusive melted mass underwent a process of contact metamorphism, turning in hornfels (Fig. 5.13, ST element). In the site are also visible aplitic dykes, generated by the infiltration of some melted material in a fracture of the schists.

Bobrowe Skały (Beavers Rock), Piastów[82]

This site represents the encasing rocks of the intrusive mass (Fig. 5.13, BS element). It is identified in the geologic units of the Jizera Massif, among which a unit characterized by Orthogneiss is outcropping in this locality (Fig. 5.14e). In the rocks is preserved evidence of the Variscan metamorphism (occurred 350-330 million years ago, Mississipian period, Lower Carboniferous). The rock is outcropping from the top of the hill above which is found (Fig. 5.14d), creating a ridge with a panoramic view, equipped as a climbing gym and a stair for the tourists' access to the top.

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[79] Descriptive form for the Krucze Skały in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4475

[80] Descriptive form for the Zakręt Śmierci in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4472

[81] Descriptive form for the Skałka Teściowej in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4477

[82] Descriptive form for the Bobrowe Skały in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=9801

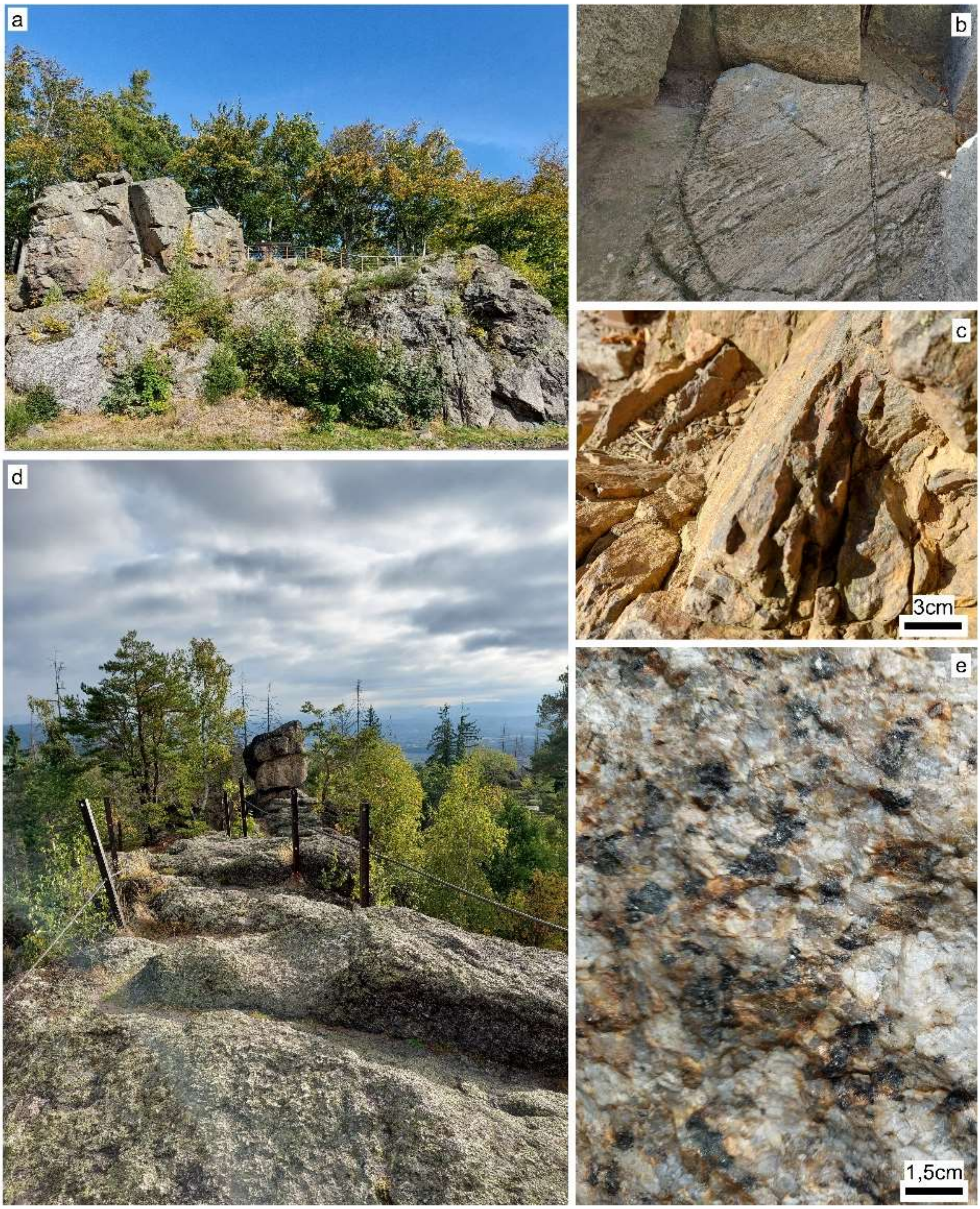

Figure 5.14 - Overview and details of the Zakręt Śmierci and Bobrowe Skały geosites. ZS: (a) overview of the outcrop of ZS, with visible contact between the granites and the hornfels; (b) detail of the granites with texture elongated parallel to the contact; (c) detail of the hornfels; BS: (d) ridge of the rocky outcrop, with a rounded block at the end; (e) detail of the texture of the orthogneiss (black bar: 1.5 cm)

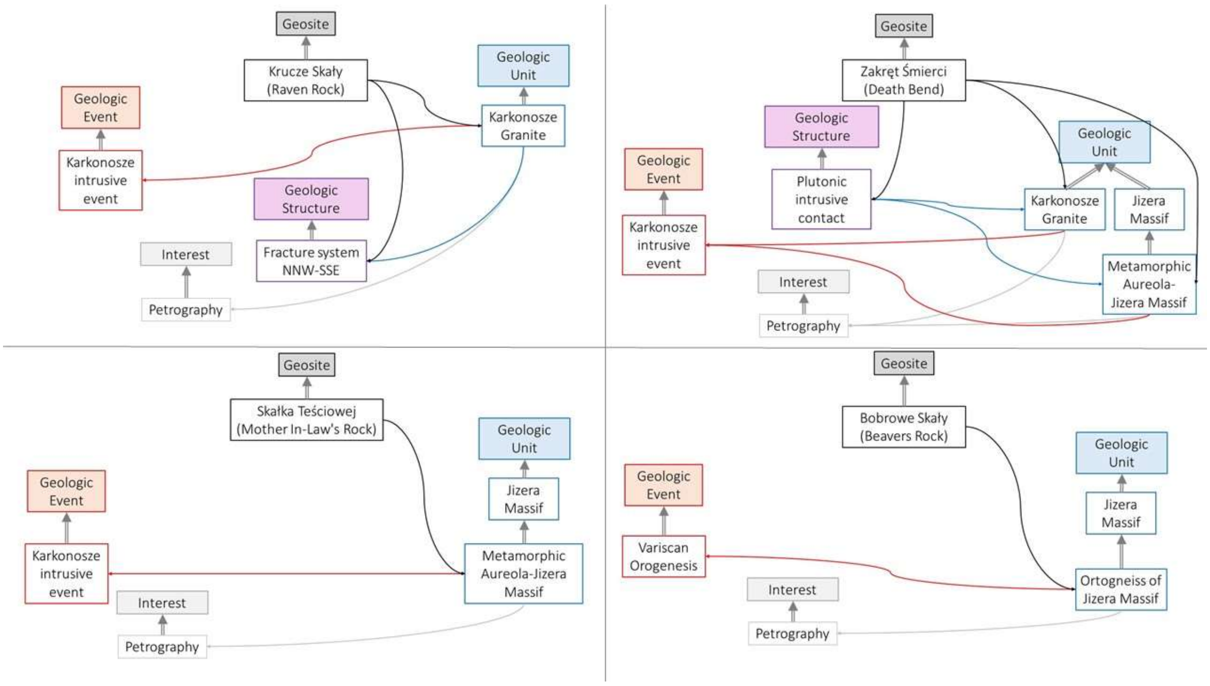

Figure 5.15 - Schematic representation of the geosites in Karkonosze Jizera Massif (dark grey square). In red the events, in blue the units, in purple the structures and in light grey the interests.

5.1.2.4 - Conclusion on the Polish case studies

In this section, we presented an overview of some geosites in Poland. The environments and processes are like those that occurred in the Italian geosites described in section 5.1.1, namely the magmatic processes in the Earth's crust, and the glacial environments. The latter, however, is different, as for the Italian geosite we deal with an alpine glacier, while in the Polish geosites it is a polar ice cap, much bigger than the alpine glacier, and capable of generating landforms that are not common within the Italian territory (as the esker).
In the next section, we will show these geosites can be encoded into items belonging to classes and described in the tables that we have presented in Chapter 4.

5.2 - TEST ON THE GEOSITE DESCRIPTION

The geosites that are described in the previous sections are the object of the test of description and data search that will be presented in this section. The previous part should be considered as a preliminary data collection. Now, all the collected information will be described following the structure designed following the ontology rules and presented both as a website page (published and visible by the Omeka-S powered website) and as a table representation in a QGIS file, within the tables that are designed in chapter 4. The geosites[83], described with this new method, will be subject to some tests of data retrieval, to testify the improvement of the data interoperability.

[83] All the described items are visible at the webpage https://bearchaeo.di.unito.it/exercise/s/geontologicsite/page/geosite-collection

5.2.1 - Description of the items

The process of description of every geosite followed the path described in Chapter 4 for the guided procedure. Hence, the starting point is the text provided by the sources; in our case, the forms for the description of the geosites. For each geosite there is a file, which can be found in Appendix 3, collecting the descriptions. The original texts in Italian and Polish are translated in English (Polish texts are translated with the aid of Google or DeepL.com); for the geosites whose original source is not easy to find on the web, there is the picture of the original text. In particular:

- Italian geosites: for the Susa Valley geosites, the information comes from the work by Aigotti et al. (2004). The relevant pages from the book are present as images with the English translation; for the Sesia Val Grande UGGp, the information come from the description of the sites in ProGeo Piemonte (Giardino et al., 2014; Perotti et al., 2019)[84], which are published on a website, hence in the appendix we have reported only the English version.
- Polish geosites: the information comes from the Polish National geodatabase, accessible online. In the appendix it is possible to find the English translation of the geodatabase form, in a table format. For the Wielkoploski geosites, also the panels that are present in-situ are exploited for the description (pictures and translation are present in the related files).

The goal of this description test is to explain how the textual description can be integrated in the database as instances and be part of the information that is available for data search and interoperability of data. To show the process of translation of text into items and properties, the text in all the geosite forms has been highlighted in different colours: blue for the lithological/mineralogical description (information that concern geologic units), red for the process/environment/age (geologic events), green for the morphology (geomorphologic features) and purple for the structural (geologic structures).

For the description of the items, the information was crossed among the geosites that shared the same element, in order to:

- describe the items in the most complete possible way;
- having enough information to use a given item for the description of all the other items that are involved.

One example is in Tab. 5.1, in which all the elements that are uploaded in the system for what concern the Susa Valley geosites are listed. The Geomorphologic Feature of the Borgone Roches moutonnées is a landform in common for all the geosites of Borgone, but it is not involved in the Castellazzo geosite. However, two items in the system connect the geosites in Borgone and in Caprie. One is the Geologic unit that is outcropping in the Borgone geosites and that probably provided the rocky boulder that fell on the glacier and moved toward the Po plain for 10 km, till the top of Castellazzo hump.
The other common element is the genetic event, i.e., the glaciation that involved the low Susa Valley during Pleistocene. A moving mass of ice leaves several traces, among which erosive and depositional forms. In our case, the landforms of Borgone are an example of the erosive processes operated by the Susa Valley glacier, while the deposition of the Castellazzo Erratic Boulder on the top of Castellazzo

[84] At the link https://www.progeopiemonte.it/path/valsesia.html there are all the geosite in ProGeo Piemonte for the Sesia Val Grange UGGp; al the link https://www.progeopiemonte.it/aree/piemonte-nordorientale/ a general description of the area

hump is an example of transport and deposition operated by the moving ice. The "Susa Valley glaciation" instance is a Geologic Event that occurred during Pleistocene. In a different span of time there was the maximum erosion of the rocky slopes over Borgone (possibly during the advancement of the glacier) and the consequent creation of the Roches moutonnées, while in another moment, namely during the ice melting, the Castellazzo boulder was deposited. However, in the absence of more precise data that could suggest some phases of the event in analysis, we can associate all these processes to the same Event.

<table>
<tr><td></td><td colspan="3">Borgone</td><td>Caprie</td></tr>
<tr><td>Geosites</td><td>Rocca Furà GEOSITE</td><td>Borgone Roches moutonnées GEOSITE</td><td>Cava Chiampano GEOSITE</td><td>Castellazzo Erratic Boulder</td></tr>
<tr><td rowspan="2">Geologic units</td><td rowspan="2">Micaschists lens in Borgone Metagranite</td><td colspan="3">Borgone Metagranite</td></tr>
<tr><td></td><td></td><td>Low Susa Valley Serpentinite and Peridotites</td></tr>
<tr><td>Geomorphologic features</td><td colspan="3">Borgone Roches moutonnées</td><td>• Castellazzo Erratic Boulder
• Castellazzo hump</td></tr>
<tr><td>Geologic event</td><td colspan="4">Susa Valley Glaciation</td></tr>
</table>

Table 5.1 - Comparison of the geodiversity elements occurring in the two studied geosites of Susa Valley.

The geosites in the Sesia Val Grande Geopark represent different phases of the activity of the Supervolcano, and different levels on the magmatic chamber, and consequently the lithologies and the geologic units are different. It is the Permian post Vasiscan magmatic activity that is common for all these geosites (Tab. 5.2).

Geosite	Vocca Island	Montorfano	Prato Sesia
Geologic units	Ivrea Verbano Zone, Mafic Complex	Serie dei Laghi	Megabreccia
Geologic event	Post Variscan magmatic activity		

Table 5.2 - Comparison of the geodiversity elements occurring in the three studied geosites of the Sesia Val Grande UGGp.

Similarly, with the geosites of Karkonosze: four geosites represent different aspects of the intrusive history of the Granites of Karkonosze (Tab. 5.3). In two geosites the granites are visible, both in their inner part and in their external part, next to the contact, which is outcropping in Zakręt Śmierci. Also, the encasing rocks are included in this overview, both near the contact with the granites and in a distal position, which was not involved in the contact metamorphism process, and preserves the last regional metamorphic overprint (Early Carboniferous). Hence, the Jizera Massif macro geologic unit, containing the older metasedimentary sequence and the metamorphic derivatives are in common for all the geosites that represent a part “outside” the geologic contact (Krucze Skały, Zakręt Śmierci, Skałka Teściowej). Differently, the geologic event that did not involve the Bobrowe Skały geosite directly connects the other three explored geosites.

<table>
<tr><th>Geosites</th><th>Krucze Skały</th><th>Zakręt Śmierci</th><th>Skałka Teściowej</th><th>Bobrowe Skały</th></tr>
<tr><td rowspan="2">Geologic Unit</td><td colspan="2">Karkonosze Granite</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Metamorphic Aureola-Jizera Massif</td><td>Orthogneiss of Jizera Massif</td></tr>
<tr><td>Geologic Structure</td><td></td><td>Plutonic intrusive contact</td><td></td><td></td></tr>
<tr><td>Geologic Event</td><td colspan="3">Karkonosze Late Carboniferous Intrusive Event</td><td></td></tr>
</table>

Table 5.3 - Comparison of the geodiversity elements occurring in the four studied geosites of the Karkonosze Jizera Massif.

Similarly, very distant geosites as those in Poznań and those in Wolin can be connected (Tab. 5.4). The distance between the geosites is very long (around 260 km), but they have a common similar genesis. In particular, the Esker is interpreted as related to the Warta glaciation (210000 years ago), which is the same geologic event that is responsible of the deposition of the greyish clay level (the older and the thicker one) of the composite moraine that is known as Międzyzdroje Wisełka cliff.

The second clay level of the moraine in Wolin, which is dated around 14-12000 years, is interpreted as related to the Vistula phase of the Northern Poland glaciation (Marks, 2005) that involved northern Europe approximately from 115000 to 11000 years ago. This time span is compatible with the age of deposition of the erratic boulder in the Wielkopolski NP, which is interpreted as around 20000 years. All these ages are compatible with the final stages of the Vistula glaciation, which left its last traces on the Polish lands in its northern territories, near the Baltic Sea (namely, the cliff).

<table>
<tr><th>Geosites</th><th>Bukowsko-Mosiński esker</th><th>Międzyzdroje Wisełka cliff</th><th>Professor’s A. Wodziczko boulder</th></tr>
<tr><td>Geologic Unit</td><td>Glacial deposits of Bukowsko-Mosiński</td><td>• Warta glaciation clay till level
• Vistula glaciation clay till level
• Fluvio glavial level
• Aeolian sand level</td><td>Järeda granite</td></tr>
<tr><td rowspan="2">Geologic Event</td><td colspan="2">Warta glaciation</td><td></td></tr>
<tr><td></td><td colspan="2">Vistula glaciation</td></tr>
</table>

Table 5.4 - Connection between the geosites in Wielkopolski and Wolin National Parks

5.2.2 - Crossed searches of items and conclusion

The geosites that are described in this chapter are some examples around Europe of magmatic activity and glacial processes. The glaciation is different: the Polish glaciations are related to the spreading of the Northern Pole Ice Sheet, while the glaciation in Susa Valley is related to an alpine glacier. The morphologies modelled by the glaciers are different, for example, Eskers are much more usual within an ice sheet glacier than in the alpine glacier.
However, what is interesting to notice, from the point of view of our work, is the similarity of the periods of these glaciations, all occurred in the Pleistocene period. Among the described items we could search for all the geosites that have a relation with a "Geologic Event" that has

Event Environment: glacial related setting (from the CGI vocabulary)

AND

Age: Pleistocene (from the Geologic Time Scale)

Two Susa Valley geosites are found, along with the two geosites near Poznań (Wielkopolski NP) and the morainic deposits in the Międzyzdroje Wisełka Cliff.
A similar example can be found for the magmatic processes in Sesia Val Grande Geopark and in the Karkonosze Jizera Massif. For example, both the Granites of Karkonosze and the Granite of Montorfano derive from intrusion and cooling of acid magma in the upper crust. These events are interpreted as late-post Variscan intrusions, processes that are due to the overheating of the crust during collisional processes. This causes melting of masses of the lithosphere, and the resulting melted material gets in place at different levels of the crust depending on its density. The more acidic, the less dense, and reaches higher levels in the crust. The melted material reaches a temperature around 700°C and, after cooling, they will be light crystallized rocks, like in Karkonosze and Montorfano Granites. The more basic, the denser, and remains in a deeper level of the crust, maintaining for a longer time a temperature that can reach 1200°C. The resulting rocks are dark, like gabbros and amphibolites of the Ivrea Verbano Zone. Despite this difference in chemism of the rocks, temperature of the melted material and crustal level of cooling, these materials (and the consequent geosites) are the result of the same process type, which is "intrusion", describing the geologic events that are responsible for the generation of the exposed features. Hence, like for the previous example, the elements with a relation to a geologic event which is characterized by the "intrusion" process type, and with a Late Variscan interpretation (corresponding to a span age between Carboniferous and Permian) can be found together.

5.3 - TEST OF THE SYSTEM WITH VOLUNTEERS

The test with the volunteers had a fundamental role in the development of the final interface (presented in section 4.2). In fact, we organized several test sessions with different groups (see details in Tab. 5.6), and each test inspired some improvement to the system. The testing activity (with a duration variable between 2 and 4 hours) was always organized following this schema, composed of three parts.

<u>An explanation part</u>: a presentation concerning some theoretical bases of this system, aided by examples both explained in the presentation and repeated in the system as a tutorial. The examples

were based on the description of the "Karkonosze Pluton" intrusive history and on the "Roches moutonnées of Borgone" geosite. The examples aimed at:
show how to identify the geodiversity elements from a textual description.
Explain that some of the elements may be added, others could be already present in the system, and they should not be described again.

The test of the system: every tester had a geosite to describe, starting from the interpretation of the textual description, from which they had to identify the elements of geodiversity to insert in the system and finally describe the geosite in its global aspects connecting it to the geosite elements.
For the tests in Italy, we assigned some Italian geosites, while during the test in Poland, we selected some Polish geosites. The purpose was to assist the testers who could access materials in their native language for the task. In fact, for the Polish geosites, the information came from the national inventory[85]. Differently, the materials for Italian geosites were mostly unpublished forms for the description of the geosite from the Geopark, along with the book for the Turin geosites (Aigotti et al., 2004).
During this phase, some difficulties emerged, most of them related to the use of the interface:
the order in which the elements should be uploaded for a complete description. This problem that affected the first two tests in Italy, inspired the creation of the guided procedure that was presented in the test in Poland and then modified till its final form for the test in Biella.

- The reuse of the elements: only during the last test (Biella), the testers applied a proper reuse of the uploaded element, avoiding the creation of "twin" elements. For example, during the second test in Turin, the "Sesia Lanzo Zone" geologic unit was described several times.
- Difficulties in the use of vocabularies: most of the testers reported difficulties in understanding the proposed vocabularies. Also, the navigation was difficult, as in the drop-down menu the terms appear in a linear list. For this reason, some help pages were introduced, proposing a hierarchical representation of the terms, along with the links to access the definition of the terms (from the source in the GeoScienceML website). It has to be noticed that among the testers only one had a background in geology, hence the knowledge about the terms in the vocabulary.
- The occasional inadequacy of the vocabulary: the tester with a geological background reported a partial inadequacy of the proposed vocabulary (CGI simple lithology). In fact, some terms that are normally used for the description of alpine geology and petrography are not considered within that vocabulary. One example is the term "Prasinite", indicating a basaltic metamorphic rock (Leardi et al., 1986) made of albite in a matrix of chlorite, actinolite and epidote. In the Simple Lithology CGI vocabulary this term is missing, although there is the "Chlorite actinolite epidote metamorphic rock"[86], that can be used instead. To overcome this problem, the free text field for the description of the lithology (and other controlled vocabulary-based fields) was added.
- ID creation for the objects: sometimes, attributing the proper name to the geodiversity elements was difficult for the testers. In place of the proper name of the element (e.g., "Sesia

[85] Link to the Polish website for the geosites: https://cbdgportal.pgi.gov.pl/geostanowiska/
[86] Definition of Chlorite actinolite epidote metamorphic rock:
http://resource.geosciml.org/classifier/cgi/lithology/chlorite_actinolite_epidote_metamorphic_rock

Lanzo Zone" is the proper name of a geologic unit) the tester inserted a general name, like "Sands" or "Moraine".

- Repetition of information: an ideal situation would be if once indicated a previously uploaded geodiversity element, e.g., a geologic unit, all the related information (e.g., the lithology) would automatically appear in the related fields. Unfortunately, the Omeka-S system does not support auto-filling of the fields, hence the information must be repeated even when describing reused elements in the final geosite form. This is a system limitation that cannot be overcome in the Omeka environment and would require system programming for this specific case.

All these problems occurred in the tests and inspired changes on the system and in the presentation method in the explanatory part. Some comments that were referred to by voice in the discussion at the end of the test, and in the questionnaire was that this method supports the reasoned description of the geosite, guiding the user through the process and encouraging in focussing on one element a time before looking at the global scale.

The evaluation of the system: the testers were required to evaluate the system through a questionnaire (designed as google form[87]) which was organized into three sections, one with general questions and two containing pre-designed questionnaires for the evaluation of the user experience.

The first section contained some general questions on the tools used during the test, opinions on the vocabularies, and general comments on the system. These questions were designed ad hoc for the evaluation of this specific system. Most of the questions of the section were meant to indicate which type of tools they used, which collecting form, which vocabulary and how often they used the free text. Two questions are an evaluation of the system in general: one for the completeness of the geological description (79,1 % agree) and one for the possibility of using the system during field work (72,1 % says yes, but in a simplified version).bb

The second section contained the questions for the UEQ (User Experience Questionnaire) evaluation method (Laugwitz et al., 2008). The UEQ consists of 26 couples of words of opposite meaning (e.g., slow/fast, or creative/dull). Each couple of words is separated by 7 circles, the user is invited to tick the circle that most closely reflects his/her impression with respect to that couple. This is translated into values that ranges from -3 to +3, where:

- values from -3 to -0.8 are considered negative;
- values from -0.8 to +0.8 are considered neutral;
- values from +0.8 to +3 are considered positive.

To submit the questionnaire, the material is provided on the UEQ website[88]; in this case, we used the pdf forms with the couples of adjectives available in 37 languages, and the excel files to elaborate the results. In the google form submitted to the testers, we reported the couples of adjectives from the pdf forms, and proposed them in English, Italian and Polish, to facilitate the correct understanding of the terms to the majority of the testers. Then, we recorded the obtained values (marked from 1 to 7 extreme left - extreme right) in the excel file downloaded from the website, in which the results are

[87]The full questionnaire is visible in Appendix 4, or at the link: https://docs.google.com/forms/d/1oJXw5WHgXK82UXaLTgzmVlm3smCprIR6qCNHHlEiJ2s/edit

[88] UEQ website: https://www.ueq-online.org/

immediately transposed into a graphic representation. As it is possible to see in Fig. 5.16, in which the mean of all the results is represented) the majority of the values (14) range into the neutral zone (among which 4 below the 0), while 12 are considered positive (mean over 0.8). No mean values range below the negative limit (minor that -0.8). The worst values are "difficult to learn", "slow", "complicated" and "confusing". On the other side, the best values (above 1) are "valuable", "interesting", "supporting", "good", "meets expectation". In Fig. 5.17 all the session tests are presented singularly, with the mean represented with the cropped red line. As it is possible to see, the green and blue lines, corresponding to the tests performed the 8 November in Turin and the 11 January in Biella are those with the best evaluation, above the mean, while the purple line (30 November in Poznań) is the one with the worst results. Finally, the yellow one has an irregular disposition of values, some that are much above the mean and others much below the mean. It has to be noticed, however, that only two series of data are considered for this group of tests.

These 26 values are grouped into six scales that represent the final evaluation of the system (Schrepp, 2023). Tab. 5.5 shows that attractiveness, dependability, and stimulation as positive, while efficiency, novelty and perspicuity as neutral (with the latter below 0).

For a general comment of the results of the UEQ evaluation, see section 5.3.1, in which these results are compared with those obtained from the next evaluation questionnaire, the SUS, described below.

Scale	Description	Average value
Attractiveness	General impression on the system, like or dislike	0,845
Perspicuity	Evaluation of the level of difficulty in using the system	-0,157
Efficiency	Effort in solving the task	0, 529
Dependability	Confidence in the interaction with the system	0,977
Stimulation	Enjoyment in using the system	0,866
Novelty	Creativeness and interest of the users in the system	0,523

Table 5.5 - scales of the UEQ and evaluation, with a description of the type of value and the average obtained by the tests. Green and orange indicate positive and neutral values respectively.

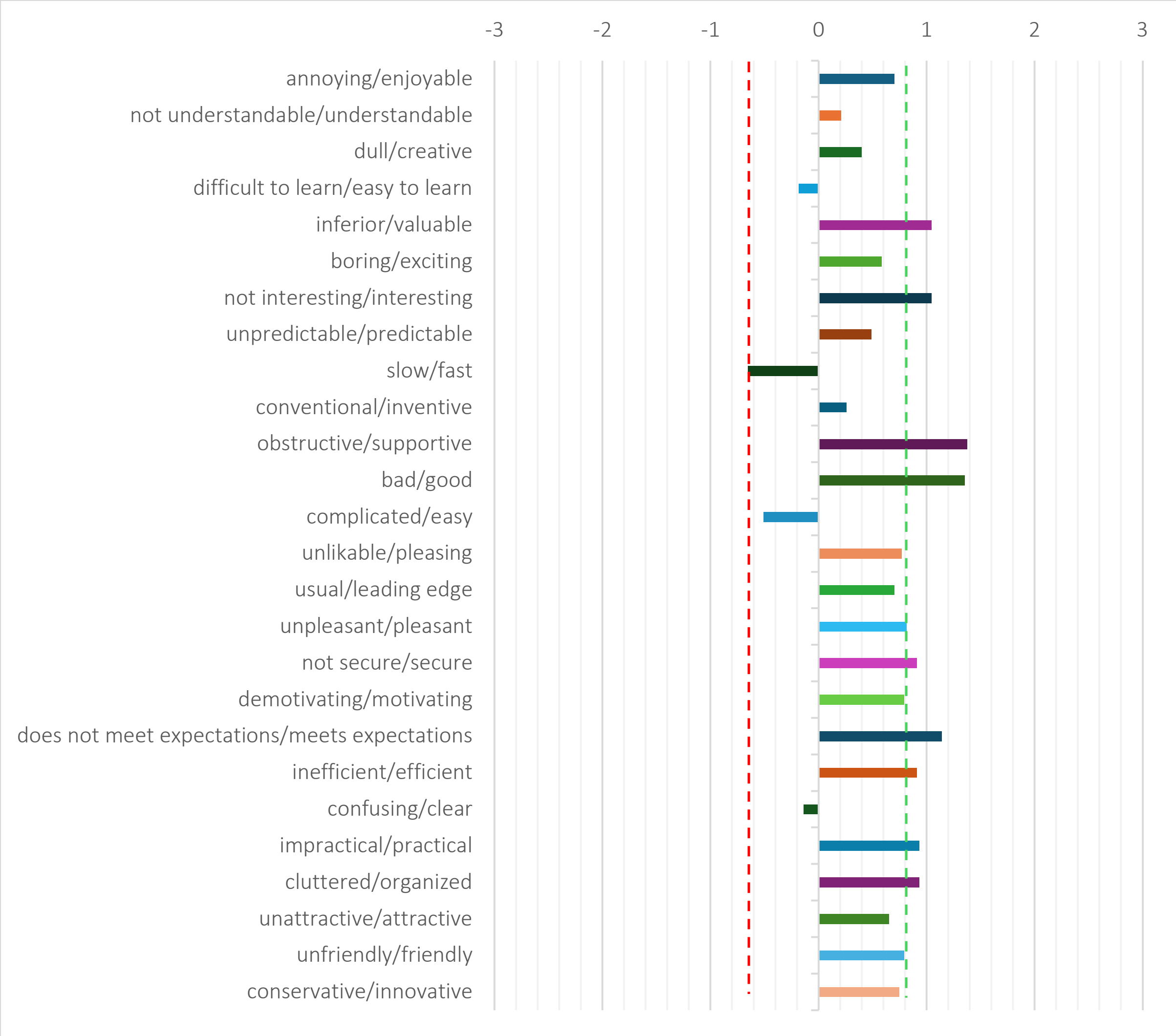

Figure 5.16 - UEQ results: mean of all the couples of words. The red and green spotted lines mark the values -0.7 (the lowest) and +0.8 (indicating the threshold for the positive range).

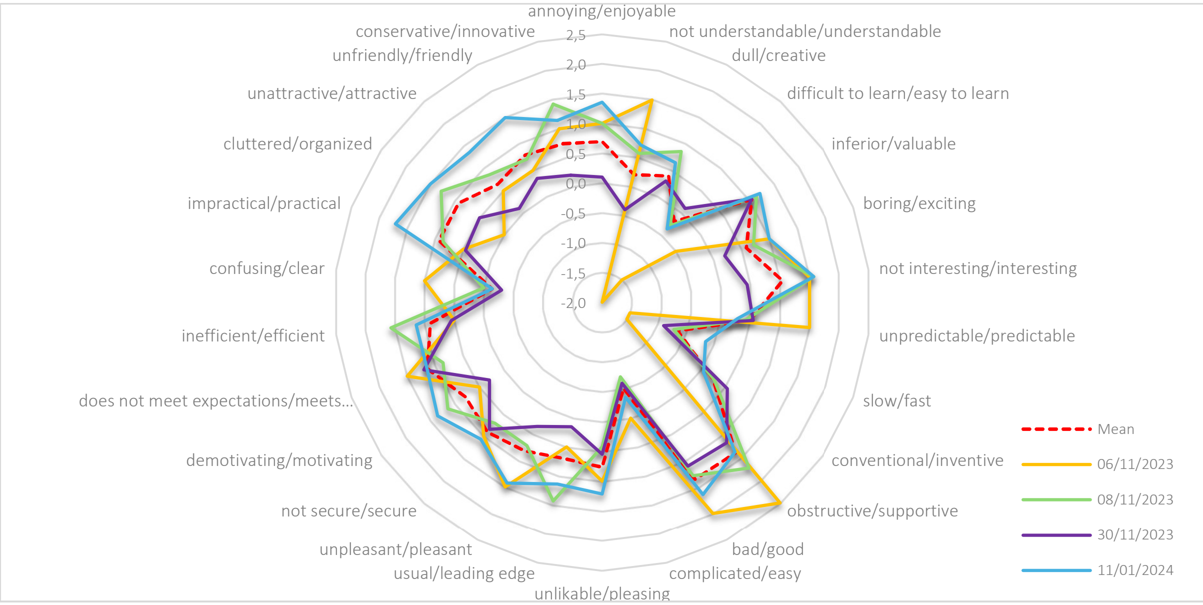

Figure 5.17 - Comparison of the means of the single tests, marked with different colours (legend on the right). The mean of all the results is marked with the red spotted line.

The **third** and last section contained a different questionnaire form, named SUS, System Usability Scale (Brooke, 1995). This questionnaire is based on 10 questions on the impression felt on the system by the testers; to each of them, an answer from strongly disagree to strongly agree (values from 1 to 5) is required.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

To evaluate the results, the score obtained by the questions is calculated as follows:

- to the odd question, the final result comes from the given score minus 1;
- to the even questions, the final result comes from 5 minus the given score.

These final values are then added up (singularly for each questionnaire) and multiplied by 2,5. The final result scores from 0 to 100. From the questionnaires, we obtained 49 SUS scores, with a general mean of 52,33.

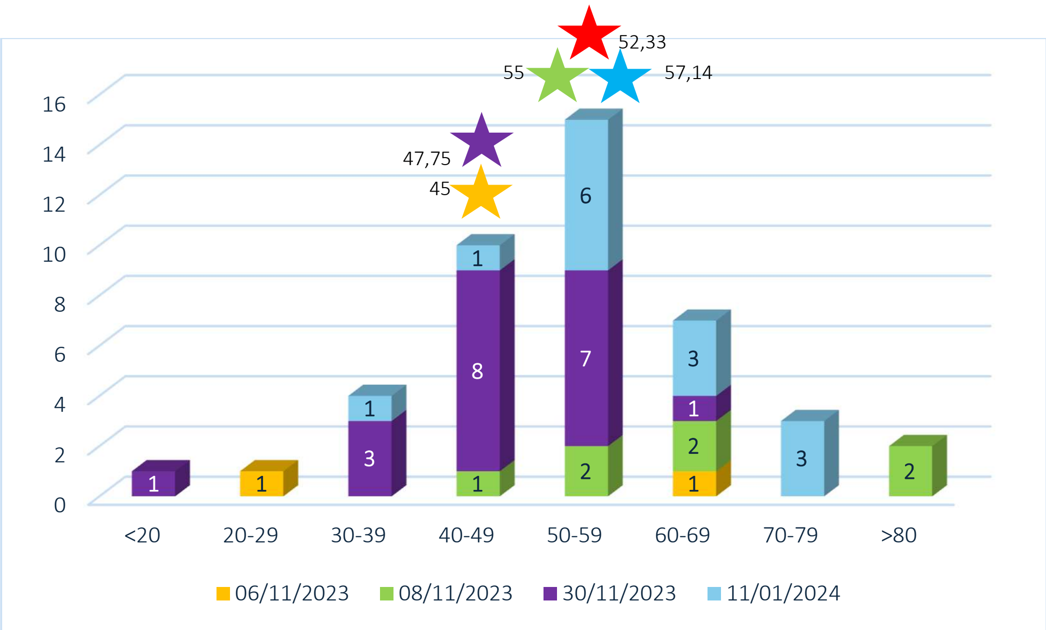

Figure 5.18 - SUS scores. The columns represent the number of obtained scores in each range. The stars indicate the average value for each test (values near the stars).

The means of the scores, as represented with the stars in Fig. 5.18, are above the mean for the test performed on 8 November and 11 January. Vice versa, the means of the tests performed 6 November in Turin and 30 November in Poznań are lower than the general mean. However, the questionnaires for the 6 November are very differently rated, as one of the values is the second worst value (see Fig. 5.18), while the other is one of the results that ranges over the sufficiency (range 60-69). In fact, it is the only data series that shows this high discrepancy, while the others show values grouped into near ranges. For the interpretation of the SUS scores, several sources[89] share the ranges of scores that are related to level of appreciation of the system. In this case, with a general mean of 52, the system can be considered as marginally appreciated. Scores below 50 are negative, while scores above 70 are good. In the next section, we conclude this chapter with a comparison of the result of the SUS and UEQ evaluation systems.

5.3.1 - Conclusion on the tests with volunteers

The tests with the volunteers offered several hints for improving the system, which obtained its final form for the final test, 11 January in Biella. In fact, we operated deep reviews of the system after the test in Italy (6-8 November), introducing the interface for the guided procedure, and after the test in Poland (30 November), with the perfectioning of the guided procedure through the addition of graphical features to ease the compilation procedure.
It must be underlined that we performed all the tests within class lectures that involved people coming from different contexts with respect to Earth Sciences (detail of the tests in Tab. 5.6). Hence, many of the difficulties during the activity concerned the comprehension of how to classify the elements in the main classes (units, structures, ...); this point is also underlined by some of the collected comments in the questionnaires. In general, we could overcome the majority of the difficulties by discussion during the tests; in fact, the best questionnaire results were obtained from the tests in which there has been more time for discussion and tutoring of the testers during the activity.
If necessary, new tests could be performed in the future with people with a geological background. In fact, this model is deeply related to the geological aspects of the geosite, that the tests underlined to be not so immediate to understand for a non-geologist (e.g., it is easier for everyone speaking of rock-type or lithology, while the geologic unit is a less common concept). Moreover, it would be interesting to test possible differences in the description of the same geosites: the test could be performed with separate testers that work on the same textual sources to describe the same geosite. After the description the differences in the description would underline limits in the descriptive system.
Despite the difficulties, on the 52 assigned geosites, 32 were completely and correctly described. In general, the system was evaluated by the tester as a possible good tool for field activity in a simplified version (72%), while 23% considered it a good tool for field activity in its complete version.
The best results were obtained for the tests in Turin on 8 November and for the test in Biella on 11 January. This information is obtained both by the SUS scores and by the UEQ scores, which show a comparable trend of results, despite the differences in the score obtaining process. In fact, the UEQ evaluates each couple of values singularly, comparing all the results for that couple in all the questionnaires. Vice versa, in the SUS are calculated the sums of all the results of the single questionnaire.
The final evaluation seems to be comparable, both considering the single test sessions and in average. In fact, willing to compare the scales of SUS and UEQ, we can notice that almost all the results of the mean in the UEQ final graph (Fig. 5.9) range from 0 (corresponding to 50 in a 0-100 scale) to around 1

[89] Source of information for the evaluation of a SUS questionnaire results: https://www.userfeel.com/blog/sus#:~:text=The%20SUS%20rating%20is%20a,answer%20after%20completing%20a%20test.

(corresponding to 66,67 in a 0-100 scale), with some exceptions above and below this range. Finally, the general mean of the UEQ values is 0,6 (around 60 in the scale in hundredths).
Hence, the UEQ evaluation appears to be more encouraging, due to the numerous (almost half) values that score in a positive range, with no negative (mean) values, and a general mean that appears to be higher than the one achieved in the SUS.

Date and place	Nember of participant	Background and nationality of participants	Successfully described geosites	Filled questionnaires
6/11/2023, Turin, Italy	4	Professors and Phd Students involved in the "Historical Landscapes, Traditions and Cultural Identities" research project. ITALY	100% (4/4)	2
8/11/2023, Turin, Italy	7	5 students from "Geoheritage and Geodiversity" course (Geographers and Environmental Scientists) and 2 Earth Sciences PhD students ITALY	100% (7/7)	7
30/11/2023, Poznań, Poland	25	Students from geoinformation engineering (University of Poznań) POLAND	32% (8/25)	20
11/01/2024, Biella, Italy	17	Students of the "Cultural Heritage and Creativity for Tourism and Territorial Development" degree INTERNARNATIONAL (among which Russia, China and Italy)	81,25 (13/16)	14
	53			43

Table 5.6 - Details of the test sessions: date and place, number of participants, background of the testers, successfully described geosites and number of filled questionnaires.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

In this chapter, the last of this thesis, we will discuss the research that we performed and highlight some conclusions and future perspectives. The work leans on some research questions, here recapped:

- What is geodiversity, geoheritage and geosites, and which are their mutual relations?
- Can we represent these concepts and their relations with semantic studies and ontological models?
- Can we apply these models to the representation of the data in a database format and will this impact on the interoperability of data?

In the following sections we will discuss the results of the work based on these questions. We will start with a summary of the thesis (section 6.1), from which we will take the hint for some discussion on the theoretical model that we propose and on its practical application (6.2 and 6.3). Finally, we will summarize these aspects with the presentation of the expected impact of our work (6.4) and conclude with the open issue and perspective for future research (6.5).

6.1 - SUMMARY OF THE RESEARCH AND OF THE THESIS

In the present work, we discussed the concepts of geodiversity, geoheritage, and geosite and their relations. In literature, this research topic has been deeply debated in the last 30 years, namely since when the term of geodiversity was introduced to indicate the variety of the abiotic nature, like biodiversity for the living nature. Several authors proposed their models for those concepts and the dependent mutual relations. Deep bibliographic research highlights that these models present mutual discrepancies, resulting in incongruences when establishing which elements are geoheritage or not, how and if the concepts are related and also misuse of the terms (sometimes used as synonyms, Gray, 2018). Our research aims at reviewing these concepts and their relations, by applying semantic and ontological studies. A reference to the use of these methods was firstly introduced by Zwoliński et al. (2018), in which the authors propose the possible application of ontological methods to the geodiversity assessment as a future perspective. Indeed, we did not focus on the geodiversity assessment, but our goal was the representation of the concepts in general and in mutual relation.

Hence, in our work, a lot of space was dedicated to a detailed study of the definitions, which are numerous in literature and present several differences, starting from each concept one by one till the analysis of their relations. The first point on which we focus is that the use of the concepts of geodiversity and geoheritage is difficult from an ontological point of view. In fact, while “geosite” is a countable noun (1 geosite, 2 geosites, ...) geodiversity and geoheritage are uncountable nouns; there is not 1 geodiversity or 1 geoheritage, hence these concepts cannot be considered as classes (namely, they cannot be set of items). To overcome this problem, we used the concept of “element”, which is a countable term (we can imagine a group or set of elements) that is frequently used in the context of the definitions of geoheritage and geodiversity (e.g., by Brilha, 2016, 2018). The “Geodiversity element” and “Geoheritage element” are in a hierarchy, the latter as a subset of the first. The Geodiversity element class characterizes the type of elements that represent the abiotic nature, and it is connected to several other classes from ontologies for the geosciences in which those concepts were already encoded (e.g., OntoGeonous, Lombardo et al., 2016, 2017, 2018; Mantovani et al., 2020a, b), in alignment to the paradigm of linked data (Bizer et al., 2009).

The Geoheritage element class collects all those items from the Geodiversity element class to which a value is attributed. The attribution of the value is dependent on the fulfilment of an interest: according to the philosophical theory on the concept of value by Perry (1914), an object has value when it is able to satisfy someone’s interest. The attribution of an interest to the items of the Geodiversity element class achieves a crucial importance, both for what concert the attribution of the value and thus the characterization of geoheritage, and for the characterization of the geosites. In fact, in our model, the class “Geosite” belongs to another hierarchy, as it is a type of site. The connection with the other hierarchy is that a generic region, to be a geosite, must include at least one element of geodiversity to which an interest is related.

In order to test the theoretical model, we designed an ontology driven database for the description of the geosites, through the CMS Omeka-S. With “ontology driven” we mean that the structure of the database is grounded on the ontological constraints for the classification of the items. In particular, each class of the ontology is related to a table in the database, and the relevant properties inspire the columns of the tables. In each table there are columns for the reference to items from other tables, making it an ontology driven relational database. The developed tables concern some types of geodiversity element (Geologic units, structures, events and geomorphologic features) and a table for the geosite. The latter has numerous slots to indicate which elements of geodiversity are involved in the context of the geosite, plus the columns for the indication of the interests that each geodiversity element may satisfy (not all the geodiversity elements of a geosite must satisfy an interest: it is mandatory that at least one does, the others are optional). By the one hand, the use of the relational database format causes the loss of the reasoning capacity that is typical of the ontology. By the other hand, the choice of collecting the data in this format is more compliant to the nowadays methods of geodata representation, more familiar to the scientists that deal with this topic, and easy to manage for the data consultation by the users.

To drive the filling of the database and to facilitate the testing of the method, we created a guided procedure on a publicly accessible website. This procedure is organized into numerous steps that lead the user through the filling of the database. The idea is that a geosite needs one or more geodiversity elements, but also some of them need other elements to be described. Our guided procedure is organized to prepare the base for each following step. For example, the Geologic events are the first items to be described and filled in the table, because they are needed to describe almost every following element type. At a theoretical level, once resumed previously described items, the required knowledge should appear automatically. Unfortunately, this is not possible with the used software (Omeka-s), the involvement of software engineers would be necessary to solve this issue.

The database and guided procedure were tested during this research, both to describe some case study geosites to present the proposed organization of the knowledge, and by submitting the guided procedure to some groups of volunteers that were asked to describe an assigned geosite through the guided procedure and evaluate the system with a final questionnaire.

Our research results in an approach for the consideration and description of the geosite and geoheritage data which is different from the one that is normally adopted. In the next sections we will explore these points, grounding the further proposal of some insights for future research.

6.2 - THEORETICAL LEVEL: RESULTS OF THE SEMANTIC STUDY AND ONTOLOGICAL REPRESENTATION

The state of the art in the geodiversity, geoheritage and geosite field is rich in works and initiatives. Since the recognition of geodiversity in the early nineteens, several descriptions, definitions of these concepts and classifications of the elements that constitute geodiversity, geoheritage and geosite have been published. In particular, the high number of definitions in literature describe a number of models for their description, that however, may present some mutual incoherence. In all the models, the concepts are highly dependent on one the other, even if in different ways. The main examples of these differences are:

- The dependency relation of geoheritage on geodiversity ("Geodiversity as a Backbone of Geoheritage", Gray 2018), which is not accepted by a group of authors (among which Brocx and Semeniuk, 2007).
- The relation between geosite and geoheritage: according to some authors (e.g., Brilha 2016; 2018) geosites are in-situ occurrences of geoheritage, while according to other definitions this is not a restriction.

We will discuss these themes in the next subsections.

6.2.1 - Geodiversity and geoheritage

Although geodiversity and geoheritage are well defined in literature, sometimes the use of these terms is taken lightly. According to Gray (2018) there is a recurrent use of the term geodiversity as a synonym of geoheritage, earth heritage, geoconservation or geology. Moreover, the concept of geodiversity is used also in the promotion of natural reserves, such as the geoparks (Gray, 2018; Dahlgren, 2006).
This misuse of the term geodiversity can lead to interpretation issues and discussions on the correct use. For instance, the relation between geodiversity and geoheritage is subject of a discussion in the academic world, as reported in the papers by Brocx and Semeniuk (2019), Gray and Gordon (2020), Brocx and Semeniuk (2020), Gray (2021).
The genesis of this discussion is nested in the divergence of theories on what geodiversity is, to which scale it could be applied and the relation that it has with geoheritage.
According to Gray (2013) and Gray et al. (2013), geodiversity is a characteristic of the Earth that involves the abiotic nature, both from a global and from a local point of view (namely, all the abiotic nature elements existing in the world, and those that are present in a given limited area). Differently, according to Brox and Semeniuk (2007, after Joyce, 1997, and Semeniuk, 1997) the concept of geodiversity should be applied only at a local scale (e.g., the geodiversity of a Country, or of a Geopark). The meaning of geodiversity grounds this difference: in fact, according to Brocx and Semeniuk (2007), the concept of geology is wide enough to cover the global point of view of geodiversity, as meant by Gray (2013).
This divergence in the theories about geodiversity influences the concept of geoheritage. Several authors ground the concept of geoheritage on the concepts of geodiversity, as highlighted in the definitions for geoheritage, and by the high relation with the promotion of the Geoparks. Differently, Brocx and Semeniuk (2007, 2019, 2020) reject the direct association of geoheritage - geodiversity. At a local scale, an area characterized by a very rich geodiversity does not necessarily contain occurrences of geoheritage, while an area with a very low geodiversity could host one single element that is rare or of special significance and thus considered as geoheritage. Considering the global scale, to which geodiversity should not be applied according to Brocx and Semeniuk, the elements of geoheritage are selected among the geological elements. This relation (graphically represented in Brocx and Semeniuk, 2019, and in Fig. 6.1, left) puts geodiversity and geoheritage as hierarchically equivalent (siblings) under a wider class, which is geology (Brocx and Semeniuk, 2020).
These two theories present deep differences that lead to a deeply different conceptual model: in fact, while Brocx and Semeniuk (2019, 2020) see geoheritage and geodiversity as siblings, both daughters of the wider class "geology", the theories by Gray (2013), Gray et al. (2013) seem to underline a dependency of the concepts of geoheritage on the concept of geodiversity (more similar to a parental relation that to a sibling relation, Fig. 6.1 right).
This recent academic discussion offers an interesting platform for our discussion: our work aims at providing a model for the representation of geodiversity, geoheritage, geosite. The question is, does our system offer a way to harmonize such different theories on what apparently is the same topic?

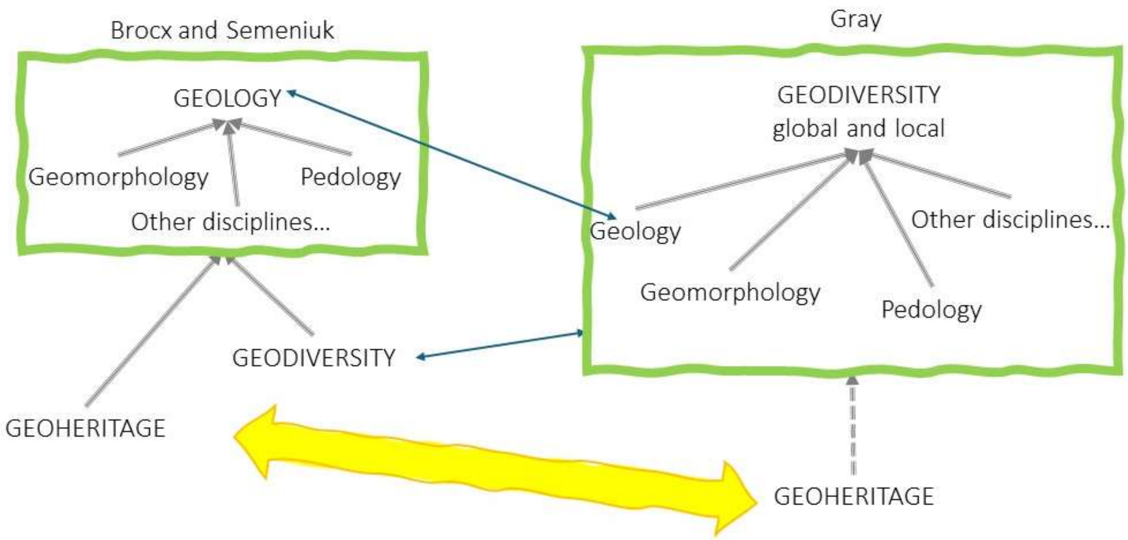

Figure 6.1 - Relations among the concepts according to the different theories. Geology stands in a different hierarchical position, as well as geodiversity and geoheritage.

6.2.1.1 - The concept of geodiversity (alone and from a geoheritage perspective)

GEODIVERSITY	The natural range (diversity) of **geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features**. It includes their assemblages, structures, systems, and contributions to landscapes	Gray
	the natural variety of **geological, geomorphological, pedological, hydrological features** of a given area, from the purely static features (i.e., products such as shorelines, sandy spits, or limestone pinnacles, or river canyons) at one extreme, to the assemblage of products, and at the other, their formative processes (e.g., active parabolic dunes forming under a given wind regime) (After Semeniuk, 1997)	Brocx and Semeniuk
GEOHERITAGE	Globally, nationally, state-wide, to local features of **geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, paleontological, geomorphic, pedologic, and hydrologic attributes**, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference. (After Semeniuk, 1997; Semeniuk and Semeniuk, 2001)	

Table 6.1 - Definitions of geodiversity by Gray and Brocx and Semeniuk, plus the definition of geoheritage by Brocx and Semeniuk

As discussed in Chapter 3, and recapped in Tab. 6.1, the definitions of geodiversity by Gray and by Brocx and Semeniuk differ from one aspect that is explicit in the sentences: "of a given area", in the definition by Brocx and Semeniuk. The remaining parts are highly compatible with the parts of the definition by Gray.

This suggests that we can distinguish two levels of geodiversity: the local and the global scale.

At the local scale, the definitions for geodiversity are aligned, and mean the diversity of the abiotic elements, listed in the definitions and in time aligned, that occur in a limited area.

At the global scale, we have on the one hand, the "global" geodiversity by Gray, meaning all the abiotic elements (material and non-material, like the processes) that exist on and in the Earth. On the other hand, we have the geology, wide enough to describe all the existing abiotic elements of our planet (Brocx and Semeniuk, 2007). Gray (2021) supports the existence of the global geodiversity arguing that with respect to the geology alone, geodiversity is more open to all the types of abiotic elements. Indeed, some sources and authors use to differentiate "geology" from other disciplines, like, e.g., pedology or geomorphology. For example, in the definition of geosite by Wimbledon (1995), in which "geological and geomorphological interests" are explicitly differentiated.

Hence, the breadth of the concept of "geology" is crucial to this discussion. In some cases, geology is considered in a restrictive way, namely as the study of bedrock, and it is supported by other disciplines, like geomorphology, pedology and many others. This view justifies the arguments by Gray (2021). In some other cases, however, geology take a much wider significance, embedding all the disciplines that regard the study of the Earth[90], among which geomorphology, pedology, and the others. The difference is represented in Fig. 6.1, with Geology as a superclass of geomorphology and pedology in accordance with Brocx and Semeniuk's theory and geology as siblings of the same disciplines in accordance with Gray's theory.

The aim of this thesis does not include the deepening of the hierarchy of geology, we leave space for further studies on this topic. This section, however, introduces the discussion on the relationship between geodiversity and geoheritage (object of Chapter 3).

Indeed, our research is mostly centred on the representation of geoheritage and geosite, and the deepening of geodiversity in this context is devoted to that specific task.

We ground our discussion on the dependency of geoheritage on the abiotic nature (geodiversity as well as from geology). We noticed that all the definitions refer to "elements", "parts", "components" of geodiversity or geology. These terms are treated as synonyms in the definitions, and we decited to adopt the "element" term, which achieves the greatest importance in our model. In fact, our goal is the representation of the information about real occurrences of geoheritage and geosites, we aim at representing "elements".

Geodiversity and geoheritage are not elements or groups: the first is a characteristic of our planet (local or global scale, depending on the theories); the latter is a status attributed to a special feature, or a general term to indicate the important geological features of an area (as it is for the term "cultural heritage"). If we mean to represent the elements, they need to be encoded. From here, our model proposes the `Geodiversity Element` class with its subclass `Geoheritage Element` (note that these concepts are already used by Brilha 2016, 2018; more detail in section 6.1.2.2).

In our analysis, we highlighted how the two main definitions and theories about geodiversity differ for the spatial limitation. Vice versa, as resumed in Tab. 6.1, the elements that compose geodiversity (first two rows) and that compose the group of features among which there is geoheritage are quite aligned: geological, geomorphological, soil, hydrological features, fossils… (more detail in chapter 3) In general, these are sets of non-living elements occurring on our planet, over and below the surface, both concrete and non-concrete (as the processes). In our model, these are represented by a number of subclasses of the `Geodiversity Element` class.

Hence, our encoding fits to both the models; the only disagreement point is the name of the upper-class `Geodiversity Element`, that according to Brocx and Semeniuk theories could possibly be "Geological elements". We chose the first name, adapting it to the majority of theories that ground

[90] Remember the origin of the term geology: from Ancient Greek γῆ (gê) "earth", and λογία (-logía) "study of, discourse" (source, wikipedia: https://en.wikipedia.org/wiki/Geology)

geoheritage on elements of geodiversity. But what really matters, is that the types of elements are the same, with the same encoding: that supports a harmony between the theories.
With our model, we can suggest that it is not geodiversity Sensu Strictu to support geoheritage, but its elements.

6.2.1.2 -Does "high level of geodiversity" mean "geoheritage"?

In relation to the conclusion of the discussion of geodiversity, we can discuss the dependency of the high geoheritage on high geodiversity. This question is addressed in Brocx and Semeniuk (2007). The authors describe two possible situations:

- a monotonous section of limestones that represent 10 My, very low geodiversity, but very high importance for the reconstruction of the geologic history of that area;
- a very complex area affected by faulting, plutonic intrusions, many lithotypes, products, structures, processes… resulting in a very high level of geodiversity but not necessarily these are elements of special significance.

The authors underline that if geoheritage would be exclusively grounded on the geodiversity, the first element (limestones succession) could not be considered as geoheritage, in opposition to the second very complex and geodiverse area; hence they conclude rejecting this view of a geodiversity-dependent geoheritage.
In literature, the relation between high geodiversity and high geoheritage is vaguely addressed (Crisp et al., 2021). For example, as reported by Gray (2018) the word geodiversity has been confused with geoheritage, and the concept of geodiversity as support in the promotion of natural reserves.
Guerini et al. (2024) tested the correlation between geoheritage and geodiversity through a case study in the Sesia Val Grande UNESCO Global Geopark, in the area of the Alagna Valsesia municipality. The first step of the work involved the geodiversity assessment of the area, considering data about lithology, geomorphology, soil, hydrology, and quarries/mines. The result is a geodiversity index map, categorized into 5 classes, from "very low" to "very high" geodiversity. On this map, the authors overlapped the most valuable elements in the area, considered as geoheritage and represented as geosites. The result is that only 12% of the points fell in "high geodiversity" areas, while none in the "very high geodiversity". The majority fell in the moderate and low geodiversity classes (44% and 32% respectively). The study by Guerini et al. (2024) demonstrates that in the area there is not a relation between high geodiversity and geoheritage, being thus in accordance with what was discussed by Brock and Semeniuk (2007, 2019, 2020).

6.2.1.3 - Conclusion

The theoretical base that grounds our model aims at discussing the criteria of identification and representation of data about geoheritage. Our semantic and ontological study aims to define classes of geoheritage elements. Despite the frequent reference to the dependence of geoheritage on geodiversity, our model brings to the conclusion that they are separate concepts. Differently, our approach, as widely discussed, is based on the concept of "element", both for geodiversity and geoheritage, which differently, can be classes, can contain instances and can be organized in a hierarchical relation.

The consequence of our model is that (see Fig. 6.2):

- The geological heritage is a "status" that characterizes the individuals of the "geoheritage element" class.
- The "geoheritage element" is a subset of a wider class that contains all the individuals of the "geodiversity element" class. The class that we call "geodiversity element" contains a given set of feature types, and in other theories would be called "geology". This is a matter of the name (label) of the same group of features.
- Neither geodiversity Sensu Stricto (which is a quality), nor geology (which is a discipline) support geoheritage; it is their elements (geodiversity/geological elements) that hold in a direct relation with the geoheritage elements.
- Even if they can be used as synonyms, and often high geoheritage is used to indicate the relevance of natural reserves such as geoparks, in none of the definitions of geoheritage there is a reference to the high geodiversity. The elements achieve the status of geoheritage for their value, that comes from what they are and what they represent, considering them without taking into account their surroundings.

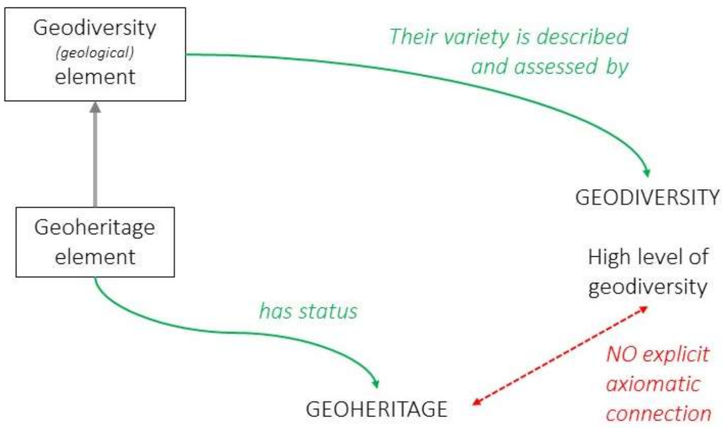

Figure 6.2 - Relations of the concepts in our model.

6.2.2 - Geosites and their relationship with geoheritage

In several works, the connection between geoheritage and geosite is direct. For example, Reynard and Brilha (2018b) involve the geosite in the geoheritage management issue. Moreover, the whole book that is entitled "Geoheritage" collects 24 research papers, of which 16 contain direct reference to the geosites, while the remaining 8 refer generically to "site".

Hence, in literature, the connection between geoheritage and geosite seems to be extremely rooted, such as to be used, sometimes, as synonymous. The issue of the abuse of the term geosite has been addressed by Brilha (2016), who suggests the restriction of the use of the term to the in-situ occurrences of geoheritage.

As discussed in Chapter 3, the four definitions of geosite can be distinguished into two groups, namely those that relate directly geosites to geoheritage (García Cortés and Carcavilla, 2013; Brilha 2018) and the others that relate the geosite to an interest (Wimbledon, 1995; Newsome and Dowling, 2018).

The first aspect on which our semantic study focussed about geoheritage and geosite is the reason why they are not the same:

- Geoheritage is a status that some element can have, or the general group of important geological features of an area (country, region, park…), analogously to cultural heritage;
- Geosites are "areas", portions of land, in which an interest is recognized.

In our research, we focussed on the identification of the elements of geodiversity and geoheritage, instead of geodiversity and geoheritage Sensu Stricto. However, also the "Geoheritage element" class refers to a different object with respect to the "Geosite". Inspiring our model to all the definitions, we underline that a geosite is a type of (in the ontology, a subclass of) Site, which is characterized by the presence of at least one element of geodiversity that is interesting. The evaluation of the geosites by their interest is a commonly used practice. In numerous inventories at a regional, national, and international scale, the geosites are described with their *scientific* or *contextual* interest. The *scientific* interests consist in the indication of the discipline of the geological field (e.g., geomorphology, petrography, volcanology, ...). This approach is different from the one normally adopted for the description of the geoheritage elements, which is related to the attribution of a value to the elements. These values, differently from the interests, refer to more general concepts, like Scientific or Cultural values.

Our study aims at exploring the relation between geoheritage (elements) and geosites, evaluating whether values and interests can have a relation. To investigate this aspect, we ground our model on a philosophical theory on the value and on the interest (Perry, 1914), resumed in Chapter 3. According to the value-interest theory, an object (generical) has a value only when it satisfies an interest. This relation is complicated by several other elements, for example, the involvement of an actor (e.g., a person, or an institution) is crucial, because it is the actor who has an interest in that object; consequently, the object fulfils that interest and achieves a value. Other factors are involved in this process, more details in Chapter 3.

This theory is applied to our type of objects, belonging to the `Geodiversity element` class. For example, the Castellazzo Erratic Boulder (Chapter 5.1) is included in a geosite collection for the Province of Turin (Aigotti et al., 2004). To apply our model, we can identify one element of geodiversity (the boulder) which fulfils the geomorphological interest. Consequently, the territory in which that element with the interest is found (Castellazzo hump) can be classified as a geosite in our model.

According to Perry's (1914) theory, the objects that fulfil an interest can have a value. In our model, to achieve the status of geoheritage and being classified as a "Geoheritage element" a "Geodiversity element" must have a Geoheritage value. Hence, if an object fulfils an interest, and that interest leads to the attribution of a value that is included among the geoheritage values, then that object is an element of geoheritage according to our model inspired by Perry (1914). For example, the Castellazzo Erratic Boulder, that fulfils a geomorphological interest, might be connected to a Scientific value, and possibly be classified as an element of geoheritage.

6.2.2.1 - The values of geoheritage and the interests for the geosites, open questions

As discussed in the state of the art, geoheritage is related to many different values, which are listed by several authors. These lists are not fully compatible, namely, only the Scientific value is shared by all the analysed lists, while Aesthetic, Cultural and Educational values have more than 75% of sharing, as analysed in Chapter 2.
Moreover, analysing the definitions of geoheritage, some other constrictions are set. For example, the definition by Sharples (2002) explicitly excludes from the elements of geoheritage those that have an importance “for depleting purposes” (e.g., ornamental stones or building materials, features that are important if extracted and used). Consequently, some of the aspects of the Economic Value are not compatible with this constraint, for example the economic value concerning the Escondida Mine in Chile by Brilha (2018), related to the impact on the country economy of the high amount of copper extracted every year.
Similarly, it is for the interests that are used for the characterization of the geosites: many of the interests are in common, but not all are.
The issue of the values and the interests, hence, is very complex and dependent on the point of view, for example it may depend on the task (namely, for what reason we are describing geosites/geoheritage?). Our model proposes a method for the representation of the geosites and of the geoheritage elements, through making explicit the necessary and sufficient conditions for an item to be included in one of those classes. This model leans on the presence of vocabularies for the values and for the interests. However, we propose to leave “freedom” for those vocabularies. In fact, the goal of our model is the description of the items, aiming at making it explicit and retractable. In particular, we aim at making explicit the data that ground the process of attribution of interests and values. We recognize that the attribution of value and interest might be dependent on the task, by the chosen vocabularies, and by the experience of the operator. The novelty of our model is nested in the possibility of reproducing the interpretative path on the explicit data and grounding on them a new interpretation.

For example, let’s take the site of Rocca Furà (section 5.1). The main geodiversity elements that are included in the site are the Roche Moutonnée of Borgone and the Mica schists lens in the Borgone Metagranite (a Geomorphologic Feature and a Geologic Unit respectively). Leaving out the importance of both the features for the reconstruction of the geological history of the area, we can recognize some other interests in the features. To the Roche Moutonnée we have attributed the interest of Hiking and Climbing, since there are tools for practicing those sports on the flanks of the landform (e.g., some historical equipped climbing routes are present there). To the Micaschists lens we have attributed a geomining interest, because of the historical activity of extraction of materials for the mills. Speaking in terms of Geosystem Services, they could be “Geotourism and leisure” and “construction materials”. Those interests (and services) could be related to the Recreational Value and to the Economic Value respectively. According to the lists of values analysed in Chapter 2, this site would contain elements of geoheritage for:

- Dong et al. (2013) and National Park Service for both the values
- Szepesi et al. (2017) only for the Economic value
- Sharples (2002) only for the Recreational value

Such a description of the feature, with explicit relation to the reason why we consider them geoheritage, or geosite elements, would enhance transparency and reproducibility of data and interpretation.
In fact, our aim is to propose a method of description of the elements that could harmonize the models that are already present in literature. The major limit is the one imposed by the choice of the list of values and interests. In the context of our research, we aim at proposing a representation method that could enhance transparency in decision making and possibility of reproducibility of data, rather than indicating which values or interests are more "right" than others. This is because we acknowledge the relevance of the task or the goal of every single case of inventory of geoheritage or geosites.

Another open question is an explicit relation between the interests and the value. One possible distinction is discussed in Chapter 3. The scientific value can be related to the interests that are indicated as scientific, namely, the disciplines of geosciences. Then there are the context (or other) interests, which can be related to the other values. The proposal of association is based on the definitions of the values, and the related keywords, but some deeper studies should be performed for a stronger association. In the research performed with the WordNet resource (Mantovani and Lombardo, 2022) almost no results about the relation with values and interests were not found.

6.2.2.2 - Geodiversity and geoheritage elements and their relation with the geosites

As mentioned in section 6.1.1.1, the use of the elements of geoheritage and geodiversity is not new to the literature in the field.
As represented in Fig. 2.2 (Chapter 2), Brilha (2016; 2018) already uses these concepts. Moreover, both the works contain numerous mentions of geodiversity elements. In Brilha (2016) the geodiversity elements are included in the first rows of the introduction, as "minerals, rocks, fossils, soils, landforms, etc.": namely, all the elements that are cited in the geodiversity definition. Our description of the "Geodiversity element" class is perfectly aligned with this point of view.
However, in the schema represented in both the papers (see Fig. 2.2), geodiversity and geoheritage elements assume a precise position in a hierarchical organization which is different from the one that is built with our semantic and ontological research.
In the schema, "Geosite" and "Geoheritage element" are the two faces of geoheritage, representing in-situ and ex-situ occurrences of geoheritage respectively. For example, an outcrop with a rare mineral can be a geosite, but if that mineral is extracted from its native place and exposed in a museum, that is a geoheritage element (as intended by Brilha). This group of features (geosite, geoheritage element and geoheritage) stand below "Geodiversity", which is differentiated into two groups, distinguished by the value: "scientific" or "others". According to the schema and the theories by Brilha (2016, 2018), geosites should be only intended as in-situ occurrences of geoheritage, and geoheritage should be only used for elements that show an extraordinary scientific value. The proposal of the author is grounded on the will of avoiding an abuse of the term, preserving its significance.
Geodiversity with other values rather than scientific is called geodiversity sites and elements (in- and ex-situ respectively) and should not be considered geoheritage. However, to all these features, rules for the geoconservation should be set.

Our semantic and ontological studies brought us to design a different model and hierarchy for these types of objects.

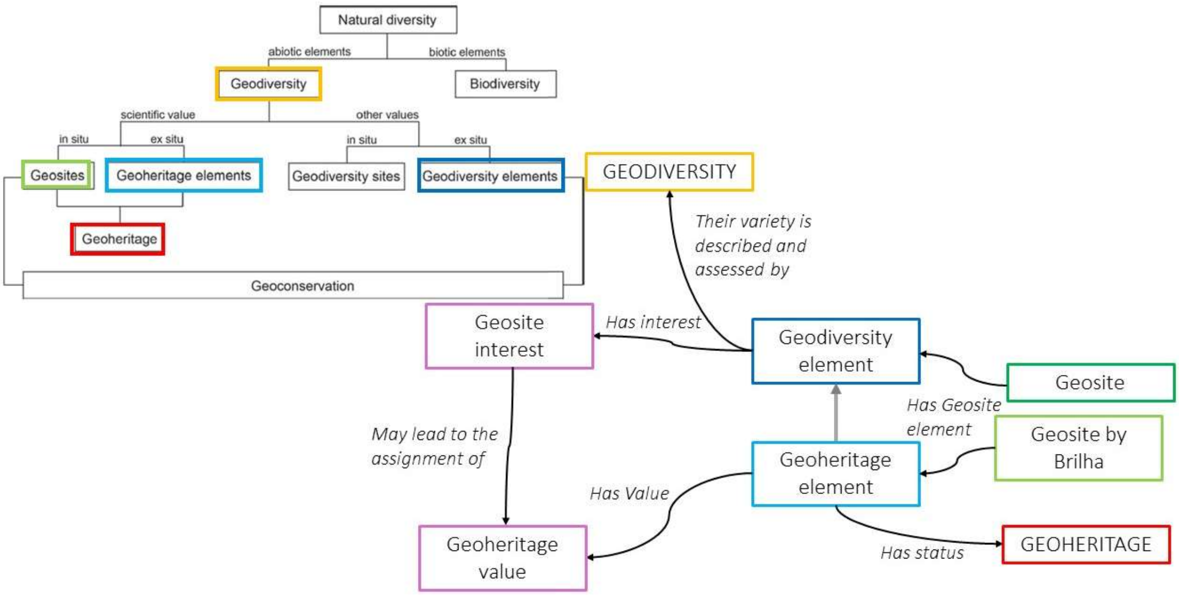

Figure 6.3 - Comparison of the schema by Brilha (2016) and the schema representing our organization of the classes.

In our hierarchy, Geodiversity and Geoheritage are not included, as they are not explicitly features, but qualities/condition of features and areas, and cannot be thus represented by classes (Fig. 6.3, green square). Instead, we have Geodiversity element and Geoheritage element are not siblings below geodiversity, but two classes with a parental relation discriminated by the attribution of a value of geoheritage. Namely, geoheritage elements are geodiversity elements to which a geoheritage value is attributed. A geosite is not included in this taxonomy, as it is a subclass of another type of feature, the Site. The relation with the "elements" is based on the property: a geosite needs to contain at least one geodiversity element with an interest. If then that interest leads to the attribution of a geoheritage value to that geodiversity element, that the geosite would contain a geoheritage element. Geosites contain geoheritage elements, which in turn display the consequences of the geologic processes.

The parental relation of geodiversity and geoheritage elements and the independence of the geosite on geoheritage are the main differences of our model with respect to the one proposed by Brilha (2016, 2018).

The last aspect is the mandatory presence of a scientific value for the geosites and geoheritage in the proposal by Brilha. This issue has already been discussed in the previous sections (6.1.2.1).

A possible encoding of Brilha's proposal according to our model would be as represented in Fig. 6.3 in dark green. We will have that:

- the vocabulary for the geoheritage values would contain only the Scientific value;
- the Geosite would be more restrictive than how they are in our model: a Site would be classified as a geosite only if at least one of the occurring geodiversity elements would have been previously classified as a geoheritage element.

Hence, according to Brilha, all geosites are in-situ geoheritage. Applying our model to the author's theory, this is translated in "a geosite must contain at least one geoheritage element". According to our model, which is open to other values, rather than only the scientific one, we can say that all in-situ geoheritage elements are contained in a geosite, but not all the geosite must contain geoheritage elements (all in-situ geoheritage "is" geosite, but not all geosite "are" geoheritage).

6.3 - APPLICATIVE LEVEL: GEOSITE DATA REPRESENTATION, IMPACT ON THE INTEROPERABILITY

The theoretical model presented in Chapter 3 and discussed previously in this chapter grounded the design of an ontology driven database for the representation of geosite information. The information that we included in the table for the geosite is mostly inspired by the possible type of geodiversity element that can be found in a geosite and, most of all, by the information that we found in some national databases for the description of geosites (in particular, we based our research on the geosite databases for Italy and Poland).
In the next subsection, two points will be discussed, i.e., the alignment of our database with the publicly accessible national databases (Italy and Poland) and finally some examples of how GeOntoLogic Site System overcomes some problems in the context of the data search and comparison.

6.3.1 - Connection with the present-day database for the geosite data

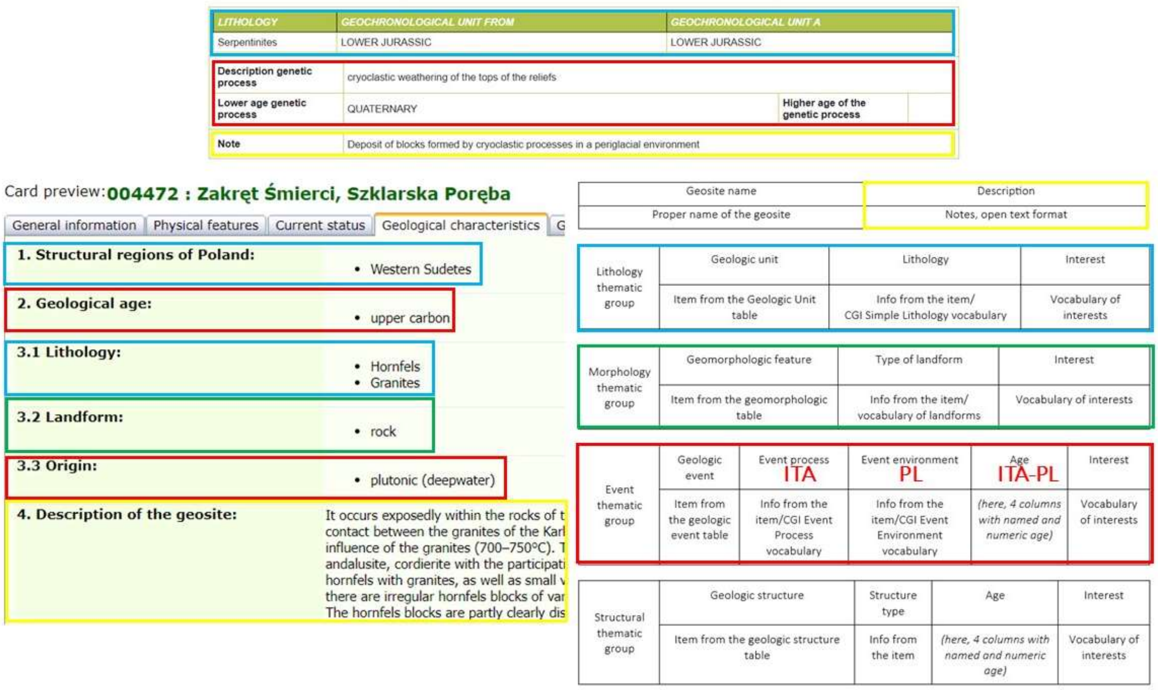

Figure 6.4 - relation between the table for the geosites in GeOntoLogic Site database and in the descriptive forms for Polish[91] (left) and Italian[92] (right) geosites.

[91] Descriptive form for the Zakręt Śmierci in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4472
[92] Description from the ISPRA website of the Mohorovicic discontinuity in Premosello geosite: https://sgi.isprambiente.it/GeositiWeb/scheda_geosito.aspx?id_geosito_x=21615&token=E19ED0809598AF379CE0257A

Our table of the geosites in GeOntoLogic Site database is inspired by some national databases for the representation of the geosites. In particular, we observed the Italian and the Polish geodatabase, and designed our table in order to host all the geological information that are reported in those databases. Our survey is limited to the geological data, and much other information is reported in those forms, but it is not an object of discussion within this context.

Analysing the Polish and Italian forms for the geological information about the geosites, we notice that only the field for the lithology is perfectly compatible. Starting from the Italian form, which has less information than the Polish one, the other information concerns the genetic process and the ages of the rock and of the process.

The genetic process is not present in the Polish form. Differently, the origin is described by the generic environment. The information about the age in the Polish form is not differentiated as it is the Italian one. For example, in the geosite of the Lapidarium of Geology institute of Adam Mickiewicz[93] are listed several geologic ages, related to the different samples of rocks that are included in the open-air museum. A similar approach is adopted for another Lapidarium around Poznań, namely the one that is found near the Wielkopolski National Park centre[94].

Other information that is collected in the Polish form are the landform (field that in original language is called "Form of Terrain") and the "Structural Region of Poland".

The cited information is addressed both in free text and in close text format. In the Polish forms it is usual to find "formulas" that are repeated in many different and distant geosites (e.g., "*Sands (sands, sands with...)*" was found in many forms, like in Międzyzdroje-Wisełka Cliff[95] and in Krosno gravel pit[96]). Moreover, the terms are displayed in a bullet list format. This suggests that those fields are managed in a close text format, maybe with proposed vocabulary.

The Italian form, differently, seems to be managed mostly with open text fields. E.g., the field "lithology" in Fig. 6.4 describes the two lithologies of the two geologic units that are in contact in the outcrop. The geosite described in that table is the Mohorovičić discontinuity of Premosello: in outcrop is visible the geologic contact between the mantle Peridotites and the lower crust granulites and gabbros. In the "Lithology" field, those lithologies are named together, in a string of textual description. Similarly, the genetic process is described with a short text.

Both the forms have a "Note" field that can be filled with open text; in addition, from the Italian form it is sometimes possible to download a text file with a wider description (written in a free format).

All the fields can be connected to some element that is included in the Polish and Italian forms, as shown in Tab. 6.2.

[93] Descriptive form for the Petrographic Lapidarium of the Poznan University in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1253

[94] Descriptive form for the Petrographic Lapidarium of the Wielkopolski National Park in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1245

[95] Descriptive form for the Międzyzdroje-Wisełka cliff in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=3723

[96] Descriptive form for the Krosno Gravel Pit in the Polish website for the geosites: http://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1530

Field name in national DB	National DB	Field in GeOntoLogic Site DB	Table in GeOntoLogic Site DB
Lithology	Italian and Polish	Lithology	Geologic Unit
Geochronologic age of the rock	Italian	Age (named)	Geologic Unit
Process	Italian	Event process	Geologic Event
Age of the Process	Italian	Age (named)	Geologic Event
Age	Polish	Age	Geologic Event
Form of Terrain	Polish	Landform type	Geomorphologic Feature
Origin	Polish	Event environment	Geologic Event
Structural Region of Poland	Polish	Name	Geologic Unit

Table 6.2 - Connections between the national databases forms and the GeOntoLogic Site database.

Finally, the note field may contain any kind of information that can be integration of the information present in the other fields or additional information, like in the Zakręt Śmierci Geosite, in which much information about the intrusive event are found, plus the indication that in the geosite is visible the contact between the granites and the hornfels of the metamorphic aureole. Reading the close text fields alone is not enough to understand the presence of the contact in the geosite, both in Zakręt Śmierci and in the Mohorovičić discontinuity of Premosello. In our system, this information can be extracted from the text and included in the tables. Also, the indication about the ages, which are differentiated for the rock and the process in the Italian form, but not in the Polish one, would be more precise. This is because every information, before being included in the geosite table, is first described in the geodiversity elements tables. For example, the single geologic unit will have its description of lithology, age, process, boundary contacts, ... from this rich amount of information, for each geodiversity element only the data that are relevant for the description of the geosite would be taken and will fill the geosite table. The indication of the name of the geodiversity element is fundamental: if a reader wishes to deepen the information about one of the geodiversity elements that compose a given geosite, all the information can be found in the row dedicated to the desired element in its original table.

In conclusion, our method does not intend to change the representation of the present day geosite databases. Our work aims at showing that all of them aim at describing the same elements, but using different terms, and not only from a language point of view. However, a study of the content of the fields, and of the terms that label them, demonstrate that they can be connected to the same properties that ground our database structure; this could be a base for the enhancement of interoperability of data, without changing the interfaces and the method of data display.

6.3.2 - Impact of GeOntoLogic Site database on data organization and comparison

The application of the theoretical model is the GeOntoLogic Site database and system. Consequently, our database is organized in order to focus on the elements of geodiversity that compose the geosite and thus provide the information for the description of the geosite.
The key point of our database is the explicit relation of the geosite and its geodiversity elements. This is one of the aspects that supports interoperability, along with the use of shared vocabulary resources (better if standard).
In this subsection we will discuss some tests for the interoperability of data. In particular, we will show that the search can be more precise exploiting the organization of the knowledge that is required in our database.
A good example is the retrieval of the geosites of the intrusive history of Karkonosze. We aim at finding all the geosite that represent a part of this story, for example, the outcropping granites, the hornfels of the metamorphic aureole, or both. The geosites descriptive forms that we have described in section 5.2 contain the information resumed in Tab. 6.3.

	Krucze Skały, Szklarska Poręba	Zakręt Śmierci, Szklarska Poręba	Skałka Teściowej, Szklarska Poręba	Bobrowe Skały, Piastów
Structural Regions Of Poland	Western Sudetes	Western Sudetes	Western Sudetes	Western Sudetes
Geological Age	Upper Carbon	Upper Carbon	Upper Carbon	
				Lower Carbon
Lithology				Granitogneisses
	Granites	Granites		Granites
		Hornfels	Hornfels	
Form Of Terrain	Rock	Rock	Rock	
				Rock Forms
Origin	Plutonic	Plutonic		Plutonic
			Metamorphic	Metamorphic

Table 6.3 - Data from the analysed geosites in the Karkonosze Jizera Massif as they are represented in the official national geosite database.

Focussing on these four geosites, first we need to remember that only the first three represent some step of the Karkonosze intrusive history. In fact, the fourth geosite (Bobrowe Skały) represents a part of the encasing rocks. So, for our test, we need to find all the three geosites and only them. We base our search on the "close texts" fields because the open text is not available for this task. The information that is common concerns the Form of Terrain, which is not of particular significance because it only indicates that it is a rocky outcrop, and the Age (Upper Carbon).
Other information is related to only some of the features: for example, the lithology "hornfels" is only present in Zakręt Śmierci and Skałka Teściowej, leaving out Krucze Skały and achieving an incomplete

result. Differently, the "granite" is present in Krucze Skały, Zakręt Śmierci and Bobrowe Skały. This search, besides providing incomplete results, also results to be incorrect: in fact, the Bobrowe Skały geosite is not directly related to the history of the intrusion, it is part of the encasing sequence. Also the information about the origin "plutonic" leads to the same result provided by "granite".

At the opposite, geosites Zakręt Śmierci, Skałka Teściowej and Bobrowe Skały contain rocks of the encasing rocks, that have been or not involved in the intrusive process. In this case, no information is in common, with the only exception of the Structural Region of Poland, which is not of particular significance for our task as every other geosite in that area shares that information.

Our searches could be satisfied through the search of given elements of geodiversity. All the elements that are generated or influenced by the Karkonosze intrusion (namely, Krucze Skały, Zakręt Śmierci, and Skałka Teściowej) can be found by searching the Geologic Event named "Karkonosze Late Carboniferous intrusive event". If all the geosites displaying the granite of Karkonosze and the contact metamorphism influence on the encasing rocks would be connected to this geologic event, then all these geosites will be connected. The other search, the one about the rocks of the Jizera Massif would be based on the Geologic Unit "Jizera Massif", of which both the so called "granitogneiss" of the encasing not-involved rocks as well as the "hornfels" of the metamorphic aureole are part.

This type of search could also apply at an international scale. Our case studies concerned two similar types of features, the magmatic related and the glacial related. The events that generated those features are well distinguished, by they have something in common. For example, the in the column "event process" of the item "Karkonosze Late Carboniferous intrusive event" in our database is indicated as "intrusion", which is compatible with the event process in the "Post Variscan magmatic event" for the "Sesia Magmatic System". The ages are not fully compatible as the Karkonosze Pluton was dated around 312 My (Słaby and Martin, 2008, Kusiak et al., 2014), while the Montorfano granite is estimated between 276 and 295 My (Origoni et al., 1988). However, both the intrusive events are interpreted as post-Variscan magmatic activity (Kusiak et al., 2014; Origoni et al., 1988). The model still does not include parts dedicated to the interpretation, but this would be an information that could connect the geosites in Karkonosze with those in Sesia Val Grande Geopark, as evidence at European level of the latest phases of the Variscan Orogenesis.

Similarly, the geosites in Susa Valley and those in Wielkopolski and Wolin National Parks have the event environment in common (glacial related settings) and also the age, Pleistocene. These geosites would answer the question about the Pleistocene glacial evidence in Europe.

Conclusion

The organization of the knowledge in geodiversity elements increases the number of close text fields that are needed for the description of a geosite. However, we remark the importance of a twofold approach, with both close text fields and a field for notes and open text description. For example, as a reader that did not know the history of the plutonic intrusion in the Karkonosze area, the interpretation of the information that is contained in the close text fields would be very hard for the geosites that are resumed in Tab. 6.3. The "description of the geosite" field supported the understanding of the information, the reconstruction of the history, the integration of the elements that did not have a reference in the fields (e.g., the contact) and finally, the deepening of the description of all the elements.

Our proposal is to lean on both the approaches. On the one hand, the close text fields in this increased approach, support several tasks:

- The completeness of data representation: each element is described first of all for what it is; then its characteristics are used for the description of the geosite (one or more) in which they are present.
- The interoperability of data: the elements of geodiversity are described and related to other elements and to the geosites. This creates a network that supports cross search of data, allowing for data retrieval about the geosites that in the present-day data representation may be difficult.
- Avoid the repetition of data: the elements are described once. A geologic unit will have its item (row) in the proper table of the database, then it can be used infinite times for the description of other elements or geosites. From time to time, we will only use information that is useful for the specific case. For example, for the description of a geosite not all the information that are included in the geologic unit tables are relevant. However, when consulting a geosite it is possible to deepen all knowledge of a given element, e.g. A geological unit, thanks to the explicit link with the element itself. This avoids redundancies of information in the system.

On the other hand, we underline the importance of the free text, which still is the better support for the understanding of the geological context of a geosite from the point of view of a human reader.

6.4 - FINAL DISCUSSION AND IMPACT OF THE PROPOSED MODEL

To discuss the impact of our model on the field, on the one hand we discussed the relation of our model with those that are present in literature, on the other hand we performed some tests on the collected data to evaluate the enhancement of interoperability. The expected impacts on the field concern the transparency and reproducibility of data, and the interoperability of data.

From the theoretical point of view, we have applied our model to some of the main models for geoheritage and geosite, discussing the differences in the organization of the knowledge. In particular, we applied our method to some ongoing debates on the relation between geodiversity and geoheritage, proposing a way for the harmonization between those models based on the newly encoded “Geodiversity element” and “Geoheritage element”. Also, the constraints for the definitions of geosite were discussed, proposing a new hierarchy and property relation between geosites and elements of geodiversity and geoheritage. Finally, the encoding of the “Geodiversity element” class can be a partial response to the future perspective announced by Zwoliński et al. (2018), namely, the possibility of using ontology to support geodiversity assessment.
We wish to remark that our model does not mean to decide if one element deserves the geoheritage status or not. Our aim is to propose a step-by-step descriptive approach that could be furtherly reproduced and reinterpreted. In fact, the final decision if an element can be considered or not as geoheritage depends on the connection with one of the Geoheritage values, which are collected into numerous different lists. The values for geoheritage can change depending, e.g., on the reason why geoheritage is assessed/inventory. We preferred not to create a new vocabulary for the values, leaving space for the numerous existing lists (that become vocabularies). We only point out that among the numerous present values, the most acknowledged are Scientific (100% of sharing), and Cultural, Educational and Aesthetic (more that 75% of sharing). Using our model for the representation of the data allows us to leave untouched the integrity of data, with the achievement of different interpretations based on the applied vocabulary.

Our model is organized with the task of enhancing the transparency of the representation of data. In fact, we start from the characterization of the elements of geodiversity based on standard encodings. Then, through the attribution of interests and/or values we classify those objects as geoheritage elements or elements that makes relevant a geosite. Consequently, the organization of the database, which is inspired by others already existing for the geosciences, aims at supporting the representation of the knowledge about the geosites in an interoperability perspective. In fact, grounded on the theory resumed above, the table for the geosite is filled with the information that comes from the tables of the geodiversity elements, and the geosites are explicitly connected with those elements. Consequently, items (e.g., geosites) that share connection with the same feature (e.g., a geodiversity element) can be connected and satisfy element searches.

From a practical point of view, the expected impact is the enhancement of interoperability of data. Although the impact could be fully visible after a massive harmonization of geosite data with our model, we can say that on our small sample of described geosites, this method of data representation can enhance the interoperability. As discussed in chapters 5 and 6, the explicit reference to the geodiversity elements in the description of the geosite establishes a connection between the geosites that differently is not clear. In particular, two or more geosites that share the connection with the same geodiversity element are consequently connected. On the base of the connection among the elements, articulated queries can be performed, and geosites with similar characteristics can be automatically found. We applied some example searches on our case study geosites (see chapter 6), obtaining precise answers from the searches performed in GeOntoLogic Site database, while incomplete or imprecise answers were achieved if searching on the "classic" data representation model.
Also, the visualization of the data benefits from this organization. We have organized a prototype website with dedicated pages for all the geosites, on which it is possible to navigate the information about the geosites and the composing geodiversity elements.

6.5 - FUTURE RESEARCH PERSPECTIVES AND FINAL REMARKS

The final products of our research are a theoretical ontological model for the representation of the geodiversity and geoheritage elements and for the geosite, and the geosite database that is designed after the theoretical model. At the beginning of the research, some achievements were expected, the path we have taken has required us to abandon some aspects in favour of others. To conclude this thesis, we leave the following insight for future research:

- Initially, the aim was to deepen the "geodiversity" and "geoheritage" concepts. However, based on semantic studies, we considered that these concepts are not very supportive from a practical point of view. To achieve our practical results, namely a model for the representation of the geosite data, we characterized the elements, more than the root concepts. The semantic characterization and encoding of geodiversity and geoheritage Sensu Stricto are a gap in our research that should be filled, to achieve a comprehensive encoding of the theoretical knowledge on the field
- The explicit relation between the values and the interests or the geosystem services is an aspect that would need further studies: with our research we highlighted how the recognition of a value in one object is dependent on the capacity of that object to satisfy an interest. Hence, to give a value of geoheritage to one element, it needs to be first connected to an interest (or to a geosystem service). However, a semantic based study on the direct connection between values

and interest still lacks. Namely, is it possible to establish a solid relation to one interest and one value (this specific interest assigns this precise value and not others)? Such information would improve the model, making the attribution of the geoheritage status more direct, based on the fulfilled interest. This thesis is only a first investigation on the notion of value and the conservation of geoheritage sites. We believe that further studies should address the notion of value for human being in an evolving perspective.

- In chapter 3 we have dedicated a small section to the analysis of the concept of the "Geomorphosite", which some authors mention in their works. According to our model, it could be a geosite which main geodiversity element (the one that gives to the geosite an interest) is an element of the geomorphologic feature class. However, other geodiversity elements can provide interest to a geosites, thus it might be possible, in the future, to explore and encode the geomorphosite and other types of geosites.

In conclusion to this Chapter, and this thesis, we wish to remark that the final result of our work consists in the modelling of the knowledge representation. We aim to enhance the reproducibility of data, through a transparent representation of the knowledge that we have about geosites and geoheritage. As in the field of cultural heritage, sometimes for humans it is easy to identify as geoheritage some elements that are of special value based on the personal sensibility. In these fields, in which emotions play a relevant role, the subjectivity of the choice among which is geoheritage (or a geosite) or not is difficult to cancel. With our method, we hope to propose a way of representing the decision concerning geoheritage and geosite in a formal and rigorous way. In the meantime, however, we ought to keep in mind that the subjectivity, both emotional (choice of the elements) and descriptive (the importance of the free text in the descriptions), is human heritage. We do not want to cancel subjectivity; instead, we invite ourselves to reflect on the choices that the subjectivity inspires and make an effort for its valorisation through a coherent representation.

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APPENDIX 1

Values of geoheritage with the definitions provided by Sharples, Georgousis and NPS, plus examples provided by Brilha (2018). In the last column, some proposed keywords, extracted from the texts of the definitions to support further studies on the values.

	Brilha (2018)	Georgousis et al. (2021)	NPS	Sharples (2002)	keywords/key concepts
Aesthetic	*Iguacu National Park (Argentina/Brazil): One of the world's largest and most impressive waterfalls extending over some 2700 m, attracting about 1.5 million visitors each year to enjoy the natural beauty of the site.*	The aesthetic value of a landscape is related to its intrinsic beauty and uniqueness or in the appreciation of its beauty	- Provoking feelings of inspiration, awe, and humility; - Serving as settings for memorable life events and community gatherings; - And Providing opportunities for tourism and enjoyment of natural beauty.	Features which inspire us because of their aesthetic qualities or because of the insights they give us about the nature and origin of the Earth, and of life on Earth	•Inspiration •Appreciation of the beauty •Emotion
Artistic			- Inspiring awe and fuelling creative expression through the arts; - And Promoting conservation through artistic appreciation of natural landscapes.		•Inspiration

Cultural	*Uluru-Kata Tjuta National Park (Australia): The inselbergs of this park form an integral part of the traditional belief system of one of the oldest human societies in the world and it is considered a sacred place for the Anangu Aboriginal people.*	The cultural values of geodiversity are associated with mythological, historical, archaeological, and spiritual and religious aspects	- Helping people identify with their communities' unique geologic places, as well as their connections to regional or even global landscapes and stories; - Highlighting the human stories connected with geologic landscapes; - Providing a communal reference for stories, music, and other arts and social practices; and - Protecting natural places deemed sacred and inspirational, perhaps as destinations for personal exploration or pilgrimage or as monuments to previous cultures.	Features which form the basis of landscapes that have contributed to the 'sense of place' of particular human communities; features which play a role in the cultural or spiritual values of human communities (e.g., sacred caves and mountains	•Spiritual •Historical •Human communities •inspirational
Ecological		The ecological value of geodiversity is understood both in terms of the conservation of geological and geomorphic processes as well as the conservation of biological processes that depend on these natural systems	- Supporting a diversity of ecosystem services such as groundwater retention, nutrient reservoir, and carbon supply and sequestration; and - Conserving portions of the geosphere and the linked portions of the other spheres in a natural state to maximize their resilience on a changing planet.	The ecological value of a thing or process is its importance in maintaining natural systems and ecological processes of which it is a part. Noting that 'ecosystems' are understood as comprising both biotic and abiotic components which interact and are interdependent, the 'ecological value' of geodiversity can be understood as its importance in both maintaining geological, geomorphic and soil processes in themselves, and also in maintaining the biological processes which depend upon those physical systems	•Maintaining natural system and processes

Economic	*Escondida Mine (Chile): Chile is the top copper-producing country in the world. In 2015 this mine alone produced 1148 million metric tons comprising mostly copper concentrate, which generates important revenues for this country*	The intrinsic social and economic value of geoheritage and geodiversity is supported by geoethics [26], which promotes responsible action by adopting social and professional values [27], in order to maintain "a more balanced relationship between humans and nature, considering modern economic and social development expectations	- Supporting tourism, commerce, and employment in surrounding communities; and - Showcasing natural resources that have supported economies and shaped American cultural history.		• Supporting tourism, commerce, employment • Natural resources that support economy
Educational	*Terras de Cavaleiros UNESCO Global Geopark (Portugal): The occurrence of a complete ophiolite sequence resulting from the obduction of Palaeothetys oceanic lithosphere over the Allochthonous Basal Complex attracts students from universities of different countries.*	(value present, but not defined)	- Offering examples of geologic principles and processes for study; - Providing formal and informal settings for instructing students or the public in science, history, culture, and other subjects; and - Enhancing Earth science literacy—demonstrating natural processes and hazards and the impact of human activities	sites of importance for research and education	• Study • Research • Instructing in science • Demonstrating natural processes
Functional	*Goreme National Park (Turkey): The volcanic rocks of Cappadocia sculpted by erosion were used as dwellings, troglodyte villages and underground towns, which constitute the remains of a traditional human habitat dating back to the 4th century.*				

Intrinsic	*Volcanoes of Kamchatka (Russia): Independently of human appreciation, this is one of the areas of higher density and diversity of active volcanoes on Earth.*			the concept of Intrinsic Value (or 'Existence Value') simply means that the existence of a thing may be of value in itself, rather than only because of some purpose that humans (or even other living things) might put it to	
Recreational			- Offering outdoor settings for improving physical health through activities and exploration; - Providing natural areas for improving mental health through stress relief, appreciation of nature, and wilderness experiences; and - Presenting opportunities for personal enrichment and discovery at local sites or those across the country.	features of recreational or tourism significance (e.g., mountains, cliffs, caves, beaches, etc	• Recreation • Tourism • Improving health
Scientific	*Basque Coast UNESCO Global Geopark (Spain): The definition of two Global Boundary Stratotype Sections and Points (GSSPs, lower boundaries of the Selandian Stage and of the Thanetian Stage, both belonging to the Paleocene Series)turns the coastal cliffs of Zumaya into a place with global importance for geosciences*	(value present, but not defined)	- Preserving the records of planetary history and evolution at geologic heritage sites and in museum collections; - Allowing for the study of natural sites to facilitate scientific examination, discovery, data collection, and experimentation; and - Providing access to scientifically monitor, evaluate, and understand natural processes and human impacts as they change over time	providing scientific evidence of the past development of the Earth, and of the evolution of life on Earth	• Record of planetary history • Scientific examination • Evidence of the development • Type site

APPENDIX 2

Overview of the Brazilian, Italian, Polish and Portuguese national geosites viewer, analysed from the map visualization, information displayed in the database and in the descriptive forms. The geovisualizers were accessed in summer 2022.

	Brazil	Italy	Poland	Portugal
Map visualization	One symbol with different colours to distinguish the validation state	The visualization on the map is based on the relevance of the site (local, national, international...). Visualization is also bound by scale: if we look at the whole map of Italy, it will only show sites of national relevance and GSSPs. Zooming in will show all sites of minor relevance	Geosites are displayed on the map separately with 9 symbols, identified in the legend as follows: ● Forms of accumulation ● Forms of erosion ● Other ● Water objects ● Mining activity features ● Paleontological sites ● Presence of minerals or rocks of interest ● Natural geological exposure ● Artificial geological exposure	One single symbol for every geosite

Database	• geographical information (locations, coordinates) • geological information, • information on tourist, educational, scientific relevance..., • geological interest (sampling I found sedimentology, tectonics, geomorphology, palaeontology...) • management information (responsible, protection...) • a very quick description, bringing together information of various kinds, accessibility, summary geological description... • links to the geosite data sheet and a representative photo	There are only the coordinates, the name, the degree of interest and the link to the tab.	The database contains geographic information, such as location in regions etc., and various fields with geographical coordinates, conservation, and access conditions	It provides some geographical information, the relevance of the geosite (national, international) and the vulnerability. A link to the form

Descriptive form	Divided into sections ● **Identification**: extends the info that is already in the database ● **Context**: general geologic context ● **Geological Characterization**: geologic features details; describing the rock type (in three distinct fields sedimentary, igneous and metamorphic) and the type of deformation ● **Relief Features**: pictures of the site ● **Interest**: content interest (scientific/geological interest), associated interest (other interest) and use interest (e.g., scientific, educational, tourist). ● **Conservation**: aims to describe conservation measures ● **Quantification**: a whole series of scores quantifying scientific, educational, tourist value and risk of degradation ● **Responsible**: contact details of the responsible person ● **Comments**	Divided into three sections: **Localization and geology:** ● geographical info, ● interest (scientific, contextual, plus an evaluation), ● some geological info (lithology, age, description and age of the geological process) **Description, usability and protection**: ● the description is in a separate file that is sometimes attached to the sheet, sometimes not. In any case it is a free text ● soil type/use ● protection and use of the site ● other annexes **Identification, conservation and protection** ● some "bureaucratic" data ● category ● situation of degradation, protection, risks	The information on the geosite is collected in a form that is divided into a number of sub-groups: ● **General information**, which collects information mostly of a geographical nature, plus the type of geosite according to the list above ● **Physical characteristics**, which collect 'numerical' information describing the size of the geosite ● **Current status**, has to do with observational characteristics of the geosite, such as how it is accessed, whether it is in a protected area, relations with tourism ● **Geological features**, such as domain, age, lithology, morphology, origin and description ● **Pictures** ● **Processing**, who uploaded and updates the sheet ● **Bibliography**	It opens with a showcase of photos. It has a first descriptive section of the geosite, which appears to be rather free form (each geosite has a description with its own architecture) The characterization has a database row, with geographical, cartographic, vulnerability info, plus a second table listing the interests, associating each one with its degree of importance. This is followed by a stratigraphy field, which appears to be dedicated to the chronological description of the geosite but is not always present. Recommended protective measures and author, are other text fields, also not always present.
research tool				● tool for searching geosites based on the interests

APPENDIX 3

DESCRIPTION OF THE GEOSITES

In the following pages, the reader can find the translation of the original material about the studied geosites. We translated the original texts, in Italian and Polish respectively, in English (for the Polish texts, the translation is based on google translate and DeepL.com translator). When available online, we referred to the original text as a link. However, in some cases the information came from book pages or pictures to locally present panels; in these cases, the pictures of these sources are present along with its translation.
The text is coloured after the analysis, to highlight the passage from the text to the encoding into geodiversity elements:

- Red for the event descriptions
- Blue for the geologic unit/material description
- Green for the morphological description
- Purple for the structural description
- Black for other information

After the description of every geosite, there is a schema with the representation of the geodiversity elements (in squares) and their mutual relation (arrows). The colours of the squares and arrows follows the above-mentioned criteria.

Index of the geosites

VOCCA ISLAND - IN THE BOWELS OF THE SUPERVOLCANO

Original text at link https://www.progeopiemonte.it/path/valsesia/stop4.pdf

We are in the deepest levels of the Basal Complex: it formed between 290 and 282 million years ago in the deepest part of the crust, thanks to continuous injections of magma from the mantle below.

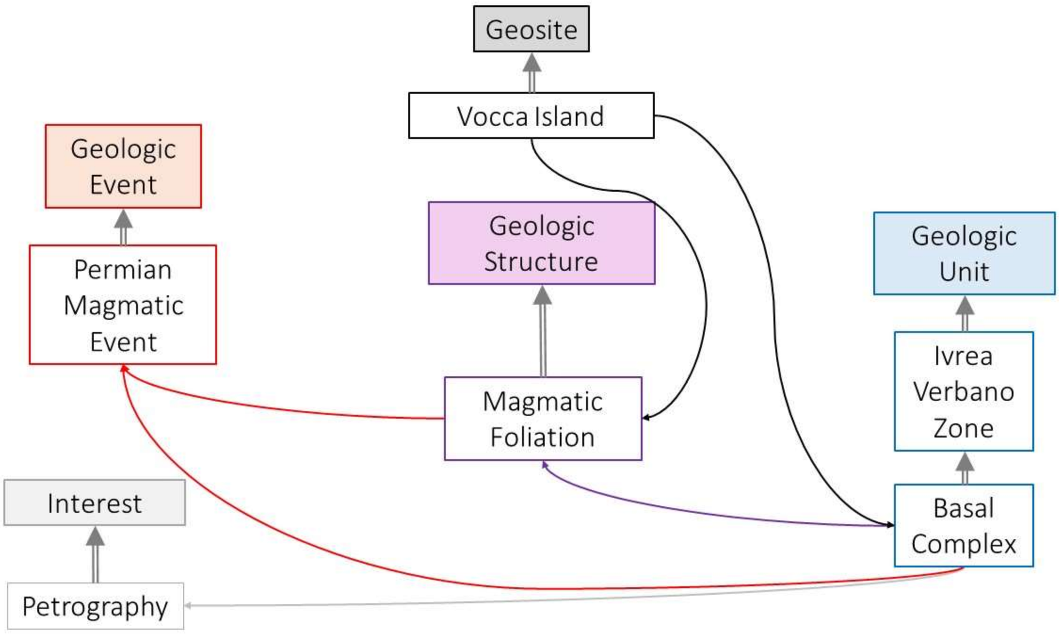
During its slow cooling, the complex consisted partly of crystals that had already solidified and partly of material that was still molten: we could imagine it as a kind of gigantic 'boiling slush'.

The resulting rocks outcropping here are gabbros, characterised by light and dark bands depending on the prevalence of two minerals: plagioclase, white, and pyroxene, black (Fig 1). A large dark boulder emerging from the river shows an area of accumulation of the black minerals: the rock forming it is an olivine pyroxenite (Fig. 2).

Here and there on the outcrop one can also see gabbros with traces of deformation that occurred at high temperature (Fig. 3).

The magmas that formed these rocks reached temperatures of over 1200°C: it was the large amount of heat given off by this enormous intrusion that triggered the extraordinary activity of the Sesia supervolcano.

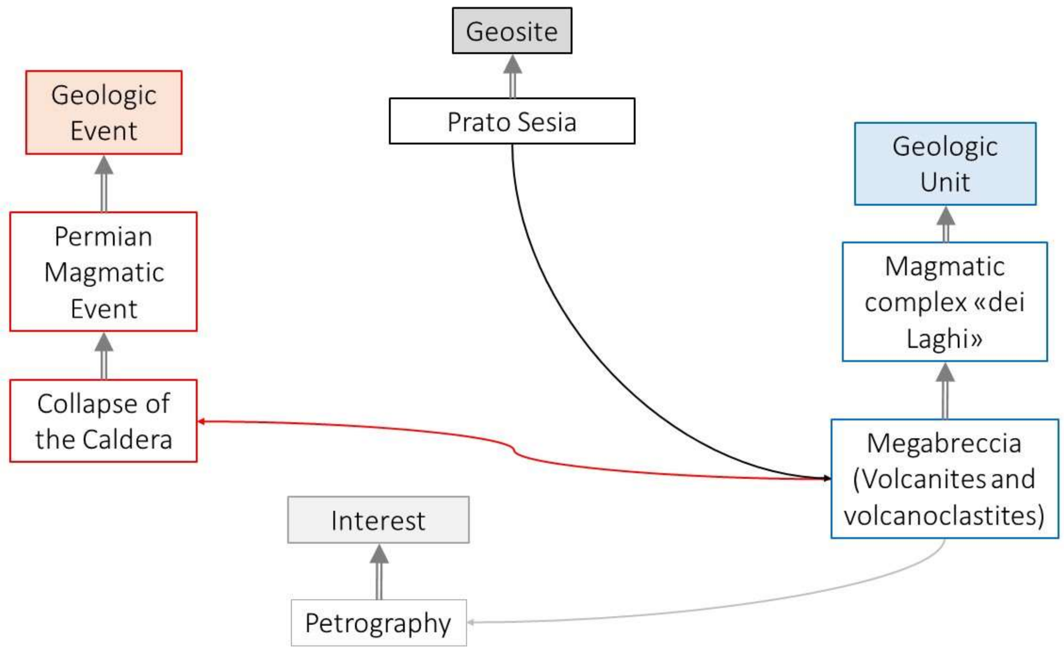
If we take a closer look at the gabbros, we observe an obvious foliated structure: the constituent minerals are elongated and displaced in the same direction. We had already encountered foliation at the first stop, in the metamorphic rocks of the Insubric Line, but it is truly anomalous to observe it in magmatic rocks. This situation can be explained by the dynamism of the environment in which the Basal Complex was formed, which intruded into the crust as it extended and stretched, like rocks in the cooling phase.



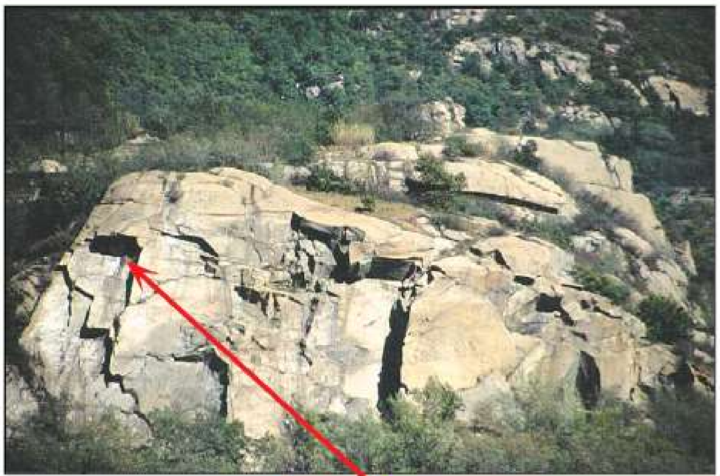
PRATO SESIA - FINAL WITH A BANG

Original text and pictures at link https://www.progeopiemonte.it/path/valsesia/stop10.pdf

The journey through the history of the supervolcano has come to an end: we have ideally ascended the entire magmatic system, starting from its deepest parts, and here we are on the surface, on the rocks of the caldera (Fig. 1). Walking on the outcrop, one can distinguish rocky blocks of different colours, enveloped in a pinkish-yellow tufa; here and there we find reddish rocks, glassy rhyolites, grey andesites or tuffs rich in rock fragments (Figs. 2 and 3). It is a kind of sampler of the rocks that had formed on the surface during volcanic activity, before the final act: the catastrophic eruption of the Sesia supervolcano some 282 million years ago.
It is estimated that more than 500 km3 of ash and lapilli were erupted in a very short time; at the same time, the entire volcanic apparatus collapsed and huge blocks collapsed into the caldera that had formed, a chasm at least 13 km in diameter. Much of the erupted material fell back into the caldera, mixing with the blocks and forming the chaotic set of rocks we have under our feet: the mega-breccia (Fig 4). Among the fragments forming it, it is even possible to find pieces of the ancient continental crust, also shattered by the explosion, such as the so-called Lake Shale, rocks recognisable by their silvery glow and characteristic foliation (Fig 5).
After the gigantic eruption, the activity of the magmatic system stopped, but many other geological events followed.
We could talk about when the sea arrived or how the mountains were formed: other beautiful stories that our Planet whispers to us. Stories that geologists are ready to listen to, to reveal to those who have never heard them.



ROCCE MONTONATE DI BORGONE



I contrafforti rocciosi che si innalzano a gradinata alle spalle dell'abitato di Borgone rappresentano uno degli esempi meglio conservati della potente azione modellatrice e levigatrice esercitata dal grande ghiacciaio quaternario della Valle di Susa.
Questi contrafforti presentano una sommità marcatamente arrotondata, con i fianchi esposti a Sud ripidi e levigati, mentre quelli esposti a Nord si raccordano a fertili ripiani, spesso allungati secondo la direzione dell'asse vallivo.
Rimaste intatte per migliaia di anni, queste testimonianze del modellamento glaciale sono state in più punti intaccate dall'apertura di cave per lo sfruttamento del pregiato metagranito di Borgone. L'attività estrattiva, esercitata intensamente per secoli, ha conferito al paesaggio una nuova architettura anch'essa non priva di spunti d'interesse.

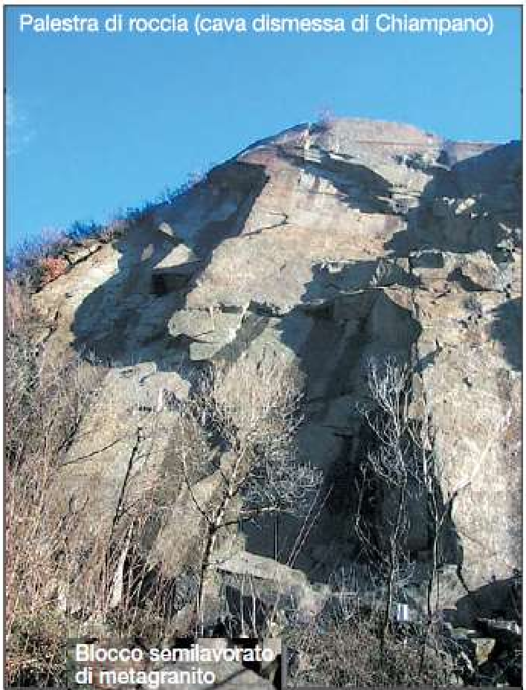
Cava di Chiampano

Cava di Roccafurà

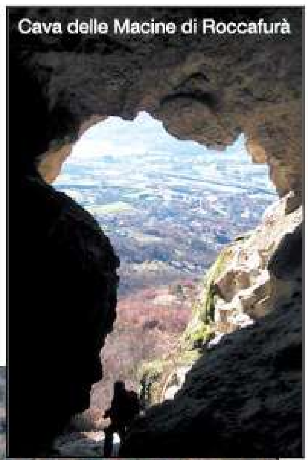
The rocky buttresses that rise in steps behind the town of Borgone represent one of the best-preserved examples of the powerful modelling and smoothing action exerted by the great quaternary glacier of the Susa Valley.
These spurs present a markedly rounded top, with the flanks south-facing sides steep and smooth, while those exposed to the north connect to fertile plateaus, often elongated according to the direction of the valley axis.
Remaining intact for thousands of years, this evidence of glacial modelling has been eroded in several places by the opening of quarries for the exploitation of the valuable Borgone meta granite. The mining activity, carried out intensively for centuries, has given the landscape a new architecture not without its own interesting features.

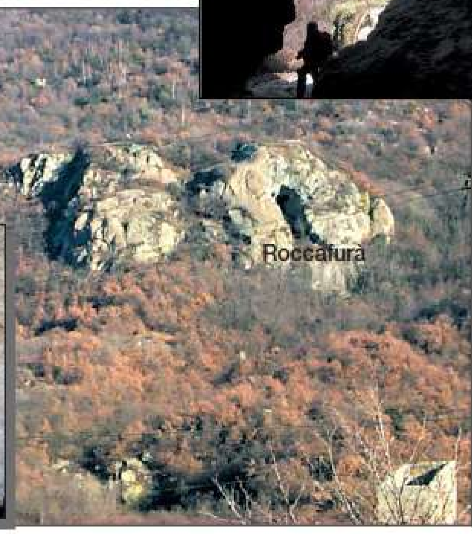
LE CAVE DI BORGONE

Il metagranito di Borgone* ha costituito per lungo tempo una primaria fonte di ricchezza per l'economia locale. Le cave aperte sui dossi montonati del versante sinistro fornivano blocchi di materiale pregiato dai quali provetti scalpellini ("picapere") ricavavano: architravi, davanzali, colonne, capitelli e conci utilizzati per monumenti, palazzi, ponti ecc... Questa fiorente attività cessò negli anni '70 con la chiusura della grande cava di Chiampano, trasformata attualmente in una apprezzata palestra di roccia che sfrutta tetti e cengie sviluppati in corrispondenza dei piani di scistosità e dei sistemi di fratturazione.



Non meno importante nel territorio di Borgone fu la coltivazione di livelli più teneri ricchi in minerali lamellari (miche) per la produzione di macine (o mole) da mulino. Questa singolare attività si esaurì anteriormente al XX sec. e si concentrò soprattutto in corrispondenza di un contrafforte roccioso a breve distanza dall'abitato di Chiampano, denominato "Roccafurà"; termine locale evocativo della grande fenditura aperta nel ventre della montagna. Lo sfruttamento avveniva a spese di corpi lenticolari di micascisti argentei** (1) inglobati nel metagranito (2) e fortemente deformati, con spessori variabili da qualche decimetro a qualche metro.





* Metagranito: roccia metamorfica derivata da un granito (roccia ignea) di cui è conservata ancora la struttura originaria.

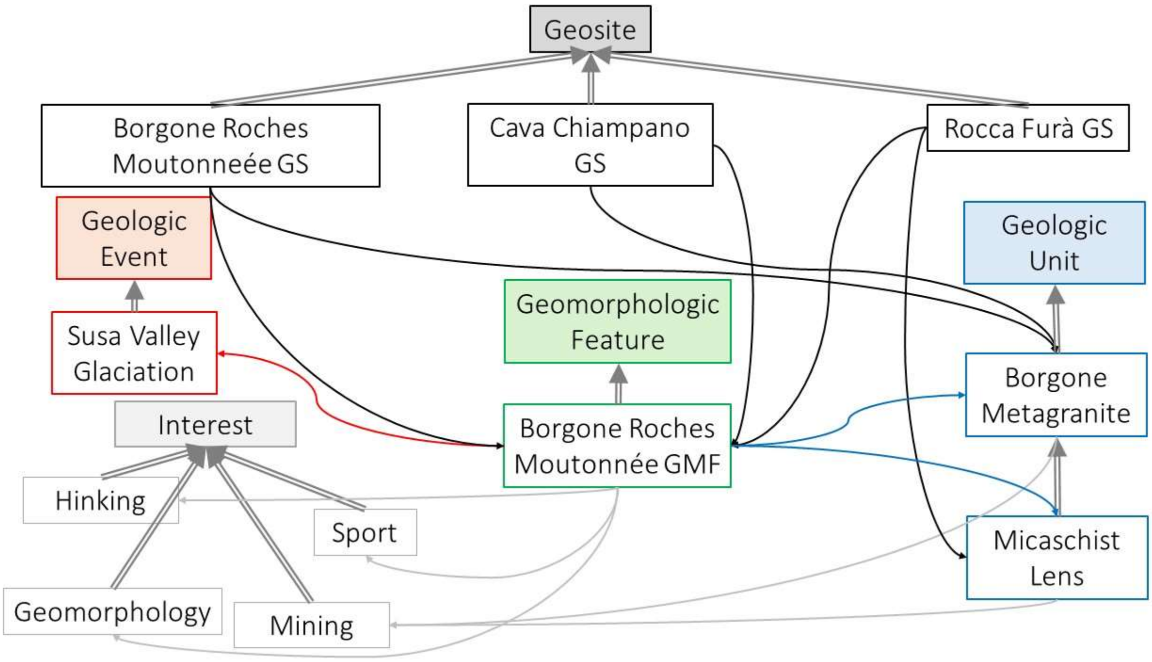
** Micascisto: roccia metamorfica caratterizzata da disposizione planare orientata dei minerali (in prevalenza miche).

Borgone's metagranite* has long been a primary source of wealth for the local economy. The open quarries on the mountain ridges of the left slope provided blocks of valuable material from which skilled stonemasons ('picapere') extracted lintels, windowsills, columns, capitals, and ashlars used for monuments, palaces, bridges, etc.

This flourishing activity ceased in the 1970s with the closure of the large Chiampano quarry, which has now been transformed into a popular rock gymnasium exploiting roofs and ledges developed in the schistosity planes and fracturing systems.

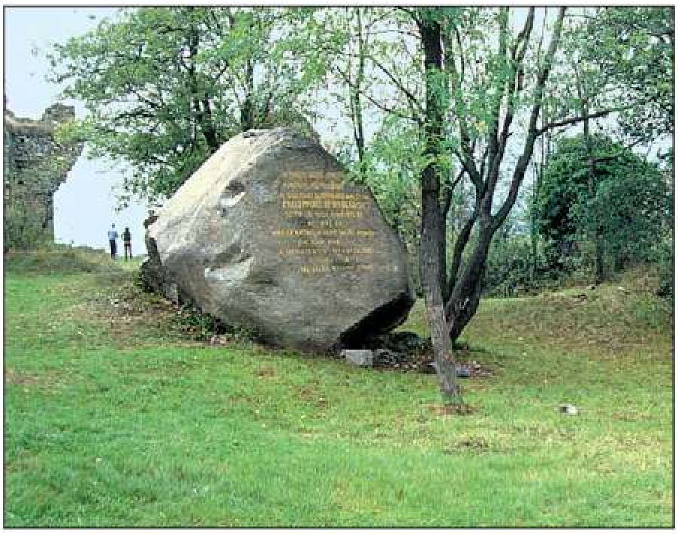
No less important in the Borgone area was the cultivation of softer levels rich in lamellar minerals (mica) for the production of millstones (or grindstones). This singular activity came to an end before the 20th century and was mainly concentrated in correspondence with a rocky buttress not far from the

Chiampano settlement, called 'Roccafurà'; a local term evocative of the large fissure opened in the belly of the mountain. Exploitation took place at the expense of lenticular bodies of silvery micaschists** (1) embedded in metagranite (2) and strongly deformed, with thicknesses varying from a few decimeters to a few metres.



CASTELLAZZO ERRATIC BOULDER

MASSO ERRATICO DI CASTELLAZZO



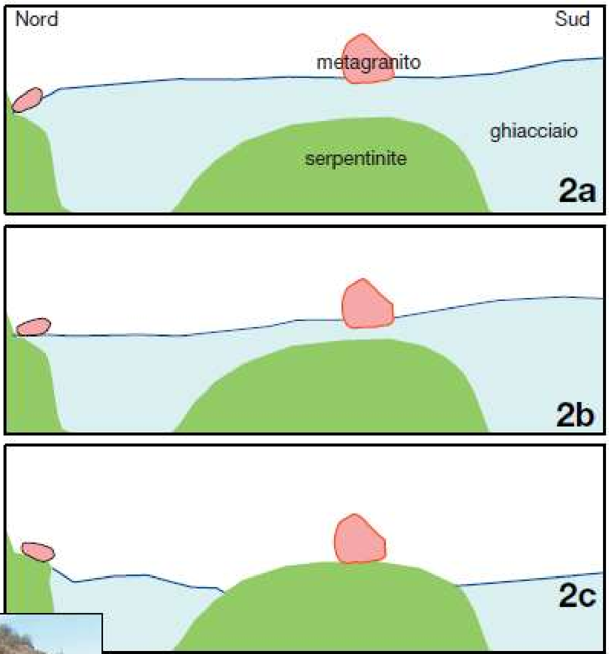
E' un grosso blocco roccioso subarrotondato che giace sullo spiazzo erboso racchiuso dai ruderi del medioevale "Castrum Capriarum", sulla sommità di un dosso roccioso che emerge per una ventina di metri di altezza dalla piana alluvionale della Dora Riparia, al confine tra i Comuni di Condove e Caprie in regione Castellazzo (Val di Susa).
Diversi sono gli aspetti di interesse che presenta questo geosito: la molteplicità delle forme legate al modellamento dell'antico ghiacciaio quaternario della Valle di Susa; il contesto storico-monumentale; la surreale valenza paesaggistica di un'isola rocciosa miracolosamente preservata dall'assedio di attività antropiche e di infrastrutture di forte impatto ambientale (cave, autostrada, elettrodotti).

It is a large sub-rounded rocky block that lies on the grassy clearing enclosed by the ruins of the medieval 'Castrum Capriarum', on the top of a rocky hump that emerges some twenty metres from the alluvial plain of the Dora Riparia, on the border between the municipalities of Condove and Caprie in the Castellazzo region (Susa Valley). There are several aspects of interest that this geosite site presents: the multiplicity of shapes linked to the modelling of the ancient Quaternary glacier of the Susa Valley; the historical monumental context; the surreal landscape value of a rocky island miraculously preserved from the siege of anthropic activities and infrastructures with a strong environmental impact (quarries, motorway, power lines).

ORIGINE - TRASPORTO - MESSA IN POSTO

Il blocco roccioso di regione Castellazzo è un tipico esempio di masso erratico, ovvero un elemento lapideo di grandi dimensioni, caduto per frana sulla superficie di un ghiacciaio e da questo trasportato più a valle, anche per distanze chilometriche (*schema 1*).

Solo con questo meccanismo è possibile giustificare la presenza di un blocco roccioso di natura litologica (metagranito*) differente da quella della base d'appoggio e del contiguo versante, che sono costituiti da rocce serpentinitiche**.



In base alla distribuzione dei litotipi con composizione mineralogica analoga a quella del masso, e al notevole grado d'arrotondamento del masso erratico, si può ipotizzare che la più probabile area di provenienza del masso stesso si collochi sulle pendici meridionali del M. Baraccone alle spalle dell'attuale abitato di Borgone.

La messa in posto del masso erratico sulla sommità del dosso montonato di regione Castellazzo, e di numerosi altri massi sul versante sinistro in località Truc le Mura, si realizzò al momento della scomparsa della massa glaciale che ricopriva il dosso del Castellazzo (*schema 2*).

* Metagranito: roccia metamorfica derivata da un granito (roccia ignea) di cui è conservata ancora la struttura originaria.

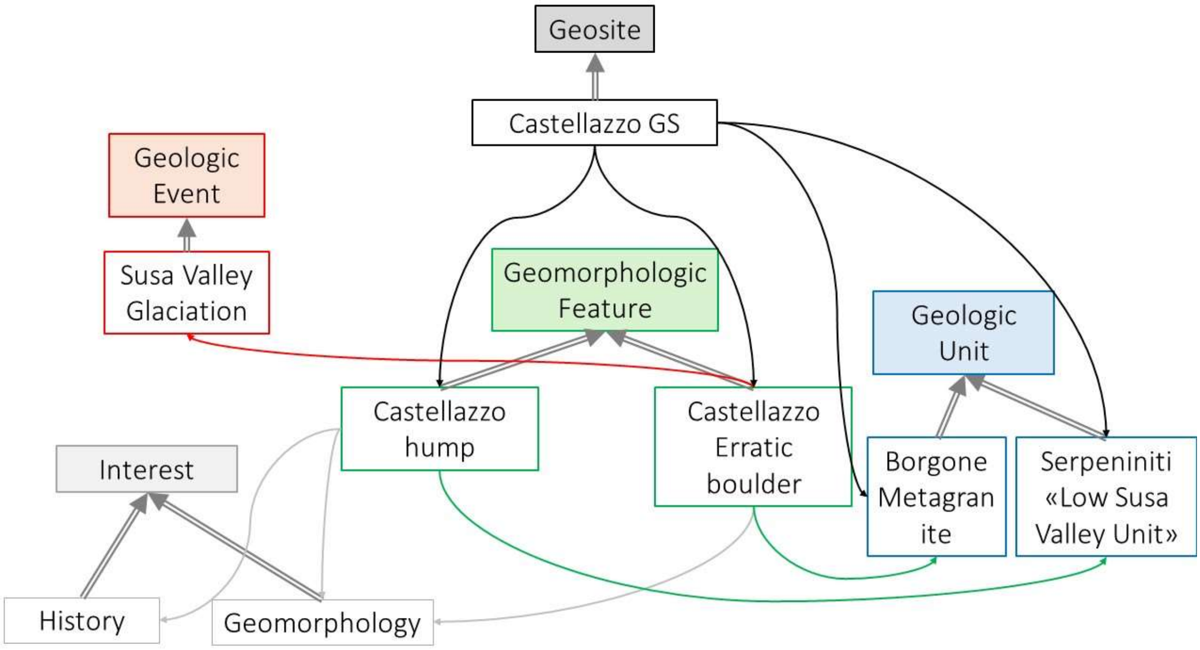
** Serpentinite: roccia metamorfica costituita da minerali del gruppo del serpentino.

The rocky block in the Castellazzo region is a typical example of an erratic boulder, i.e. a large stone element that fell by landslide onto the surface of a glacier and was transported by it further downstream, even over distances of kilometres (diagram 1).

Only with this mechanism is it possible to justify the presence of a rock block of a different lithological nature (metagranite) from that of the base and the adjacent slope, which consist of serpentinitic rocks.

On the basis of the distribution of lithotypes with a mineralogical composition similar to that of the boulder, and the considerable degree of rounding of the erratic boulder, it can be hypothesised that the most probable area of origin of the boulder itself is on the southern slopes of Mount Baraccone behind the present-day Borgone village.

The installation of the erratic boulder on the top of the mound in the Castellazzo region, and of numerous other boulders on the left slope in the Truc le Mura locality, took place at the time of the disappearance of the glacial mass that covered the Castellazzo mound (diagram 2).



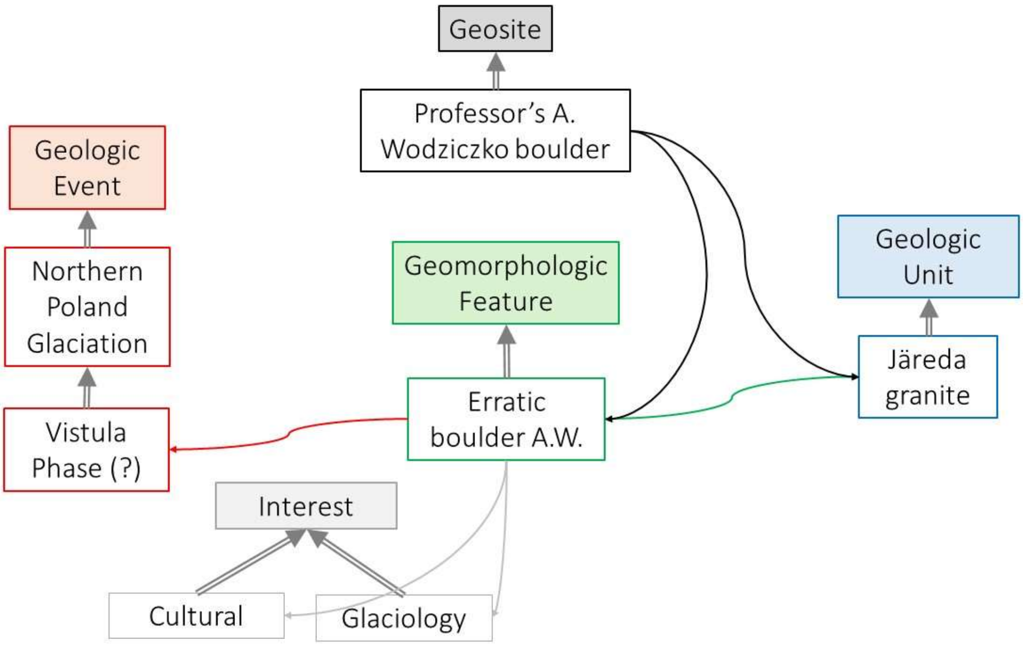
PROFESSOR'S A. WODZICZKI BOULDER

1. Structural regions of Poland:	• Fore-Sudetic Monocline
2. Geological age:	• Precambrian • Neoproterozoic
3.1 Lithology:	• Granites • Boulders
3.2 Form of terrain:	• rock
3.3 Origin:	• glacial
4. Description of the geosite:	The boulder is a guide eratite - Jaered granite from an outcrop in Smaland in southeastern Sweden.

Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1248; translation by Google translate and DeepL.com

Glacial boulders occur in areas that were covered by glaciers in the past. This also applies to the Greater Poland National Park, which became part of the Scandinavian ice sheet just over 20,000 years ago. The ice sheet, flowing from Scandinavia towards Polish lands, tore out significant amounts of rocks from the ground (glacial exfoliation), which it then transported. When it melted and disappeared a little later, it left behind rocks brought from the north. We find their fragments among fields - these are colloquially called field stones, in forests and cities. They are so common that we usually do not pay attention to them. The largest of them are glacial boulders, also called erratic boulders (thrusted by the ice sheet) or eratics. Most of them come from Scandinavia, like this granite boulder commemorating prof. Adam has Wodziczka. Less numerous are boulders coming from the bottom of the Baltic Sea, which did not exist when the ice sheet approached the area of today's Poland.

Notice the strongly rounded edges of the boulder, i.e. its surroundings. It acquired this feature during transport through the ice sheet and then in the meltwater river of the ice sheet. The boulder's circumference is 455 cm and its weight reaches 1.54 tons. It is a granite rock (Järeda granite), coming from southern Sweden (Småland). The characteristic pink colour of this rock results from the dominance of a mineral called orthoclase in its composition. Approach the boulder and you will easily see large, pink orthoclase crystals in it (photo below).



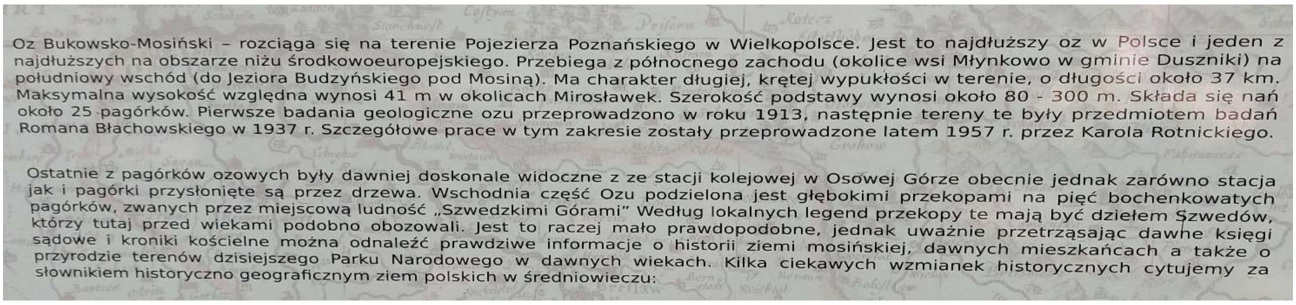
BUKOWSKO-MOSIŃSKI ESKER

1. Structural regions of Poland:	• Fore-Sudetic Monocline
2. Geological age:	• Upper Pleistocene • Holocene
3.1 Lithology:	• Gravelly sands (sands and gravels, sands with gravels) • Peats • Gytia
3.2 Form of terrain:	• subglacial troughs • eskers • forms of rift accumulation
3.3 Origin:	• glacial • glacial fluvial
4. Description of the geosite:	The escarpment is made of sand and gravel, sometimes covered with a thin layer of moraine clay, which indicates that this form was created in a subglacial tunnel. The areas adjacent to the esker are, in some places, filled with lake sediments (peats, gyttja). This situation, the appearance of the forms and the accessibility make it an attractive object in many respects.

Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=1384; translation by Google translate.

Look around you. You are standing on a long embankment, the slopes of which are very steep and high. They rise about 20 m above the surface of Lake Budzyńskie, visible between the trees. Imagine that this ridge was formed within the Scandinavian ice sheet. How is that possible?

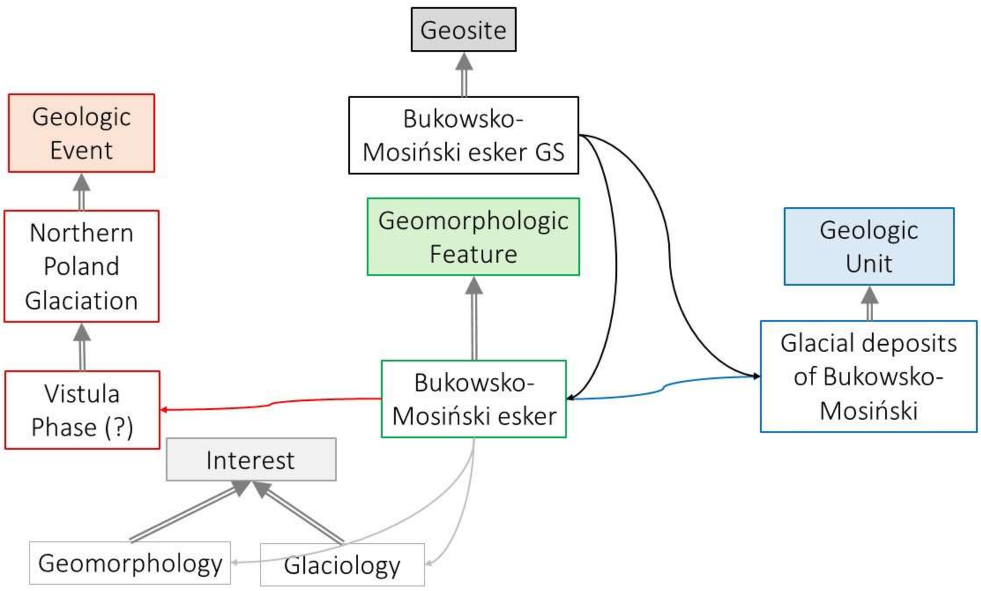
Well, under the ice sheet there were subglacial tunnels in which subglacial rivers flowed. Rivers also flowed in numerous crevices inside the ice sheet. These rivers filled the tunnels and crevices with transported sand and gravel. Later, when the ice sheet melted and disappeared, the sand and gravel that filled the tunnels and crevices remained, creating long and winding embankments on the surface. Like the one you're standing on. These are eskers.This esker is the longest form of this type in Poland. It is approximately 37 km long. It starts near Buk and ends near Mosina - a few hundred meters from this place, on the shore of Lake Budzyńskie. Hence its name: bukowsko-mosiński oz. The final part of this esker is the so-called Swedish Mountains. They are made up of five hills created as a result of the excavation of an esker in the Middle Ages (see photo). You'll get there in about 12 minutes by continuing along this esker path. Also note the information board dedicated to this esker, located next to prof.'s boulder. Adam Wodziczka.



Oz Bukowsko-Mosiński – rozciąga się na terenie Pojezierza Poznańskiego w Wielkopolsce. Jest to najdłuższy oz w Polsce i jeden z najdłuższych na obszarze niżu środkowoeuropejskiego. Przebiega z północnego zachodu (okolice wsi Młynkowo w gminie Duszniki) na południowy wschód (do Jeziora Budzyńskiego pod Mosiną). Ma charakter długiej, krętej wypukłości w terenie, o długości około 37 km. Maksymalna wysokość względna wynosi 41 m w okolicach Mirosławek. Szerokość podstawy wynosi około 80 - 300 m. Składa się nań około 25 pagórków. Pierwsze badania geologiczne ozu przeprowadzono w roku 1913, następnie tereny te były przedmiotem badań Romana Błachowskiego w 1937 r. Szczegółowe prace w tym zakresie zostały przeprowadzone latem 1957 r. przez Karola Rotnickiego.

Ostatnie z pagórków ozowych były dawniej doskonale widoczne z ze stacji kolejowej w Osowej Górze obecnie jednak zarówno stacja jak i pagórki przysłonięte są przez drzewa. Wschodnia część Ozu podzielona jest głębokimi przekopami na pięć bochenkowatych pagórków, zwanych przez miejscową ludność „Szwedzkimi Górami" Według lokalnych legend przekopy te mają być dziełem Szwedów, którzy tutaj przed wiekami podobno obozowali. Jest to raczej mało prawdopodobne, jednak uważnie przetrząsając dawne księgi sądowe i kroniki kościelne można odnaleźć prawdziwe informacje o historii ziemi mosińskiej, dawnych mieszkańcach a także o przyrodzie terenów dzisiejszego Parku Narodowego w dawnych wiekach. Kilka ciekawych wzmianek historycznych cytujemy za słownikiem historyczno geograficznym ziem polskich w średniowieczu:

The Bukowsko-Mosiński Oz stretches in the Poznań Lake District in Greater Poland. It is the longest esker in Poland and one of the longest in the Central European lowlands. It runs from the north-west (around the village of Młynkowo in the Duszniki commune) to the south-east (to Lake Budzyńskie near Mosina). It has the character of a long, winding protrusion in the terrain, approximately 37 km long. The maximum relative height is 41 m near Mirosławki. The width of the base is about 80-300 m. It consists of about 25 hills. The first geological studies of the esker were carried out in 1913, then these areas were the subject of research by Roman Blachowski in 1937. Detailed work in this area was carried out in the summer of 1957 by Karol Rotnicki The last of the esker hills used to be perfectly visible from the railway station in Osowa Góra, but now both the station and the hills are obscured by trees. The eastern part of Oz is divided by deep ditches into five loaf-shaped hills, called "Swedish Mountains" by the local population. According to local legends, these ditches are supposed to be the work of the Swedes, who supposedly camped here centuries ago. It is rather unlikely, but carefully searching the court books and church chronicles, you can find true information about the history of the Mosiń land, its former inhabitants and the nature of the areas of today's National Park in ancient times.

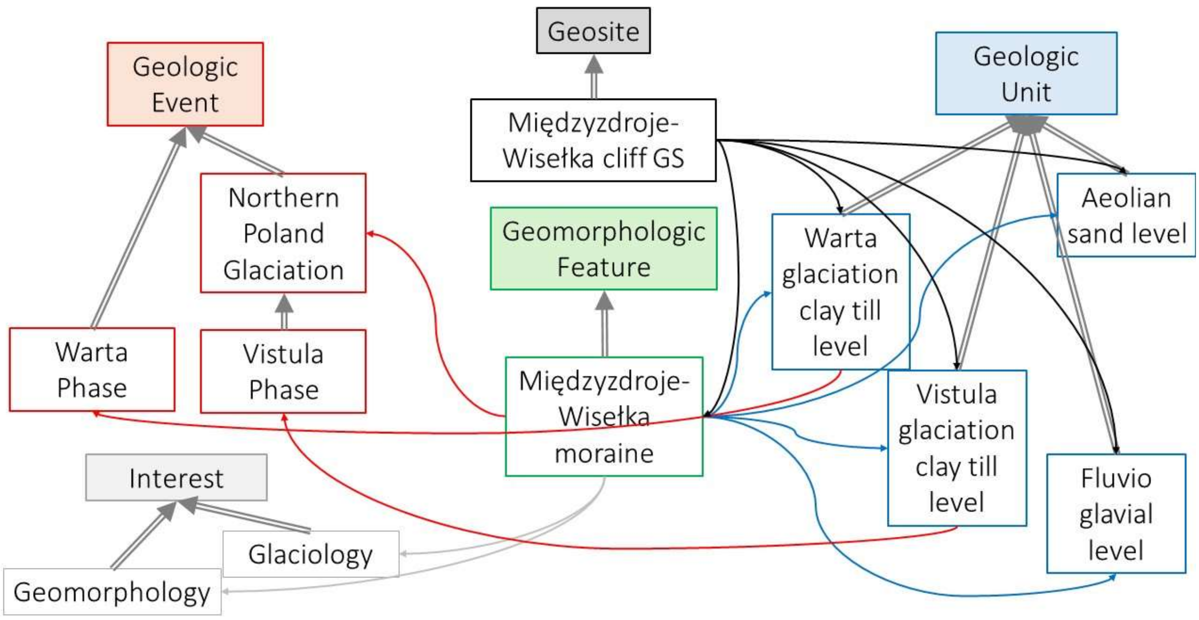


MIĘDZYZDROJE-WISEŁKA CLIFF

1. Structural regions of Poland:	• Szczecin Basin
2. Geological age:	• quaternary • Pleistocene • Holocene
3.1 Lithology:	• Sands (sands, sands with...) • Clays (boulder and other)
3.2 Form of terrain:	• subglacial troughs • eskers • forms of rift accumulation
3.3 Origin:	• glacial • sea • aeolian
4. Description of the geosite:	These cliffs stretch for approximately 11 km east of Międzyzdroje. They constitute the northern edge of the moraine-kame hills of the Wolin Range, created by the retreating ice sheet of the Pomeranian phase of the Baltic glaciation (Vistula glaciation, northern Poland). These are the highest cliffs in Poland. Mount Gosań, which is also the highest point on the Polish coast, is nearly 95 m above sea level. The height of the cliffs in this section varies, ranging from 5-10 m above sea level near Międzyzdroje and increases towards the east, reaching its maximum height on Mount Gosań, and then decreases to approximately 35 m in around Grodno and further towards Wisełka. The average slope of the cliff slopes in this section is approximately 50 degrees. In the cliff profile, two levels of boulder (moraine) clays can be observed: the lower one, gray in colour, up to 40 m thick, associated with the Warta glaciation (Central Poland, approx. 210,000 years ago) and the upper one - younger, yellow-coloured brown, up to 3 m thick, associated with the youngest advance of the ice sheet into this area (Vistula glaciation, northern Poland, Pomeranian phase of the Baltic glaciation, 14-12 thousand years ago). They are covered by a series of water-glacial (fluvioglacial) sand and gravel formations of varying thickness, and on its surface a series of aeolian sands (2-15 m). Just above the level of the beach there is a fragment of gray marl from the Cretaceous period, i.e. a large block of rock carved out of the ground by the ice sheet, moved some distance and deposited within post-glacial sediments. There are numerous marcasite concretions (clusters) there. On the cliff, in addition to analyzing the geological structure, you can observe contemporary sculpture processes shaping the sea shore. The cliff in this section is a "living" cliff (active), therefore subject to the influence of sea waves, wind and constant changes. In many places it creates an almost vertical edge with a clear abrasive niche (edge undercut) at the base. Cliff edges can be divided into: the slide-flow type (in the zone where between the levels of compact boulder clay there are sands, gravels and inter-moraine silts, with seepage of groundwater), the rockfall type (on slopes made mainly of compact boulder clay) and the scree type (composed largely of thick series of

glacial sand and gravel deposits devoid of groundwater). All the above-mentioned types of cliffs can be observed on the Międzyzdroje-Wisełka section. In this cliff, in its sandy and gravel part, there are mostly scree slopes. In places where there is sand or gravel in the ground, this material loses its compactness after drying and begins to crumble under the influence of gravity, creating characteristic pile cones. "Tongues" of sand slide systematically and continuously, although with different frequency and speed, and their shape also changes. With a strongly inclined slope, vegetation cannot settle on the shifting and constantly sliding sand. Extensive sand cones often mask the structure of the cliff in the lower parts. In turn, when the substrate is significantly moist, slides, falls or flows of the plasticized clay mass occur. Very wet materials (dust, clay, and even fine-grained sand) then begin to flow down the slope, creating long, muddy "tongues", often flowing across the beach to the sea. Their colour, depending on the clay or dust content, is most often ash or brown. Once an aquifer is exposed, water seeps constantly. The most characteristic feature of boulder clay is the fall of large blocks. They are often caused by various climatic factors, most often rains and frosts, as well as by "undercutting" by sea waves. Abrasion, i.e. the destruction and retreat of the cliff, causes it to have an almost vertical profile in many places in this section. As a result of landslides and rockfalls, characteristic "steps" are created, and often entire intact patches of grasslands, bushes, and even clumps of trees fall down.

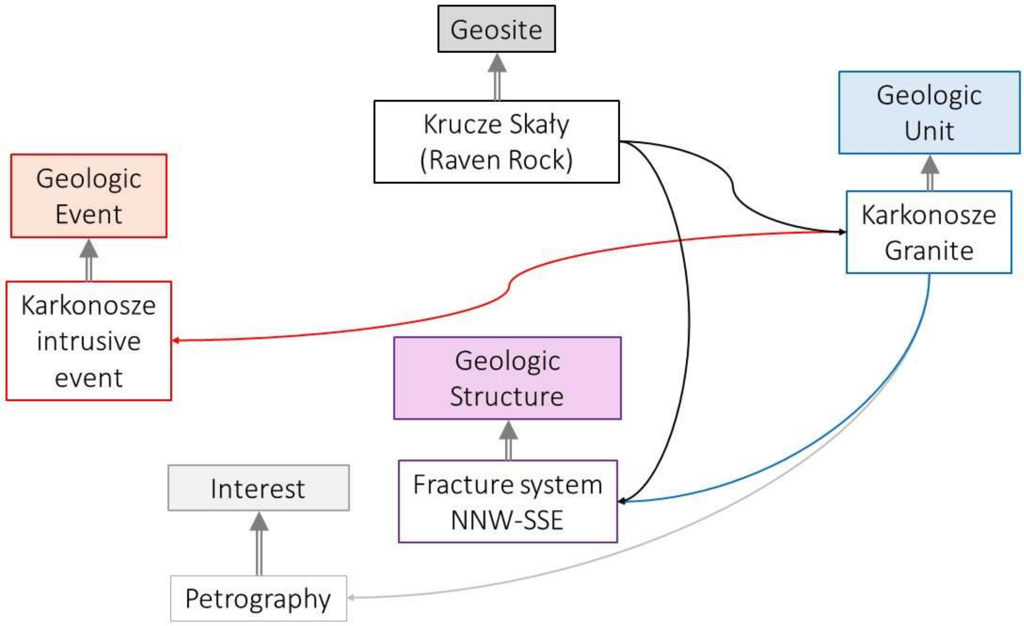
Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=3723; translation by Google translate.



KRUCZE SKAŁY, SZKLARSKA PORĘBA

1. Structural regions of Poland:	• Western Sudetes
2. Geological age:	• upper carbon
3.1 Lithology:	• Granites
3.2 Form of terrain:	• rock
3.3 Origin:	• plutonic
4. Description of the geosite:	A rock group composed of typical Karkonosze granites (Karkonosze pluton), gray and grey-pink in colour, with a chaotic rock background texture and a large variation in the size of mineral grains. The lower part of the rocks is made of light, even-grained granite, while the top is made of porphyry granite. In granites, especially porphyry varieties, wavy biotite streaks appear. Next to the szlires, there are numerous, spherical or oval enclaves with a dark colour. Aplitic veins are visible in the lower parts. Throughout the entire rock group, a characteristic system of cracks with a NNW-SSE direction is visible.

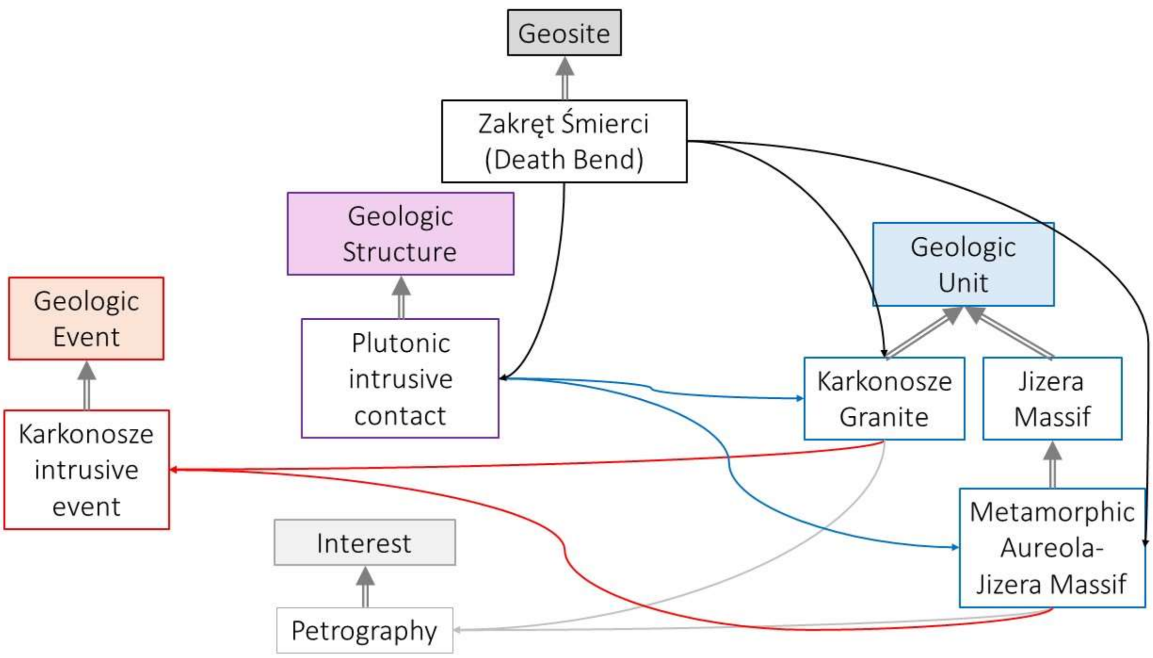
Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4475 ; translation by Google translate.



ZAKRĘT ŚMIERCI, SZKLARSKA PORĘBA

1. Structural regions of Poland:	• Western Sudetes
2. Geological age:	• upper carbon
3.1 Lithology:	• Granites • Hornfels
3.2 Form of terrain:	• rock
3.3 Origin:	• plutonic
4. Description of the geosite:	It occurs exposedly within the rocks of the Karkonosze-Izera massif. The rocks near the road show a sharp, unconforming contact between the granites of the Karkonosze pluton and the Jizera metamorphic rocks changed by the thermal influence of the granites (700-750°C). The cover rocks are represented by hornfels composed of quartz, feldspar, biotite, andalusite, cordierite with the participation of magnetite, corundum and tourmaline. We observe the interlocking of dark gray hornfels with granites, as well as small veins of light, fine-grained aplites. The contact is intrusive, in places within the granites there are irregular hornfels blocks of various sizes (up to 20-30 cm), often with quartz pockets, the so-called intrusive breccias. The hornfels blocks are partly clearly displaced by the granite.

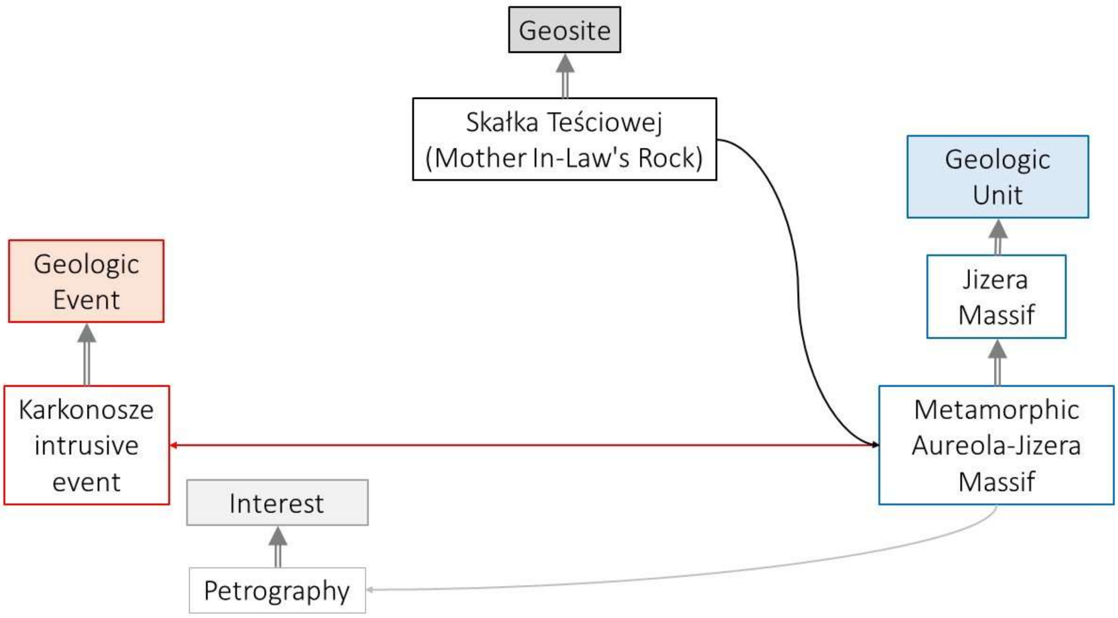
Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4472 ; translation by Google translate.



SKAŁKA TEŚCIOWEJ, SZKLARSKA PORĘBA

1. Structural regions of Poland:	• Western Sudetes
2. Geological age:	• upper carbon
3.1 Lithology:	• hornfels
3.2 Form of terrain:	• rock
3.3 Origin:	• metamorphic
4. Description of the geosite:	The Mother-in-law's Rock is composed of typical hornfels belonging to the granite cover of the Karkonosze pluton. They were created as a result of the impact of granites on the slates of the Szklarska Poręba range. Contact with the granites runs approximately 400 m to the south. These are gray and dark gray rocks with a characteristic lumpy structure and clearly visible orientation of minerals. The mineral composition includes quartz, biotite, chlorite and typical contact minerals: cordierite and andalusite, which intertwine with quartz to form characteristic lumps on the rock surface.

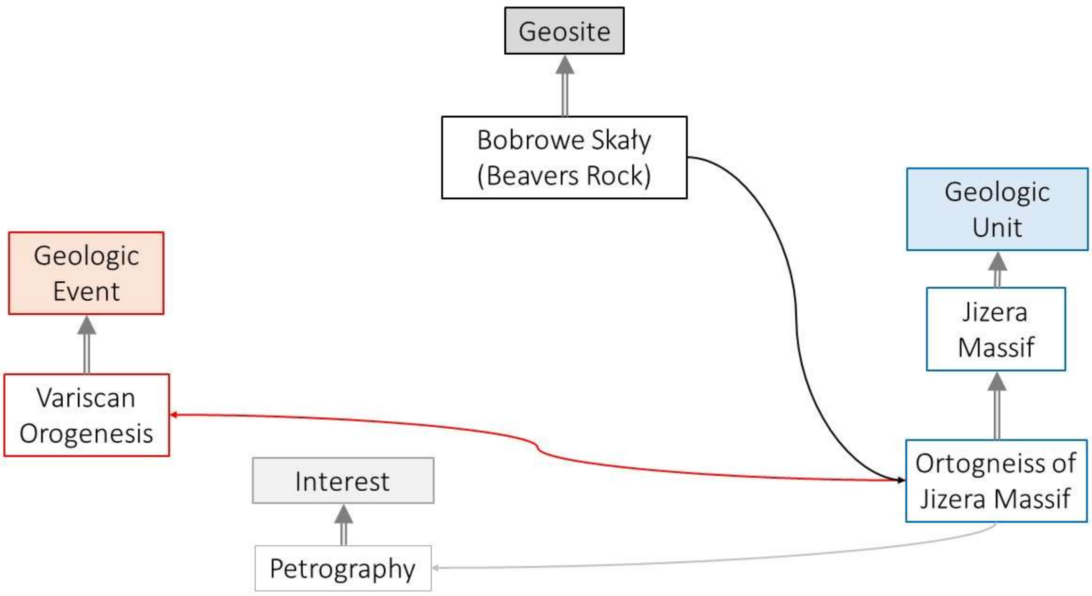
Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=4477 ; translation by Google translate.



BOBROWE SKAŁY, PIASTÓW

1. Structural regions of Poland:	• Western Sudetes
2. Geological age:	• lower carbon
3.1 Lithology:	• Granitogneisses • Granites
3.2 Form of terrain:	• rock forms
3.3 Origin:	• plutonic • metamorphic
4. Description of the geosite:	The site represents a wide, latitudinal belt of orthogneisses belonging to the Jizera Metamorphic. It is located between the Szklarska Poręba shale belt in the south and the Kamienica shale belt in the north. The main core of Bobrowe Skały is built of porphyry granites, in which large "holes" form a microcline, and the fine-grained spaces between them are made of plagioclase, quartz, biotite and muscovite. These granites occur among occluded-layered gneisses. The gradual transitions between these rocks are the result of tectonic deformation taking place at temperatures of about 300 degrees Celsius at depths of up to 5 km, which took place in the Lower Carboniferous (350-330 million years ago), i.e. during the Variscan movement

Original text at https://geostanowiska.pgi.gov.pl/gsapp_v2/ObjectDetails.aspx?id=9801 ; translation by Google translate.



APPENDIX 4

In the next pages it is reported the full questionnaire that the testers filled after the activities with the GeOntoLogic Site System.

GeOntoLogicSite System evaluation

Welcome to the questionnaire of evaluation of GeOntologicSite, our system for the description and inventory of the geological information about geosite.
First, thank you for testing the system on our Omeka-S platform. Now kindly ask you to evaluate your experience in using the system though the present form.
The survey is organized in 4 sections:
1) introduction and creation of questionnaire identification code
2) survey on the functionalities used while testing the system
3 and 4) standard questionnaires for evaluating your global experience with the system

THIS QUESTIONNAIRE IS ANONYMUS

Section 1

To identify your test, please create a 6-number code typing

- the last two numbers of your mother's year of birth (e.g., 1965=65)
- the day of your birth (e.g, 22 august=22)
-the month of birth of your father (e.g., July=07)

Answer: ……………….

Section 2

In this section, we are asking you which functionalities of the system you used and if you had any problems while using them.Used functions

Which type of features did you submit while describing your assigned geosite?

- Geosite
- Geologic unit
- Geologic structure
- Geomorphologic feauture
- Geologic event
- Composition part
- Structural region of Poland
- Other (Specify…)

Did you have any problem in understanding which type of feature you needed to add? Which one?

- Geosite
- Geologic unit
- Geologic structure
- Geomorphologic feauture
- Geologic event
- Composition part
- Structural region of Poland
- Other (specify)

How often did you use the terms suggested by the controlled vocabularies in the drop down menu?

- 1 - Never
- 2
- 3
- 4
- 5 - Always

If you used the free texts fields instead selecting a term from the controlled vocabularies, what was the reason?

- I never used the free text fields (I always used the terms in the lists)
- I needed to provide a complex answer
- I needed to provide multiple answer
- I did not find the term that I needed
- The list was too difficult to consult
- Other (specify…)

Please, select the controlled vocabularies that did not suite your task

- Lithology
- Landform shape
- Event environment
- Geologic time scale (for younger/older named age)
- Interest
- Stratigraphic role
- Metamorphism
- Every vocabulary suited my task
- Other (specify…)

Did you use the collecting form for "Composition part"? If yes, which object you added?

Answer: ………………..

Considering the goal of the system (which is the description of the geosite from a geological and geomorphological point of view) do you think that the description is complete?

- Yes
- No
- Other (specify…)

If No, which type of information would you like to add? (NA for "No Answer")

Answer: ………………..

Which type of device did you use for the test?

- PC
- Tablet
- Smartphone
- Other (specify…)

Do you think that this system could be used directly during a field survey?

- Yes, as it is now
- Yes, but in a semplified version
- No
- Other (specify…)

Do you have any suggestion for improving the usability of the systetm both in office and in the field?

Answer: ………………..

Section 3

User Experience Questionnaire

For the assessment of the system, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the sysytem. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular system. Nevertheless, please tick a circle in every line.

It is your personal opinion that counts. Please remember: there is no wrong or right answer!

PLEASE ASSESS THE SYSTEM NOW BY TICKING ONE CIRCLE PER LINE.

	1	2	3	4	5	6	7	
Annoying								Enjoyable
Not understandable								Understandable
Creative								Dull
Easy to learn								Difficult to learn
Valuable								Inferior
Boring								Exciting
Not interesting								Interesting
Unpredictable								Predictable
Fast								Slow
Inventive								Conventional
Obstructive								Supportive
Good								Bad
Complicated								Easy
Unlikable								Pleasing
Usual								Leading edge
Unpleasant								Pleasant
Secure								Not secure
Motivating								Demotivating
Meets expectations								Does not meet expectations
Inefficient								Efficient
Clear								Confusing
Impractical								Practical
Organized								Cluttered
Attractive								Unattractive
Friendly								Unfriendly
Conservative								Innovative

Section 4

System Usability Scale
Please, declare your agreement or disagreement with the following ten sentences

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1. I think that I would like to use this system frequently.					
2. I found the system unnecessarily complex.					
3. I thought the system was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this system were well integrated.					
6. I thought there was too much inconsistency in this system.					
7. I would imagine that most people would learn to use this system very quickly.					
8. I found the system very cumbersome to use.					
9. I felt very confident using the system.					
10. I needed to learn a lot of things before I could get going with this system.					