CONTENTS

ABSTRACT 2

1 INTRODUCTION 3

2 ONTOLOGY 5
2.1 Definition 5
2.2 Semantic Web 6
2.3 Foundational Ontologies 6
2.3.1 dolce 6
2.3.2 UFO 7
2.3.3 GFO 8

3 GEOLOGY 9
3.1 Petroleum Geology 9

4 GEOLOGY ONTOLOGIES 11
4.1 Geologic Map of Korea 11
4.2 NCGMP09 11
4.3 WITSML Lithology 13

REFERENCES 14

ABSTRACT

The need of integration of different fields of geoscience is valuable and important for the petroleum exploration and production. We analyze the different taxonomies, standards and ontologies that have been developed for the area of geoscience in order to find similarities concepts between models to establish the way we can integrate them. In addition, this review will describe the fundamental concepts of ontologies, geology and detailed description of each geology ontology.

Keywords: Ontology, Geology, taxonomy, standard.

1 INTRODUCTION

Nowadays many fields such as business intelligence, software engineering, medicine, petroleum engineering and biology are implementing ontologies to ensure better sustainability of the knowledge implemented in systems. We consider that ontology is a key aspect in the interchanging of systems information and also it lets humans and computers share and reuse information. Gruber (1993) define ontology as explicit specification of a conceptualization. N. Guarino(1998) refines Gruber definition as "a logical theory accounting for the intending meaning of a formal vocabulary. The intended models of a logical language using such a vocabulary are constrained by its ontological commitment. An ontology indirectly reflects this commitment (and the underlying conceptualization) by approximating these intended models". Also, it is important to mention that ontology is language dependent, while a conceptualization is language independent. One of the reasons that ontologies are the focus of many researchers is due to the current growth of semantic web. Thus, today we have the semantic web that represents the next major evolution in connecting information. This engenders a completely different outlook on how storing, querying and displaying information might be approached. Ontology is being used to develop better knowledge models, which are well founded and easy to integrate. However, we need to have a solid background and a good methodology for developing ontologies. Thus, N. Guarino and C. Welty presented the OntoClean which is a methodology for validating the ontological adequacy and logical consistensy of taxonomic relations. Also, Guizzardi (2005) has proposed Ontological Foundations for Structural Conceptual Models, and a few years later, Guizzardi and Wagner (2008) presented a foundational ontology to provide real world semantics and sound modeling guidelines using conceptual modeling called Unified Foundational Ontology(UFO). UFO is based on GFO/GOL and DOLCE/OntoClean.UFO has three parts UFO-A(endurants), UFO-B(perdurants) and UFO-C(ontology of Social and Intentional Entitties).

Petroleum geology is the application of geology (the study of the physical Earth and the process the form it) to the exploration for and production of oil and gas (Selley 1998). Geology itself is firmly based on chemistry, physics, and biology. From the combination of these pure sciences we have geochemistry, structural geology, sedimentology, petrography, stratigraphy, paleontology, geophysics exploration and logging, which are part of geology. It is important to mention that petroleum geology is only one aspect of petroleum exploration and production. However, it plays an important role. As an example, Abel (2001) in her PhD Thesis developed an ontology for sedimentary petrography used in the system PETROLEGE, which helps in the description and interpretation of sedimentary rocks. This will be studied in our review.

In semantic web applied to Geoscience, we have the Earth and Environmental Terminology (SWEET) which is a top level ontology and it is been used recently in many

projects as the basis for extend it to mineralogy, hydrology and other areas of earth science. Ajay and Hassan (2008) describe the SWEET ontology and outstand the importance of maintain consistency with other geology ontologies. Thus, we should develop geology ontologies considering, in the future, the integration with other models.

Many organizations invest huge amount of money in finding good quality reservoirs and within petroleum exploration it used different techniques in the discovery of good quality reservoirs. Thus, our motivation for doing this review is to have in mind the different kinds of models and ontologies that exist for petroleum geology in order to find similarities and identify the way of integrating these models to support a good petroleum exploration prediction.

The main purpose of our review consists of an overview of the state of the art in ontology and conceptual models applied to petroleum geology. Also, it will contain an analysis of the ontologies founded previously from the point of view of OntoClean and UFO. Concluding with a comparison of the ontologies and showing if exists similar geological concepts between them.

During the description of each taxonomy,standard or ontology, it will be explain the reason for the development, . The criteria of analysis that will be described in the comparison will be the purpose,

2 ONTOLOGY

In this part, we are going to describe the definition of ontology and types of ontologies in section 2.1. After that we are going to describe three foundational ontologies in section 2.3

2.1 Definition

Ontology begins with the field of philosoph with the classical study of being which remotes to the Greek philosopher Aristotle BC. Aristotle's description the study of being qua being involves three things: (1) a study, (2) a subject matter (being), and (3) a manner in which the subject matter is studied (qua being); which introduce the base to the science of metaphysics of first philosophy. So in a philosophical discipline, ontology is characterized by being singular, perspective- and domain independent- and oriented towards making strong claims about the world ORSTROM;ANDERSEN;SCHARFE (2005). However, the term *ontology* (or ontologia) was itself coined in 1613 by two philosophers, Rudolf Gckel (Goclenius), in his Lexicon philosophicum and Jacob Lorhard (Lorhardus), in his Theatrum philosophicumm SMITH;WELTY (2001) . The importance of ontology in computer science has growth in the last decade gaining a specific role in Artificial Intelligence, Computational Linguistics, and Database theory. Thus, ontology in computer science has begun with the definition of NECHES et al. (1991), who stated that ontology establishes the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary. Later on, Gruber (1993) defined as an explicit specification of a conceptualization. Based on Grubers definition, Borst (1997) defined as a formal specification of a shared conceptualization. After that, Studer's definition merges Borst and Gruber defining ontology as a formal and explicit specification of a shared conceptualization (Studer et al., 1998). However, in the context of information systems, ontologies are seen as engineering artifacts constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary words (Guarino, 1998). In consequence, ontology in computer science has two different approaches: In the conceptual modeling scope it is related to fundamental ontologies, called upper level ontology and defines a range of top-level domain-independent ontological categories, which form a general foundation for more elaborated domain-specific ontologies (Guizardi 2005). In the other fields of computer science ontology is related to the domain ontology that is used to describe an engineered artifact developed for a specific function without seeing aspects of conceptual modelling. There exists many classications of ontology that Gomez et al. (2004) presents, but in general they can be categorized based on the formalness of the knowledge captured. According to Baade et al. there are top-level ontology, domain

ontology and application ontology which are similar to Guarinos classification (1998), excepted for the task ontology that is not included.

Figure Ontologies Classification (Source Saripalle R 2012) Top Level Ontologies: describe very general concepts like space, time, etc., which are independent of particular problem or domain. Domain Ontologies: describe the vocabulary related to a generic domain, by specializing the terms introduced in top level ontology. Application Ontologies: describe concepts depending on a particular domain, which are often specializations. These concepts often correspond to roles played by domain entities while performing a certain activity. Some classifications we consider important to mention are the core ontologies and foundational ontologies.

2.2 Semantic Web

The Semantic Web has many synonyms such as Web 3.0, the Linked Data Web, the Web of Data and intelligent Web transition. It enables data to be linked from a source to any other source and to be understood by computers. In order to have a better understanding, we should know what is semantic. According to the dictionary, semantic implies meaning or understanding. Thus, the Semantic Web is concerned with the meaning and not the structure of data. Tim Berners Lee (Shadbolt et al., 2006) defined the concept of Semantic web such as The Semantic Web is a Web of actionable information derived from data through a semantic theory for interpreting the symbols. As we mentioned before, semantic web was one of the reasons because ontology became the focus of many researchers. That is because the heart of semantic web is the ontology layer as we can appreciate in the Figure **??** . This ontology layer consists of the blocks query, ontology and rule. Thus, ontologies in the context of semantic web, describe domain theories for the explicit representation of the semantics of the data. Thus, RDF was extended to RDF schema to include the basic features to needed to define ontologies. But, it was limited and there were different proposals such HTML ontological language (SHOE), the ontology inference layer (OIL) and DAML+OIL. Therefore in 2004, W3C set up a standardization working group to develop a standard for web ontology language resulting in OWL the ontology language standard which is based in Description Logics and KL-One.

2.3 Foundational Ontologies

Foundational ontologies are meta ontologies used to evaluate the concept modelling. There is a misunderstanding when we talk about foundational ontologies and top level ontologies. Some authors said that they are the same. However, as we are going to see, the foundational ontology is used to model any kind of ontology. Let see some of them.

2.3.1 dolce

DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) makes a variety of important distinctions that are useful for upper ontologies. It was developed in a principal way using OntoClean methodology to help ensure correct consistent distinctions. OntoClean (Guarino and Welty, 2009) presents four basic properties that an entity should have which are essence, identity, unity and dependence. Within essence property we have rigidity which states that an entity is essential to all its possible instances. The identity property refers to recognize the entity based on the essential properties. However, it could be hard to determine. The unity property refers to specify if properties

have wholes as instances. Dependence occurs when individuals of a property depend on the existence of individuals of other property in order to exist. DOLCE is an ontology of particulars, is based on a fundamental distinction between endurants and perdurants entities. The difference between these is related to the behavior in time. Endurants are wholly present at any time they are present. On the other hand, perdurants extended in time by accumulating different temporal parts. The relation between endurants and perdurants is that of participation: an endurant lives in time by participating in a perdurant. The structute of the foundational ontology is presented in Figure **??**

2.3.2 UFO

The Unified Foundational Ontology (UFO) was proposed by Giancarlo Guizzardi and Gerd Wagner in (Guizzardi and Wagner, 2004). UFO is based on a GFO and DOLCE. While their main areas of application are the natural sciences and linguistics/cognitive engineering, respectively, the main purpose of UFO is to provide a foundation for conceptual modeling, including agent oriented modeling (Guizzardi and Wagner, 2005b). As summarized in (Carbonera, 2012), the most generic UFO concept is Thing, which is specialized in two fundamental entities: Urelement and Set. Urelement is an entity that is not a set. The first distinction that is made between the specializations of Urelement is the fundamental distinction between the categories of Individuals and Universals. Individuals are entities that exist in reality, such as a person, an apple, etc. Universals, in turn, are standard features that can be instantiated in a number of different individuals; it can be understood as high-level abstractions that characterize different classes of individuals. In general, for each of the specializations for Universals, UFO also provides a corresponding specialization for Individuals. UFO Universals are specialized in Endurant and Perdurant (Event) as shown in Figure ?. This distinction can be understood in terms of the behavior of the individuals of these universals in function of time. Endurant Universals are those whose individuals are always fully present whenever they are present, in the sense that they preserve their identity thru time (e.g., Person, Chair, Planet). Moreover, Perdurant Universals are those whose individuals extend in time accumulating temporal parts, in the sense that they occur in time (e.g., War, Party, Meeting). Endurant Universals are specialized in Substantial Universals and Moment Universals according to their existential dependency. Substantial Universals are those whose individuals are existentially independent, having spatio-temporal properties and being founded on matter (e.g., Device, Car). Moreover, Moment Universals are those whose individuals are existentially dependent, so that they only can exist in other individuals; they are inherent to these other individuals. Color, for example, whose individuals can only exist in other individuals, is a Moment Universal.

The UFO ontology is divided into three categories: UFO-A which defines the core of UFO, as a comprehensive ontology of endurants; UFO-B which defines terms related to perdurants; and UFO-C which defines terms related to the spheres of intentional and social entities (Guizzardi et al., 2007). In UFO-A, a fundamental distinction in this ontology is between the categories of Particular (Individual) and Universal (Type). The former are real entities possessing a unique identity. The later are pattern of features, which can be realized in a number of different particulars. The upper part of the UFO-A is seen in the Figure **??**.

In UFO-B, described in (Guizzardi, Falbo and Guizzardi, 2008), the main focus is Event (Perdurant or Occurrent) which are possible changes from a portion of reality to another, i.e., they may transform reality by changing the state of affairs from one pre-state

situation to a post-state situation. Events are existentially dependent on their participants in order to exist. Each participation is itself an event that can be atomic (with no improper parts) or complex (composed of at least two events that can themselves be atomic or complex), but that existentially depends on a single substantial. In this ontology, being atomic and being instantaneous are orthogonal notions, i.e., the former can be time-extended as well as the latter can be composed of multiple (instantaneous) participations (Baico et al., 2009). It is appreciated in the Figure **??**.

Then, UFO-C illustrated in Figure **??**, outstands the difference between Agents and Objects. Agents can be physical (e.g., a person) or social (e.g., an organization, a society). Objects can also be further categorized in physical (e.g., a book) or social (e.g., money, language). A Normative Description is a social object which defines one or more rules/norms recognized by at least one social agent. It also defines nominal universals such as social moment universals (e.g., social commitment types), social objects (the crown of the queen of UK) and social roles such as president. Examples of normative descriptions include the Peruvian Constitution, as well as a set of directives on how to perform some actions within an organization.

Social moments are types of intentional moments that are created by the exchange of communicative acts and the consequences of these exchanges (e.g., goal adoption, delegation). A Social Relator is an example of a relator composed of two or more pairs of associated commitments/claims (social moments). An internal or a social commitment is fulfilled by an agent if this agent performs an action that the post-state of this action is a situation that satisfies that commitment (Baico et al., 2009).

2.3.3 GFO

General Formal Ontology (GFO) uses the General Ontology Language (GOL) to defines the three-layered meta-ontological architecture comprised of a basic level consisting of all relevant GFO categories, a meta-level, called abstract core level, containing meta-categories over the basic level, and an abstract top level including set and item (urelement) as the only meta-meta-categories (Herre et al., 2006). In the GFO, it is outstand the difference between an urelement and a set. It says that Urelements are divided into individuals and universals. Individuals belong to the realm of concrete entities, which means that they exist within the confines of space and time. Universals, in contrast, are entities that can be instantiated simultaneously by a multiplicity of different individuals that are similar in given respects. As concerns individuals, they can be classified into moments, substances, chronoids, topoids and situoids (capture chronoids and topoids).

3 GEOLOGY

Before start describing the concept of geology, we introduce the concept of Geoscience which Geoscience includes all the sciences (geology, geophysics, geochemistry) that study the structure, evolution and dynamics of the planet Earth and its natural mineral and energy resources. Geoscience investigates the processes that have shaped the Earth through its 4600 million year history and uses the rock record to unravel that history - it is concerned with the real world beyond the laboratory and has direct relevance to the needs of society. Geoscience is also called earth science.

3.1 Petroleum Geology

Before define petroleum geology, we will describe the concept of Petroleum. Petroleum comes from the Latin petra, rock or stone and oleum, oil. It occurs widespread in the earth as gas liquid, semi-solid, or solid, or in more that one of this states at a single place. Chemically Petroleum is an extremely complex mixture of hydrocarbon compounds, with minor amounts of nitrogen, oxygen and sulphur as impurities (Lavorsen, 1958). Petroleum in their different states constitutes an important strategic material which is connected with the vitals and safety of the national economy, and the supplier selections are related to the safety of petroleum production and supply. The term ”petroleum geology” is discussed by some authors that thought that the correct term should be geology of petroleum. However, the person who applied the geological principles to finding petroleum is called a petroleum geologist. Thus, petroleum geology or geology of petroleum is the application of geology (the study of the physical Earth and the process the form it) to the exploration for and production of oil and gas (Selley 1998). It is important to mention, that geology is firmly based on physics, chemistry and biology. Within geology the different sub fields are used to the exploration and production of petroleum as seen in the Figure **??**

Petrology is a subfield of geology that involves the study of rock, their composition, and the process that formed. Within this field, we have a subfield called experimental petrology that involves a synthesis, fusion, and/or crystallization of minerals and rocks in laboratory to understand the physical and chemical conditions in which the minerals were formed and are stables. The petrology is strictly joined to geochemistry, through the two chemical elements contained in rocks, and with the geochronology, which techniques provided the rocks age. Geochemistry deal with the quantity, distribution, and migration of chemical elements (and their isotopes) in the earth and planetary materials. These chemical elements are contained in minerals, rocks and ground. Furthermore, flows within the earth transport chemical components from one reservoir to other. Understand the interchange between those different reservoirs requires knowledge of mineral and how they react between them. One sub field of Geochemistry is geochemistry of iso-

tope which involves the use of isotopes found in minerals to determine the geological age of them. Paleontology (STEARN;CARROLL, 1989) is an historial science. From fossils paleontologists reconstruct long-dead organisms and the world in which they lived. They cant experiment with the materials they study, by they examine the producs of past events and try to reconstruct what happened. Paleontology don't deal with repeateable events. Geophysic is the study of physic of the earth

4 GEOLOGY ONTOLOGIES

4.1 Geologic Map of Korea

Hwang and colleagues (2012) prepared a geo ontology model and geologic symbology using GIS representation of the digital geologic map units in Korea in order to develop Geological Information System for the geologic map of Korea using a spatiotemporal ontology model. 4.2

4.1

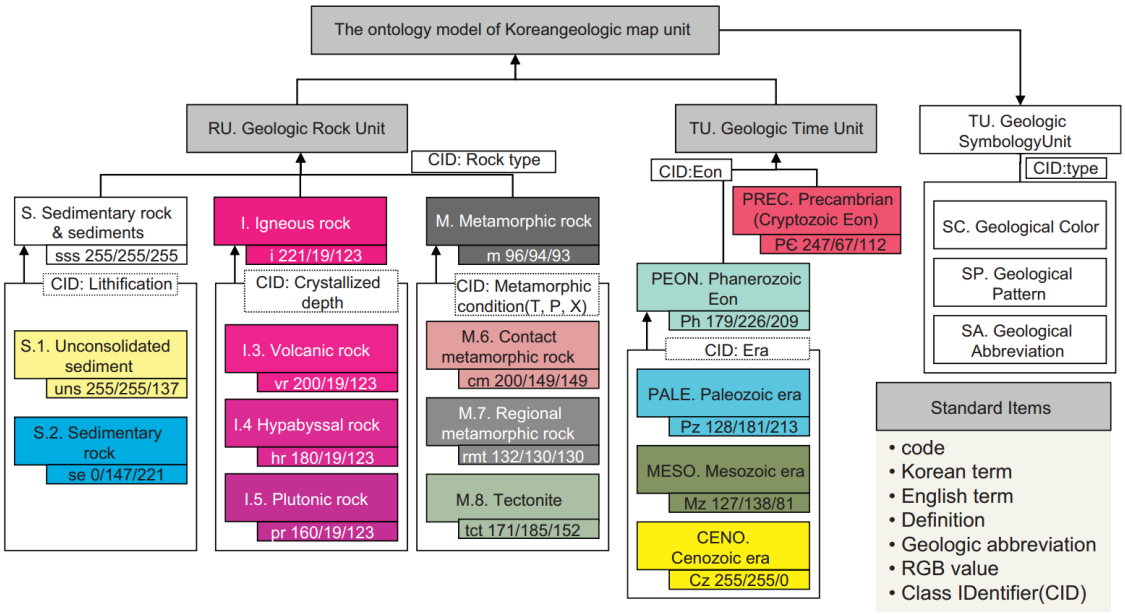

Figure 4.1: Ontology model for geologic time units (HWANG;NAM;RYU, 2012)

4.2 NCGMP09

NCGMP09 (**?**) is a proposed standard format for geologic map publications funded by the U.S. Geological Survey's National Cooperative Geologic Mapping Program (NCGMP). It is a database design for encoding content analogous to that contained in a traditional geologic map published by the USGS and by state geological surveys. As shown in Figure 4.3

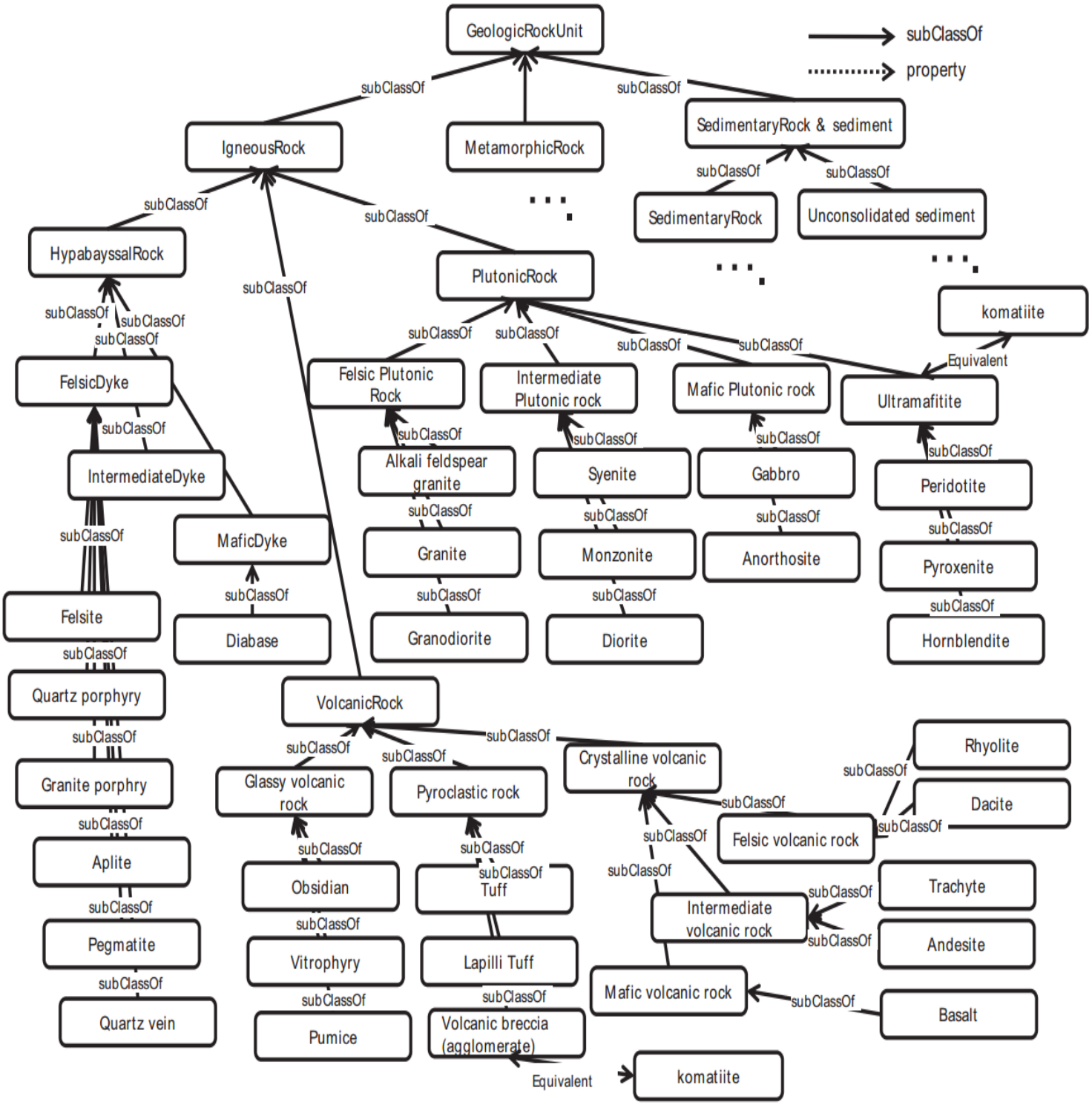

Figure 4.2: Ontology Model of the rock-time-simbology units (HWANG;NAM;RYU, 2012)

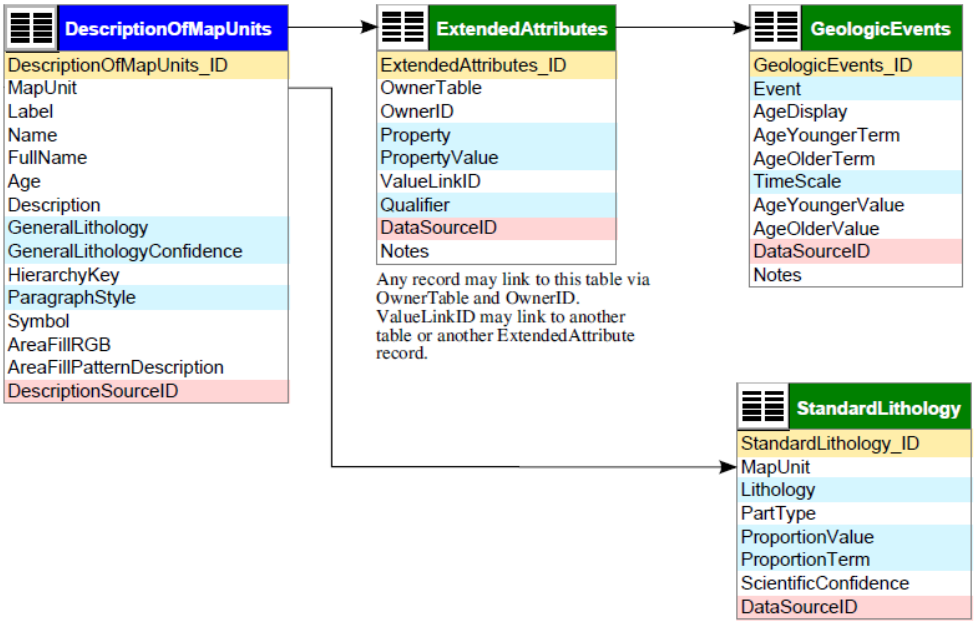

Figure 4.3: Part of NGCMP Database (**?**)

4.3 WITSML Lithology

(**?**)

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