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Subtypes of Hyponymy in the Environmental Domain: Entities and Processes

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Abstract. Hyponymy is a central relation in many models of the lexicon. However, when this *type_of* relation is not accurately represented in knowledge resources, various problems arise, ranging from information overload to failures in transitivity. A possible solution to this is the specification of hyponymy by decomposing it into a more fine-grained set of subtypes. This paper reviews how hyponymy is built in EcoLexicon, a multilingual terminological knowledge base on the environment, and proposes a set of hyponymy subtypes based on the conceptual networks contained in EcoLexicon as well as on corpus analysis.

Résumé. L'hyponymie est une relation centrale dans plusieurs modèles du lexicon. Cependant, une représentation imprécise de cette relation *type_de* peut donner lieu à de nombreux problèmes dans les ressources de connaissance, dès la surabondance d'information aux problèmes de la transitivité. Une possible solution passe par la spécification de l'hyponymie en décomposant la relation selon de différents sous-types. Cet article examine comment l'hyponymie est construite dans EcoLexicon, une base de connaissance terminologique multilingue sur l'environnement, et propose un ensemble de sous-types d'hyponymie dérivés des réseaux conceptuels contenus à EcoLexicon et de l'analyse de corpus.

1. Introduction

Contemporary theories of Terminology have had a major impact on more traditional approaches to conceptual representation and knowledge organization. Whereas the General Theory of Terminology (Wüster, 1968) is mainly based on the univocity principle and the establishment of static standardized conceptual structures, more recent proposals (Cabré, 1999; Temmerman, 2000; Faber, 2009, 2012) foreground dynamic phenomena, such as variation and multidimensionality. For example, Frame-Based Terminology (FBT) (Faber, 2009, 2012, 2015) links Terminology to Cognitive linguistics by applying the notion of frame to specialized knowledge representation. Frames account for knowledge structures that relate elements and entities associated with events from human experience, and they emphasize both hierarchical and non-hierarchical relations (Faber, 2015). This is especially relevant to Terminology work, since an accurate representation of conceptual relations is imperative in the building of a knowledge resource, such as a terminological knowledge base (TKB).

Of all conceptual relations, hyponymy is crucial in Terminology since it is the cornerstone of taxonomies and concept hierarchies. However, the establishment of hyponymic relations is not an easy task. In multidimensional concept systems, child concepts share the same hyperonym based on different classification criteria. This means that hyponymy can be further specified according to the dimensions in which cohyponyms are classified. Furthermore, the creation of conceptual networks can be greatly facilitated by the use of specialized corpora (Barrière, 2004a). Apart from making this process more empirical, corpus analysis generates data that enhance and validate information elicited from experts. The development of any terminological resource can be improved by means of the automatic extraction of hyponymic pairs from specialized texts (León-Araúz & Reimerink, 2016). This paper examines hyponymic relations in the environmental TKB EcoLexicon[1]. We analyze how the representation of hyponymy can be refined and how a semi-automatic corpus-driven extraction can nourish the existing conceptual systems.

2. EcoLexicon and hyponymy

2.1 EcoLexicon: an environmental TKB

EcoLexicon (Faber et al., 2016) is a multidimensional dynamic TKB on environmental science that is based on the theoretical premises of Frame-Based Terminology (Faber, 2012, 2015). Its objective is to facilitate user knowledge acquisition through different types of multimodal and contextualized information in order to

[1] ecolexicon.ugr.es

respond to cognitive, communicative and linguistic needs. To date, it consists of 3,601 concepts and 20,192 terms. EcoLexicon can be explored through an accessible visual interface with different modules for conceptual, linguistic, and graphical information. The conceptual relations of this TKB are classified in three main groups: generic-specific relations, part-whole relations and non-hierarchical relations. The set of generic-specific relations only consists of a single relation: *type_of*. In contrast, the set of part-whole relations contains six relations, and the set of non-hierarchical relations includes ten. This lack of balance reveals the importance of decomposing the only hyponymic relation into various subtypes so as to guarantee a more accurate representation of conceptual systems. The fact that the *type_of* relation has not as yet been subdivided in EcoLexicon has been the source of a wide range of problems, such as noise, information overload and redundancy.

2.2 Refining hyponymy in EcoLexicon

Hyponymy can be defined as a relation of inclusion whose converse is hyperonymy (Murphy, 2006:446). According to Murphy (2003:217), hyponymy is central to many models of the lexicon for three reasons: (i) its inference-invoking nature; (ii) its importance in definition; and (iii), its relevance to selectional restrictions in grammar. Therefore, the refinement of hyponymy can have an impact on many areas of Terminology work. This can be achieved by specifying subtypes of hyponymy (Murphy, 2003). The most commonly accepted distinction is between taxonomic hyponymy ('is-a-kind-of' relation) and functional hyponymy ('is-used-as-a-kind' relation).

In EcoLexicon, hyponymy needed to be refined based on criteria such as the following: (i) corrected property inheritance in concept definitions; (ii) the creation of umbrella concepts, and/or (iii) a more refined set of hyponymy subtypes (Gil-Berrozpe & Faber, 2016). After correcting property inheritance and enriching the hierarchies with new concepts, a more fine-grained set of subtypes was specified. This specification is initially based on whether the concept is an entity (i.e. ROCK) or a process (i.e. EROSION).

2.2.1 Hyponymy subtypes in the conceptual network of an entity: ROCK

Based on the network of ROCK (Figure 1), five different entity-related hyponymy subtypes were established according to the dimensions triggered by each concept:

- **State-based hyponymy:** a *type_of* relation dependent on the state of matter of the hyponyms (e.g. SOLID ROCK).
- **Formation-based hyponymy:** a *type_of* relation dependent on the formation process or the origin of the hyponyms (e.g. SEDIMENTARY ROCK).
- **Composition-based hyponymy:** a *type_of* relation dependent on the components or the constituents of the hyponyms (e.g. SILTSTONE).

- **Location-based hyponymy:** a *type_of* relation dependent on the physical situation or location of the hyponyms (e.g. PLUTONIC ROCK).
- **Attribute-based hyponymy:** a *type_of* relation dependent on the traits or features of the hyponyms (e.g. PERMEABLE ROCK).

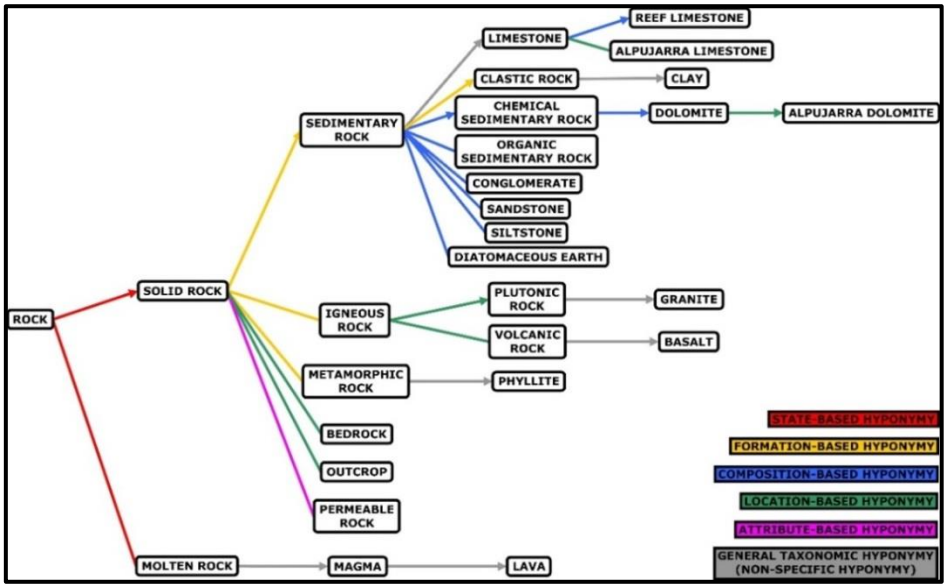


FIG. 1 – *Enhanced conceptual system of ROCK (displayed as a tree-mode network).*

According to the definitions contained in EcoLexicon, IGNEOUS ROCK is considered a *formation-based_type_of* SOLID ROCK, because it is defined as being "formed by solidification of molten magma"; REEF LIMESTONE is a *composition-based_type_of* LIMESTONE, since it is "composed of the remains of sedentary organisms"; and VOLCANIC ROCK is a *location-based_type_of* IGNEOUS ROCK, because it is "solidified near or on the surface of the Earth". However, not all hyponymic relations can be classified into a single subtype. For example, GRANITE is a *type_of* PLUTONIC ROCK based on its attributes ("coarse-grained, light-colored, hard"), its composition ("consisting chiefly of quartz, orthoclase or microline, and mica") and its function ("used as a building material"). Such cases remain classified as general taxonomic hyponymy, or as a non-specific *type_of* relation.

2.2.2 Hyponymy subtypes in the conceptual network of a process: EROSION

Based on the network of EROSION (Figure 2), four process-related hyponymy subtypes were established:

- **Agent-based hyponymy:** a *type_of* relation dependent on the agent or the promoter that causes the hyponyms (e.g. SEA EROSION).

- **Patient-based hyponymy:** a *type_of* relation dependent on the entity or location affected by the hyponyms (e.g. CHANNEL SCOUR).
- **Result-based hyponymy:** a *type_of* relation dependent on the results and effects of the hyponyms (e.g. GULLY EROSION).
- **Attribute-based hyponymy:** a *type_of* relation dependent on the traits or features of the hyponyms (e.g. POTENTIAL EROSION).

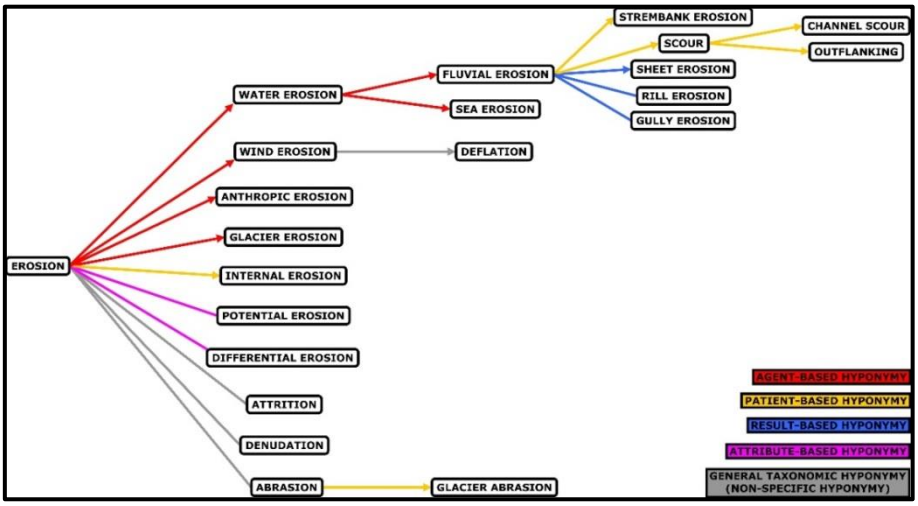


FIG. 2 – *Enhanced conceptual system of EROSION (displayed as a tree-mode network).*

ANTHROPIC EROSION is considered to be an *agent-based_type_of* EROSION because it is defined as being "caused by human activities"; GLACIER ABRASION is regarded as a *patient-based_type_of* ABRASION since it is the abrasion "of a glacier bed"; and RILL EROSION is a *result-based_type_of* FLUVIAL EROSION because it "forms small channels". Not surprisingly, the process-related hyponymy subtypes are different from those of an entity (except for attribute-based hyponymy). Since a process is generally a nominalization of a verb, it often involves an agent, a patient, and a result. This differs from formation, composition, and state, which are typical of entities. Moreover, in the case of processes, patient-based hyponymy sometimes overrides location-based hyponymy, as the patient can be a physical location (e.g. CHANNEL SCOUR affects a stream bed, and thus takes place in it).

Furthermore, the general taxonomic hyponymy (*type_of*) is also present in processes. For instance, DENUDATION is a *type_of* EROSION based on its agents ("caused by the action of water, ice, wind and waves"), its patient ("the Earth's surface") and its result ("redistribution of Earth surface material").

In the same way as for entities, these process-related hyponymy subtypes do not constitute a closed set since further research is needed to determine their extension

and scope. In addition, these preliminary findings can be crosschecked and extended through corpus analysis (Section 3).

3. Hyponym extraction and extension of the conceptual networks

After enhancing the representation of hyponymy with the data in EcoLexicon, we explored and extended the network of ROCK through corpus analysis in order to verify whether these hyponymy subtypes or even new ones could also be derived from real specialized texts.

3.1 Corpus-driven hyponym extraction

Hypernym-hyponym pairs were extracted from the EcoLexicon English corpus (59 million words) with the help of the corpus query system Sketch Engine and its main feature. word sketch. Word sketches are automatic corpus-derived summaries of a word's grammatical and collocational behavior (Kilgarriff et al., 2004). The default word sketches provided by Sketch Engine represent different linguistic relations, of which only the modifier was used for the extraction of hyponyms (through the analysis of multiword terms).

However, the system also permits the creation of customized word sketches by storing CQL (Corpus Query Language) queries in new sketch grammars. Therefore, we developed new grammars based on the knowledge patterns (KP) that usually reflect hyponymy in a corpus. The term KP was coined by Meyer (2001) to refer to the lexico-syntactic patterns between the terms encoded in a proposition in real texts. Patterns conveying hyponymic relations are the most commonly studied since they play an important role in categorization and property inheritance (Barrière, 2004b). Some of the simplest examples of such KPs are *x such as y*, *x is a kind of y*, *x and other y*, etc. These patterns were formalized in the form of regular expressions combined with POS-tags, giving rise to 18 different hyponymic sketch grammars. Table 1 shows a summarized version of the KPs, whereas Table 2 shows an example of one of the patterns converted into a CQL sketch grammar.

The grammar in Table 2 can be interpreted as follows: 1 fills the role of the hyperonym, which must be a noun. Then it can optionally be followed by a comma or a bracket, by *that* or *which*, or any modal verb. After that, we find the KP itself, acting as an anchor point, which is *classified*, *categorized* or *categorised* preceded by the lemma *be*, or a comma or a bracket, optionally followed by the preposition *by* and any word that is not a verb, plus the preposition *in* or *into*. Then there may be any number of words (included zero) that are not verbs optionally followed by lemmas such as *type*, *kind*, *example*, *group*, etc. Then again there may be any number of words that are not verbs followed by 2 others, namely, the hyponym, which must also be a noun, and none of the previous lemmas.

HYPONYM ,|(:|is|belongs (to) (a|the|…) type|category|… of HYPERNYM // types|kinds|… of HYPERNYM include|are HYPONYM // types|kinds|… of HYPERNYM range from (…) (to) HYPONYM // HYPERNYM (type|category|…) (,|() ranging (…) (to) HYPONYM // HYPERNYM types|categories|… include HYPONYM // HYPERNYM such as HYPONYM // HYPERNYM including HYPONYM // HYPERNYM ,|(especially|primarily|… HYPONYM // HYPONYM and|or other (types|kinds|…) of HYPERNYM // HYPONYM is defined|classified|… as (a|the|…) (type|kind|…) (of) HYPERNYM // classify|categorize|… (this type|kind|… of) HYPONYM as HYPERNYM // HYPERNYM is classified|categorized in|into (a|the|…) (type|kind|…) (of) HYPONYM // HYPERNYM (,|() (is) divided in|into (…) types|kinds|… :|of HYPONYM // type|kind|… of HYPERNYM (is|,|() known|referred|… (to) (as) HYPONYM // HYPONYM is a HYPERNYM that|which|… // define HYPONYM as (a|the|…) (type|category|…) (of) HYPERNYM // HYPONYM refers to (a|the|…) (type|category|…) (of) HYPERNYM // (a|the|one|two…) (type|category|…) (of) HYPERNYM: HYPONYM

TAB. 1 – *Hyponymic knowledge patterns* (León Araúz and San Martín, in press).

1:"N.*" ",|\("? [tag="IN/that|WDT"]? "MD"* [lemma="be|,|\("] "RB.*"* [word="classified|categori.ed"] ([word="by"][tag!="V.*"]*)? [word="in|into"] [tag!="V.*"]* [lemma="type|kind|example|group|class|sort|category|family|species|subtype|subfamily|subgroup|subclass|subcategory|subspecies"]? [tag!="V.*"]* 2:[tag="N.*" & lemma!="type|kind|example|group|class|sort|category|family|species|subtype|subfamily|subgroup|subclass|subcategory|subspecies"]

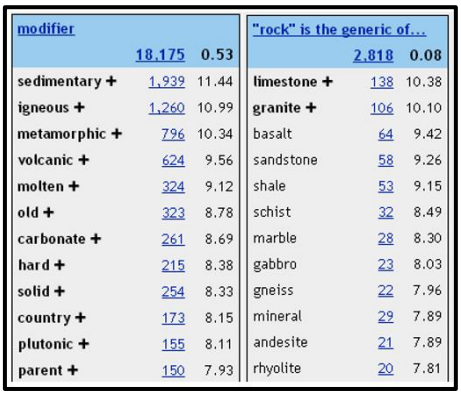
TAB. 2 – *CQL representation of a hyponymic KP*.

Examples (1) and (2) are two of the concordances that can be matched with this grammar.

(1) **Mild climates** *can be classified into three subtypes:* **humid subtropical climates**, **marine west-coast climates**, and **Mediterranean climates**

(2) **Water** *is commonly categorized into* **surface water** and **groundwater**.

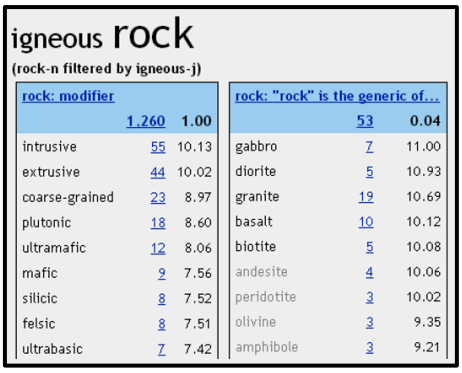
After compiling the corpus with the default and new sketch grammars, hyponymic word sketches can be derived for any lemma. In this way we can systematically analyze hyponymy in specialized texts. Figure 3 shows the default *modifier* word sketch and the newly implemented *x is the generic of…* word sketch of the lemma ROCK. As can be observed, the modifier word sketch points to a list of multiword terms that can be interpreted as hyponyms of ROCK due to compositionality (e.g. SEDIMENTARY ROCK, IGNEOUS ROCK, METAMORPHIC ROCK, etc.). On the contrary, the *x is the generic of…* word sketch provides a series of single-word hyponyms (e.g. LIMESTONE, GRANITE, BASALT, etc.). However, when clicking on the + symbol, new word sketches can be generated for multiword terms, as in Figure 4, which shows the word sketch of IGNEOUS ROCK. Browsing through these word sketches, we extracted a set of hyponyms of different levels of granularity in order to reconstruct the conceptual structure of ROCK contained in the corpus.



modifier	18,175	0.53
sedimentary +	1,939	11.44
igneous +	1,260	10.99
metamorphic +	796	10.34
volcanic +	624	9.56
molten +	324	9.12
old +	323	8.78
carbonate +	261	8.69
hard +	215	8.38
solid +	254	8.33
country +	173	8.15
plutonic +	155	8.11
parent +	150	7.93

"rock" is the generic of...	2,818	0.08
limestone +	138	10.38
granite +	106	10.10
basalt	64	9.42
sandstone	58	9.26
shale	53	9.15
schist	32	8.49
marble	28	8.30
gabbro	23	8.03
gneiss	22	7.96
mineral	29	7.89
andesite	21	7.89
rhyolite	20	7.81

FIG. 3 – *Hyponymic ROCK word sketches.*



igneous rock

(rock-n filtered by igneous-j)

rock: modifier	1,260	1.00
intrusive	55	10.13
extrusive	44	10.02
coarse-grained	23	8.97
plutonic	18	8.60
ultramafic	12	8.06
mafic	9	7.56
silicic	8	7.52
felsic	8	7.51
ultrabasic	7	7.42

rock: "rock" is the generic of...	53	0.04
gabbro	7	11.00
diorite	5	10.93
granite	19	10.69
basalt	10	10.12
biotite	5	10.08
andesite	4	10.06
peridotite	3	10.02
olivine	3	9.35
amphibole	3	9.21

FIG. 4 – *Hyponymic IGNEOUS ROCK word sketches.*

3.2 Extension of the conceptual systems through the corpus-driven extraction

After carrying out the semi-automatic corpus-driven extraction of ROCK hyponyms, a whole new set of concepts was retrieved. 57 new concepts (e.g. HIGH-GRADE METAMORPHIC ROCK, INTRUSIVE ULTRAMAFIC ROCK, etc.) were included in the conceptual network of ROCK. Moreover, the lexical representations of several concepts were replaced with preferred terms based on the number of occurrences (e.g. PLUTONIC ROCK was renamed as INTRUSIVE IGNEOUS ROCK). Afterwards, the extended network was classified according to hyponymy subtypes (Annex 1). A new subtype of hyponymy, function-based, was found (for instance, SOURCE ROCK refers to those "from which hydrocarbons are capable of being generated"). Moreover, we collected enough data to further specify attribute-based hyponymy, according to hardness, temperature, permeability, and size (e.g. HARD ROCK, PERMEABLE ROCK, FINE-GRAINED ROCK, etc.). Furthermore, analyzing the resulting network revealed the following two patterns: (1) the emergence of hyponymy subtypes depend on the

nature of the concept itself; and (2) at each hierarchical level, hyponymy subtypes tend to be of the same kind. This can be observed by focusing on the multi-level hierarchy formed by the three main types of SOLID ROCK (SEDIMENTARY ROCK, IGNEOUS ROCK and METAMORPHIC ROCK).

Virtually at all hierarchical levels of SEDIMENTARY ROCK (Figure 5), the predominant relation is composition-based hyponymy. Not surprisingly, sedimentary rocks are mainly characterized by the nature of their constituents.

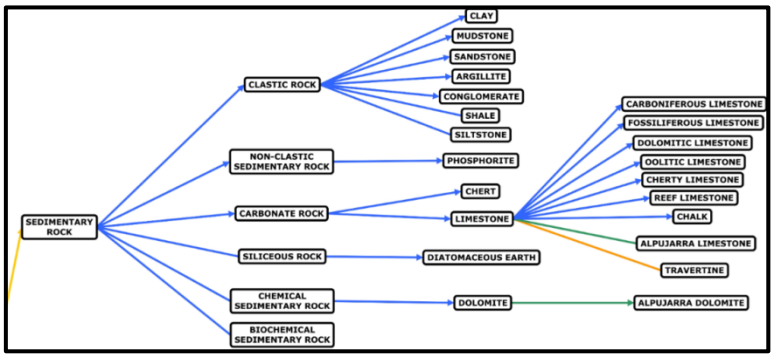


FIG. 5 – *Detail of the SEDIMENTARY ROCK hierarchy.*

In contrast, the hierarchy of IGNEOUS ROCK (Figure 6), shows more hyponymy subtypes. However, each of them appears at a different hierarchical level: location-based hyponymy appears at the first level; composition-based hyponymy at the second level; and a non-specific hyponymy at the third and last level. In Geology, igneous rocks are first classified depending on whether they are formed on the Earth's surface (EXTRUSIVE IGNEOUS ROCK) or within the Earth (INTRUSIVE IGNEOUS ROCK). Then, they are classified according to their characteristic components (INTRUSIVE MAFIC ROCK, INTRUSIVE FELSIC ROCK, EXTRUSIVE ULTRAMAFIC ROCK, etc.). Finally, they show their general taxonomic hyponyms (PERIDOTITE, SYENITE, BASALT, etc.).

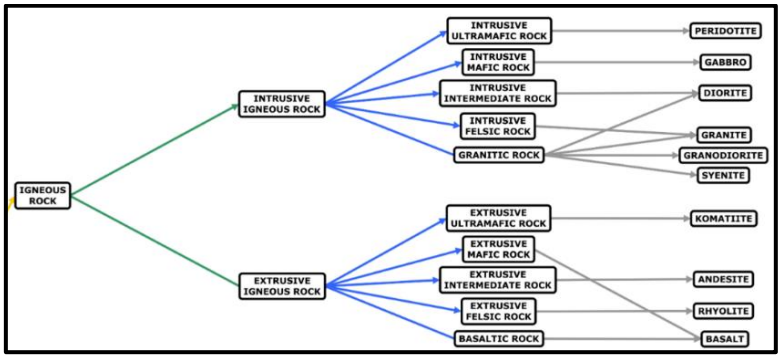


FIG. 6 – *Detail of the IGNEOUS ROCK hierarchy.*

Regarding the hyponyms of METAMORPHIC ROCK (Figure 7), only one composition-based hyponym (METAMORPHIC ULTRAMAFIC ROCK) was found. In contrast with the two previous hierarchies, in this case, the main hyponymy subtype is based on formation since metamorphic rocks are characterized by a transformation process known as 'metamorphism'. However, formation-based hyponymy could be further specified based on the result of the process (e.g. FOLIATED METAMORPHIC ROCK) and its intensity (e.g. HIGH-GRADE METAMORPHIC ROCK). As in the case of IGNEOUS ROCK, the last hierarchical level of METAMORPHIC ROCK is characterized by general taxonomic hyponyms. Nevertheless, in this network the hyponyms also show a greater level of multiple inheritance because formation-based hyponymy can still be specified.

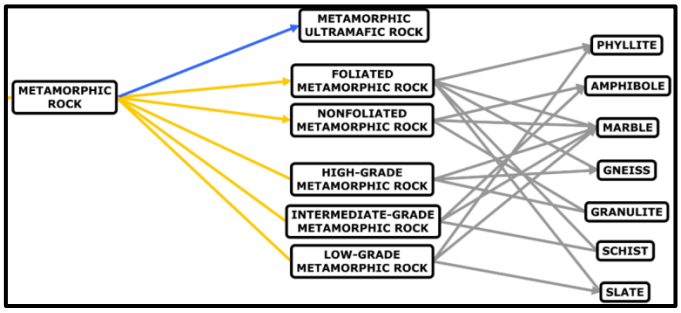


FIG. 7 – *Detail of the METAMORPHIC ROCK hierarchy.*

It is also worth noting that in all hierarchies, intermediate levels are represented by concepts designated by multiword terms, whereas the most specific level is mostly represented by single-word terms that would correspond with the basic level of categorization in sense of Rosch (1978). Up to the basic level, all previous nodes reveal the nature and status of the different parameters underlying specialized categorization.

4. Conclusion and future work

In this paper we have explored the specification of hyponymy subtypes based on the conceptual networks in EcoLexicon and corpus data. Our analysis showed how a semi-automatic corpus-driven analysis can provide a faster population and restructuring of conceptual networks. After this process was carried out and the concept hierarchies extended, it was found that hyponymy subtypes were usually activated based on hierarchical levels and concept nature.

In future work, we plan to verify the existence of hyponymy subtypes in other fields of knowledge. Further research will also involve the validation of the enhanced conceptual systems by domain experts. Finally, the sketch grammars will also be refined and expanded so as to offer more accurate results in the queries.

Acknowledgements

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Annex 1

Extended tree-like network of ROCK with hyponymy subtypes: