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Ontological Representation of Electrical Geophysical Methods

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Abstract

Geophysical methods are tools that apply principles of the geophysical sciences to obtain data from the earth surface. From the literature, these methods are rarely formalised. Due to the large datasets peculiar to geosciences in data interpretation, ontologies have been found to be a better means of representing knowledge in the field. Hence, this research work builds an ontology that formalises electrical geophysical methods. The domain concepts were gathered through knowledge elicitation. Facts, rules and relationships between the various concepts of electrical geophysical methods were formalised using description logic (DL). Protégé 5.0, an ontology editor was used to implement the system and competency questions in form of simple queries were used to test the efficiency of the ontology. The competency question "Which electrical method is naturally generated?" with the axiom: $SPM \equiv ElectricalMethod \sqcap \exists Occurence.Natural \sqcap \exists measures.BackgroundPotential$ produces the result "Self-potential method" as the main class and "Electrical method" as its super class. This ontology can be used as a training tool for geophysicists and as a shared representation for researchers in the field.

Keywords - Geophysical methods, Electrical methods, Ontology, Description logic

I. INTRODUCTION

Knowledge representation and reasoning, as a branch of artificial intelligence, helps to understand the nature of intelligence and cognition so well that computers can be made to exhibit human-like abilities [1]. It is the field of study that is concerned with using formal symbols to represent a collection of propositions believed by some putative agents [2]. Ontologies help to represent knowledge in a formal way.

Ontology can be defined as the conceptualization of a domain. It is a structure of concepts and entities within a domain organized by relationship. It is widely recognized as the best means to share domain knowledge in a formal way. It formally represents knowledge in a way software can process the knowledge and reason about it [3, 4, 5]. This implies that the representation they provide has to be agreed upon by all their users, so that ontologies can act as reference models across groups of people, communities, institutions, and applications.

There is amplified increased uptake of ontologies in several contexts and disciplines such as biomedicine, life sciences, electronic commerce, cultural heritage and enterprise applications among others [6]. Formal ontologies are built using a classic logic as means of formalization of the specified field of interest. They have been used in formalising all kind of geosciences that deal with a lot of data and concept definitions.

Geophysical tools are tools that apply principles of the geophysical sciences to obtain data from the earth surface. Geophysics is a discipline that applies principles of physics to obtain data from vertical and lateral variation of the subsurface properties distribution [7]. Geophysical tools are of various kinds. They are majorly classified by the physical properties such tool measures. There are generally, six major geophysical techniques: Seismic, Gravity, Magnetic, Electrical (and electromagnetic), Radiometrics and Well-logging [8].

Each technique has an operative physical property to which it is sensitive. This work

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focuses on the electrical method which is sub-divided by the parameter each sub-method measures:

i. The induced polarisation method measures electrical charges.
ii. The resistivity method measures resistance (resistivity).
iii. The self-potential method measures background potential and
iv. The electromagnetic method measures capacitance.

Each division is classified by how the parameter is measured. Induced polarisation, electromagnetic and self-potential methods are sub-divided by how the parameter is measured. Only resistivity method has no sub-division by the means of parameter measurement. The induced polarisation and the electromagnetic methods are either measured in the time domain or frequency domain. The self-potential can be measured either by the electrochemical or electrokinetic process. The instrument that measures resistance is potentiometer but such instrument cannot be used alone. Other instruments used alongside with the main instruments are also considered and this includes field procedures and electronic configurations.

Most data used in this field are large and consistently changing both in quality and quantity. Ontologies are more suited to be updated than databases. Databases are difficult to restructure if new dataset or knowledge is discovered. Due to the large datasets peculiar to geosciences in data interpretation, ontologies have been found to be a better means of representing knowledge in this field. The vastness of the field of geophysics also makes ontology to be a learning tool for geophysicists because formalised knowledge can easily be referred to if available. Hence, this research work builds an ontology that formalises electrical geophysical methods which enhances better interpretation of domain concepts, interoperability and minimizes information overload.

II. Literature Review

Semantics-Enabled Framework for Knowledge Discovery From Earth Observation Data Archives: The authors of this work employed an unsupervised segmentation algorithm to extract homogeneous regions and calculate primitive descriptors for each region based on colour, texture, and shape. An unsupervised classification by means of a kernel principal components analysis method, which extracts components of features that are nonlinearly related to the input variables, followed by a support vector machine classification to generate models for the object classes was said to have been initially performed. The assignment of concepts in the ontology to the objects is achieved automatically by the integration of a description logics-based inference mechanism, which processes the interrelationships between the properties held in the specific concepts of the domain ontology. The framework is exercised in a coastal zone domain [9].

Ontology based Automatic ETL for Marine Geoscientific Data: The authors built the GeoDI ETL (Extract, Transform and Load tool for Geological and Geophysical Data Integration) system that uses ontologies as a way to represent data structure and semantics. It is based on an extensible multi-strategy learning approach wherein different matchers (learners) are trained separately to match new schemas to the integrated database schema. Databases were created using ontologies as the backend [10].

Two use cases involving Semantic Web Earth Science Ontologies for reservoir modelling and characterization: The authors introduced two use cases considered within the e-Wok Hub project, which respectively concerns documentary search and subsurface modelling. They described a knowledge-driven methodology based on semantic annotation that can be used in both cases, explicitly explaining the ontology based solutions that were studied for operating this methodology [11].

Gahegan et al (2006) described a means to represent a wide variety of interactions between resources using the notion of a knowledge nexus, and illustrated its use with resources and actors from the GEON cyber infrastructure community. The authors closely linked browsing and visualizing strategies to the nexus, drawing on ideas from semiotics to move resources and connections not currently of interest from the foreground to the background, and vice versa, using a new form of adaptive perspective. They illustrated their ideas via ConceptVista, an open-source concept mapping application that provides rich, visual depictions of the resources, cyber-community and myriad connections between them. The project deploys how maps, contour lines and other spatial elements could be represented using an ontology [12].

III. Methodology

Figure 1 shows the system flow for the design of the ontology for electrical geophysical methods; from the knowledge elicitation process in the domain field through the requirements, the development and validation of the ontology and the reasoning process.

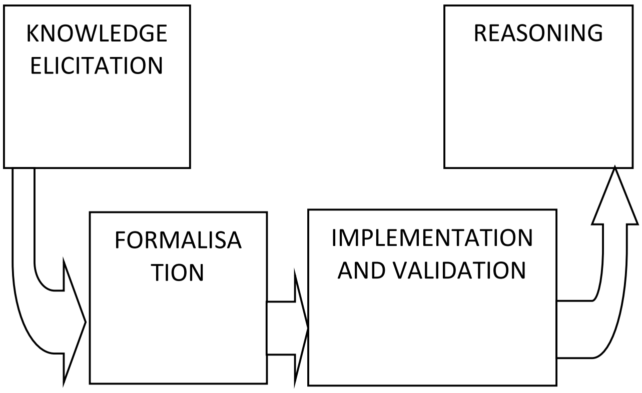

Figure 1: The System Flow for Ontology of Electrical Methods

The ontology elicits knowledge from the domain of electrical methods. The elicited knowledge is formalised using description logic (DL). DL represents the knowledge as facts, rules and relations. It shows the relationship between the identified concepts and the object properties. The system was implemented using protégé, which is an ontology editor. The validation involves the use of a reasoner to examine the correctness of the logic formalisation.

A. Domain Concepts

The major concepts identified to formalise electrical geophysical methods are listed below.

1. Applications: They are cases where a particular geophysical method is most appropriate to be used in geo-scientific findings. They could include the following:
    a. hydrocarbon exploration,
    b. regional geological studies,
    c. exploration or development of mineral deposits
    d. engineering site investigations,
    e. hydrogeological investigations,
    f. detection of sub-surface cavities
    g. Mapping of leachate and containment plumes
    h. Location and definition of buried metallic objects
    i. Archaeogeophysics
    j. Forensic geophysics
2. Calculated Parameters: They are parameters that are derived (by mathematical calculation) from other parameters that might have been derived or measured from the field of interest.
3. Data Acquisition Procedure: This is a series of steps taken by the geophysicist(s) to acquire some values to make inference to the geophysical method(s) that may be applicable in such an instance.
4. Electronic Configuration: This is the method of setting electrodes in an already predetermined arrangement to measure electrical vertical and/or horizontal diversion to measure conductivity/resistivity in the earth surface. It has three sub-classes.
5. Geophysical methods: Geophysical method of subsurface investigation provides a relatively rapid and cost effective means of deriving large area information coverage of subsurface geology. It has six sub-classes.
6. Measured Parameters: They are parameters that quantify the operative physical property.
7. Occurrence: This is the classification of geophysical methods into the way its operative physical property is propagated either naturally or artificially. It has two sub classes.
8. Operative Physical Property: It is the physical property that a particular method operates with.

B. Domain Classes

The domain classes and subclasses used in this ontology are shown in Figure 2. They are CalculatedParameter, DataAquisitionProcedure, ElectronicConfiguration (with subclass Dipole-Dipole) and Occurrence among others.

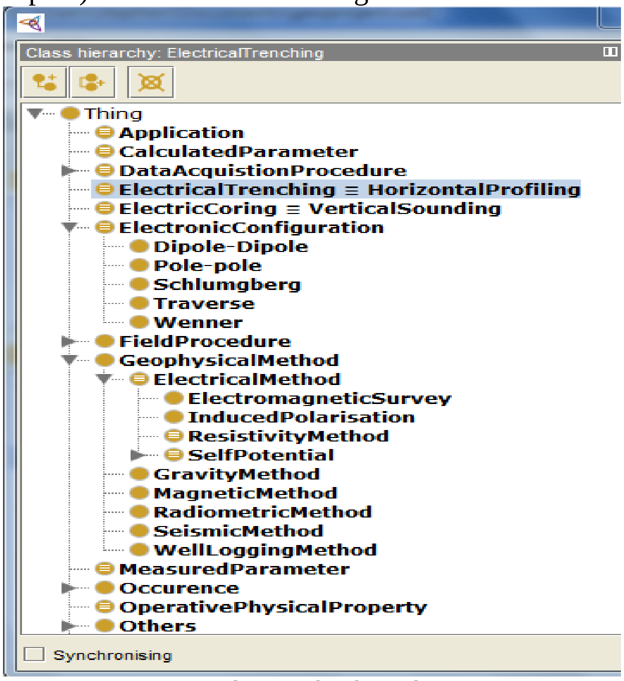

Figure 2: Classes in their hierarchy

C. Object Properties of the domain

The object properties are affects, anomaliesOf, belongs, calculatedFrom, closelySpaced, conductivityOf and dependsOn among others. This is shown in Figure 3. Object properties are also called roles. They represent functions and relationships of the classes (concepts). They can be represented as binary relations between two classes.

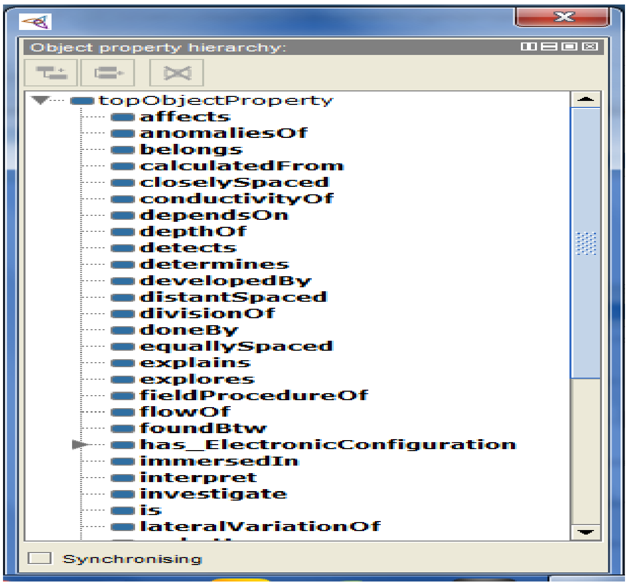

Figure 3: Object properties

D. Data Properties of the domain

Some of the data properties used are havingConc, measureIn, resistivity and sign among others. This is shown in Figure 4. They are object properties that can take in data types. They relate individuals to literal data. They are properties that give the ontology the resemblance of a database.

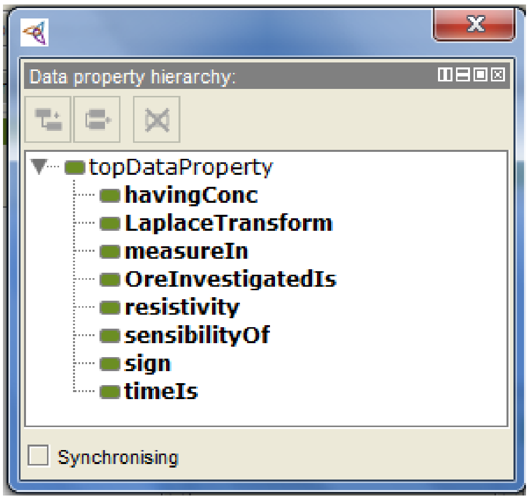

Figure 4: Data properties

E. Formalisation with Description Logic

This section gives the description logic of the various definitions, rules and relationships between the concepts of the ontology.

1. Geophysical Methods

Axiom 1:

The geophysical methods are classified into six sub-methods namely: Magnetic, electrical, seismic, gravity, radiometric and well-logging methods.

$$ElectricalMethod \sqcup Magnetic \sqcup Seismic \sqcup Gravity \sqcup Radiometric \sqcup Well-logging \subseteq GeophysicalMethod$$

2. Electrical Methods

Axiom 2:

Electrical method is a geophysical method where flow of current determines the operative physical property.

$$ElectricalMethod \equiv GeophysicalMethod \sqcap uses.ElectricCurrent$$

Axiom 3:

Electromagnetic, induced Polarization, resistivity and self-potential methods are approaches under the electrical method.

$$EM \sqcup IP \sqcup ResistivityMethod \sqcup SPM \sqsubseteq ElectricalMethod$$

3. Self-Potential

Axiom 4:

Self-potential method is an electrical method that occurs naturally which uses background potential created by bioelectric activity in the earth crust.

$$SPM \equiv ElectricalMethod \sqcap \exists Occurence.Natural \sqcap \exists measures.BackgroundPotential$$

Axiom 5:
Electrochemical process is used to generate self-potential

$$ElectrochemMtd \equiv SPM \sqcap \exists uses.ElectrochemProcess$$

Axiom 6:
Electrokinetic process is used to generate self potential

$$ElectrokineticMtd \equiv SPM \sqcap \exists uses.ElectrokineticProcess$$

Axiom 7:
Mineral self-potential method is one where the time taken is constant

$$Mineral \equiv SPM \sqcap timeIs.constant$$

Axiom 8:
Self-potential is measured in millivolt and the sign of its values determines the anomalies of the potential

$$SPM \equiv measuredIn.milliVolt \sqcap \exists sign.Value \sqcap determines(anomaliesOf.Potential)$$

Axiom 9:
The applicable field procedure for self-potential method is traverse

$$FieldProcedure \sqcap use.SPM \equiv TraverseLayout$$

Axiom 10:
The electronic configuration used is either gradient array or total fixed based array

$$ElectronicConfiguration \sqcap use.SPM \equiv (DipoleArray \sqcup TFBasedArray)$$

Axiom 11:
The electrodes are mostly inserted in its own salt.

Axiom 12:
Galvanic Cell Theory, pH Theory and Sato & Mooney Theory are propounded to explain the existence of self-potential

$$(GalvanicCellTheory \sqcup pHTheory \sqcup SatoMooneyTheory) \equiv Theory \sqcap explains.SelfPotential$$

Axiom 13:
Background potential is formed by the processes of electrofiltration, electrokinetic effect, geothermal gradient, pressure gradient and bioelectric effect.

$$BackgroundPotential \equiv Potential \sqcap developedby(Electrofiltration \sqcup ElectrokineticEffect \sqcup GeothermalGradient \sqcup PressureGradient \sqcup BioelectricEffect)$$

Axiom 14:
Diffusion potential is one that is dependent on mobility of electrolytes and having different concentration within groundwork.

$$Diffusion \equiv SelfPotential \sqcap dependsOn.(mobilityOf.Electrolyte) \sqcap havingConc.GroundWater$$

Axiom 15:
The time factor for electrokinetic and electrochemical is variable

$$Electrokinetic \equiv SelfPotential \sqcap timeIs.variable$$

$$Electrochemical \equiv SelfPotential \sqcap timeIs.variable$$

Axiom 16:
Diffusion and Nernst potentials are subset of electrochemical potential.

$$Diffusion \sqsubseteq ElectrochemicalPotential$$

$$Nernst \sqsubseteq ElectrochemicalPotential$$

Axiom 17:
Electrofiltration, electromechanical and streaming potential are other names for electrokinetic.

$$Electrokinetic \equiv electrofiltration \sqcup electromechanical \sqcup streaming$$

Axiom 18:
Nernst potential is one measured such that two electrodes are immersed in a homogenous solution.

$$Nernst \equiv SelfPotential \sqcap Electrode = 2 \sqcap immersedIn.HomogenousSolution$$

Axiom 19:
Anomalies of self-potential are interpreted by profile shape, amplitude, polarity and Contour patterns.

$$SPElectrode \equiv Electrode \sqcap immersedIn.Salt$$

$$anomaliesOf.Potential \equiv Anomalies \sqcap interpret(ProfileShape \sqcup Amplitude \sqcup Polarity \sqcup ContourPattern)$$

4. Resistivity

Axiom 20:
Resistivity method is an electrical method that uses uniquely arranged electrodes to determine resistivity of the earth subsurface.

$$ResistivityMethod \equiv .ElectricalMethod \sqcap \exists useUniquelyArranged.Electrode \sqcap measures.Resistivity$$

Axiom 21:
Vertical electrical sounding and horizontal electrical profiling are field procedures of resistivity method.

$$VerticalSounding \sqcap HorizontalProfiling \equiv fieldProcedureOf.ResistivityMethod$$

Axiom 22:
Vertical sounding measures the resistivity earth subsurface with depth around a particular point.
$VerticalSounding \equiv FieldProcedure \sqcap measures(depthOf.EarthSurface) \sqcap measures.Resistivity$

Axiom 23:
Horizontal profiling measures lateral variation in resistivity of the earth sub-surface.
$HorizontalProfiling \equiv FieldProcedure \sqcap measures(lateralVariationOf.EarthSurface) \sqcap measures.Resistivity$

Axiom 24:
The factors that affect resistivity are electron movement, water content, free ion content, temperature and permeability
$Factors \sqcap \exists affect.Resistivity \equiv ElectronMovement \sqcup WaterContent \sqcup FreeIonContent \sqcup Temperature \sqcup Permeability.$

Axiom 25:
Wenner configuration consists of equally spaced electrodes.
$Wenner \equiv ElectronicConfiguration \sqcap equallySpaced.Electrode$

Axiom 26:
Schlumberger configuration consists of closely spaced electrodes.
$Schlumberger \equiv ElectronicConfiguration \sqcap closelySpaced.Electrode$

5. Electromagnetic Survey

Axiom 27:
Time domain and frequency domain are sub divisions of electromagnetic method
$TimeDomain \sqcup FreqDomain \subseteq ElectromagneticMethod$

Axiom 28:
The electromagnetic field power source can be VLF transmitter power, Long wire power, Square loop power or Circular loop power.
$EMPowerSource \equiv VLFPower \sqcup LWPower \sqcup SLPower \sqcup CLpower$

6. Induced Polarisation

Axiom 29:
Induced polarisation is the method that measures the electric charges induced as a result of the flow of electric current.
$IP \equiv ElectricalMethod \sqcap measures.ElectricCharges$

Axiom 30:
Time domain measurement could be in IP percent, decay-time integral or chargeability
$TDomain \equiv IP \sqcap measuredIn(IPprecent \sqcup DTintegral \sqcup Chargeability)$

Axiom 31:
Frequency domain measurement could be in frequency effect or metal factor.
$FDomain \equiv IP \sqcap measuredIn(FrequencyEffect \sqcup metalFactor)$

F. Competency Questions

Competency questions play important role in the ontology development process. They represent the ontology's requirements. Competency questions help to validate the ontology. Examples of competency questions used in this ontology are:

1. Define electrical geophysical method
2. Which self-potential sub method has constant time?
3. Which electrical method is naturally generated?
4. Which sub-method depends on the concentration of the electrolyte used?
5. Which electrochemical method has its electrodes immersed in electrolytes?

These competency questions are fed in through the DL query tab. Translating from description logic axiom to a "near to English" logic language used by DL Query tab of the protégé application is necessary to ask the competency questions.

IV. Results and Discussions

OwlViz and Ontograph are two different tools represented as tabs on the protégé platform. They are visualization tools used to view the ontology. They show the interrelationship and hierarchy of concepts. The OwlViz diagram gives the relationship with the binary relation "is-a" in the class-subclass relationship. The DL Query is the means of information retrieval from the ontology by means of structured description logic acceptable to the protégé platform. It provides a feature for searching the classified ontology. Its search includes the direct super classes, other super classes, equivalent classes, direct subclasses, subclasses and instances of the search.

Two reasoners used in this work are HermiT and Racer. HermiT 1.8.3 reasoner was used to test the consistency of each axiom in the ontology while it was being built. It is inbuilt into the protégé application and has to be started and synchronised to function in line with the ontology after every change in the state of the ontology. Racer 2.0 reasoner is used to test the final output of the ontology development process. It classifies the axioms of the ontology into T-box and A-box.

A. Result for what constitutes electrical geophysical method:

Figure 5 shows the subclasses of the electrical method in which itself is a subclass of the geophysical method. Only self_potential has other sub-methods of its own.

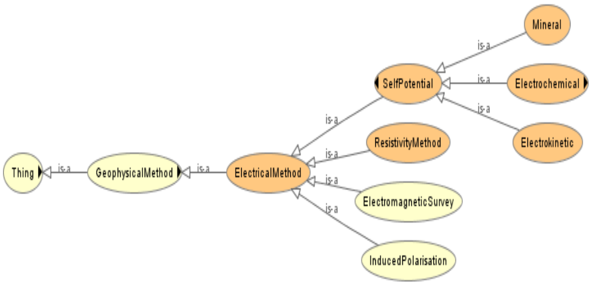

Figure 5: OWLViz chart for Electrical Geophysical Method

B. Results of the Competency Question 1:

The result of the first competency question "Define electrical geophysical method" whose axiom is represented in Axiom 2 is shown in figure 6.

Axiom 2: $ElectricalMethod \equiv GeophysicalMethod \sqcap uses.ElectricCurrent$

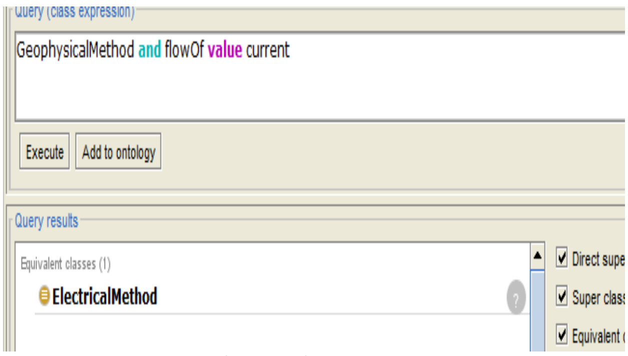

Figure 6: Definition of Electrical Method

C. Result of the Competency Question 2:

The result of the second competency question "Which self-potential sub method has constant time?" whose axiom is shown in Axiom 7 is shown in figure 7.

Axiom7: $Mineral \equiv SPM \sqcap timeIs.constant$

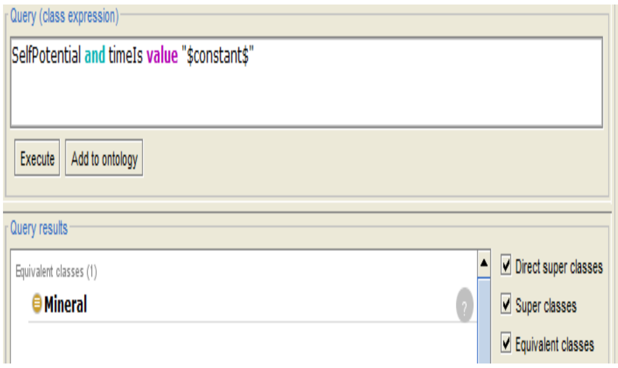

Figure 7: Self-Potential Sub Method with Constant Time

D. Result of the Competency Question 3:

The result of the third competency question "Which electrical method is naturally generated?" is shown in figure 8. Axiom 4 is used to generate the question.

Axiom 4:

$$SPM \equiv ElectricalMethod \sqcap \exists Occurence.Natural \sqcap \exists measures.BackgroundPotential$$

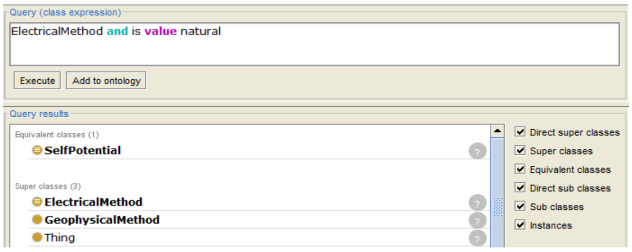

Figure 8: Naturally Generated Electrical Method

E. Result of the Competency Question 4:

The result for the fourth competency question "Which sub-method depends on the concentration of the electrolyte used?" is shown in Figure 9. Axiom 14 is used to generate the query.

Axiom 14: $Diffusion \equiv SelfPotential \sqcap dependsOn.(mobilityOf.Electrolyte) \sqcap havingConc.GroundWater$

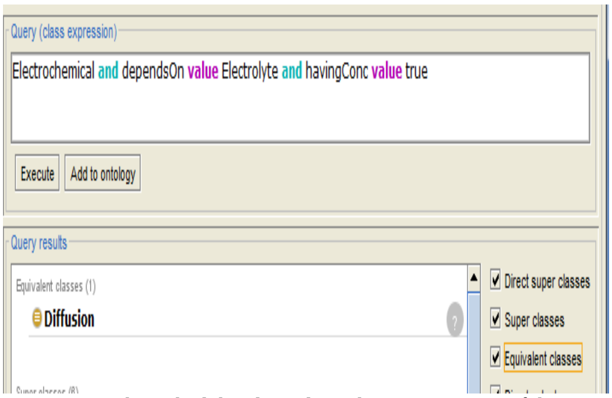

Figure 9: Sub-method that depends on the Concentration of the Electrolyte Used

F. Result of the Competency Question 5:

The result for the fourth competency question "Which electrochemical method has its electrodes immersed in electrolytes" is shown in Figure 10. Axiom 18 is used to generate the query.

Axiom 18:

$$Nernst \equiv SelfPotential \sqcap Electrode = 2 \sqcap immersedIn.HomogenousSolution$$

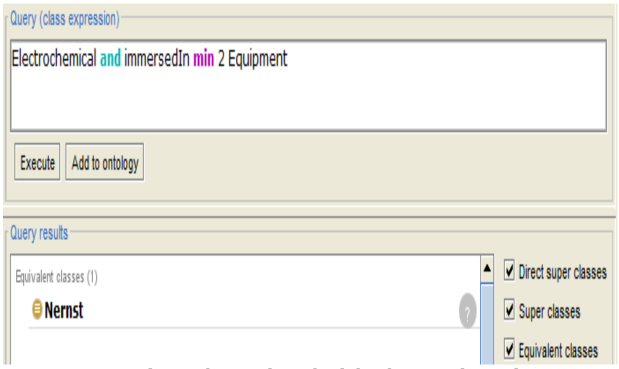

Figure 10: Electrochemical Method that has its Electrodes Immersed in Electrolytes?

V CONCLUSION

Geo-scientific (which is made up of basically geology and geophysics) data interpretation are more knowledge-driven than data-driven. Representing such data as ontologies helps easier interpretation and interoperability. The ontology developed in this study can be used for the training of geophysicists. It can also be a building block for other ontologies representing other geophysical methods other than the electrical method. It can even be used to further represent the electrical method as more knowledge and application of the method is elicited.

VI ACKNOWLEDGEMENT

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