

Ontology of Volcano System and Volcanic Hazards Assessment

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Abstract

Volcanic hazards are source dangers that caused by volcanic phenomena. Assessment of volcanic hazards require integrated access to the many sources of geoscientific data, consisting of current information phenomena and the knowledge or experience gained from similar situations in the past. Understanding of volcanic systems which involves its structure, geochemistry, dynamics, environment, and the process of volcano formation is vital to reveal information about how the volcano works and to forecast its behaviour in the future. Ontology engineering can be deployed as technology to capture and represent this domain knowledge. This paper presents volcano system and volcanic hazards assessment ontology as conceptual modelling and knowledge base for volcanic hazards management. Volcano system and volcanic hazards assessment ontology will provide a precise representation and semantic information of volcanic system and volcanic hazards domain knowledge. The ontology helps to understand the holistic and comprehensive of volcano hazard management data.

1. Introduction

Volcanic hazards are the several kinds of event caused by volcanic phenomena that can be potentially dangerous and harmful to life and property. Volcanic hazards investigations, involving a volume of heterogeneous data, consist of the current information phenomena and the knowledge or experience gained from similar situations in the past. Understanding of volcanic system which involved its structure, geochemistry, dynamics, environment, and the process of volcano formation is vital to reveal information about how the volcano works and to forecast its behavior in the future. Studying history of previous volcanic phenomena is critical step to mitigate future volcanic hazards, also identify the area and its contents that could be affected. Volcano hazards management includes all activities, programs and measures which can be taken up before, during and after volcano hazards realized with the purpose to minimize the impact of volcano hazards on people, socio-economic, activity and environment. Starting to discover, characterize and model the dynamic relationships between volcanic phenomena, trigger factors, and the affect; risk identification, measurement, and mapping; design and perform risk management and planning in multi-risk scenarios; and up to recover the volcanic hazards impact and losses. The purpose of this research is developing of volcano system and volcanic hazard assessment ontology as a

conceptual model and knowledge base, for volcanic hazard management. Ontology engineering is used as one of the technology for volcanic hazards management development since it provides information and knowledge more integral and comprehensive. Ontology engineering provides a process to identify the real world domains, capture, extract, structure, and make reusable information in the domain knowledge. Ontology is developed in order to identify and associate the semantically corresponding concepts. Gruber (1993) coined the definition of ontology as "An explicit specification of a conceptualization". Studer et al., (1998) identified four main concepts from ontology definition: formal, explicit, shared, and conceptualization. Formal implies ontology should be read and processed by machines. Explicit indicates that all concepts and constraints used are clearly defined. Shared means that ontology should capture consensual knowledge accepted by the communities. Conceptualization refers to an abstract model of phenomena in the real world (a piece of reality) by identifying the relevant concepts of those phenomena, as well as the relationships existing among them. Ontology is intended to be rigorous representations of broadly applicable domain knowledge shared by a community (Gruber, 1993 and Guarino, 1995), in this case volcanic system scientists. Many scientists have conducted research

on volcanic systems, in some views and disciplines. Each scientist may only make observations on the small scope of the volcano system domain, but they can participate in developing and sharing knowledge in this domain since they have same concept of common terms (knowledge) in the domain. Many scientists suggest applying ontology to represent the conceptual model of specific knowledge domain, make formal conceptualization, develop knowledge base, also provide semantic connectivity and resolve semantic interoperability in the work.

2. Ontology Representation

Ontology is used to represent the domain knowledge. Ontology will establish concepts, define relation between concepts and also establish the constraints on the relationships (Noy, and McGuinness, 2001). Ontology also describes the structure of concepts to determine the position of the concept related to the other concept. Notation or graphical representation is used in the conceptualization step in the ontology development process. Some diagrams are implemented in this step, such as Entity Relational (ER) diagram, Unified Modeling Language (UML) diagram (Cranefield and Purvis, 1999), LINGO (Falbo et al., 1998), and others. This research uses UML for ontology representation. UML provides special notations to represent the concept, relation, and the constraint. A concept is an abstract object. A concept represents an entity, action, or state (Sowa, 1999). As shown in the Figure 1, a concept has intension and extension. Intension refers to essential meaning and properties of the concept. Reasoning about intension depends on logic, not just on observations. A general concept can have subtypes or subclasses. Subclass inherits the intension of the general concept and has additional specific

properties. Extension refers to the group of real objects which provides the typical example of concept. A group of elements which together form the members of a concept's extension is referred to class. Class has three sections including class name, attributes and function or operation. An occurrence is an individual element that can be placed in class. The determination of the occurrences as the member of extension of a concept is done through a process called classification. The classification mechanism is based on the intension or properties of concept, for example its attributes, functions, and constraints, which leads to determine whether an occurrence belongs to a concept or not (Brodaric and Gahegan, 2002). Classification is divided to composition and generalization. Composition indicates a "part of" relationship. It refers to relate between two classes where one class is a part of another. Composition is denoted by a hollow diamond. Generalization is another name for inheritance or an "is a" relationship. It refers to relate between two classes where one class is a specialized version of another. Generalization is represented by a hollow triangle. Instances represent concrete information specified that often relate to real world objects as an instance of one or several class, whereas relation is binary relation on classes or instances. For examples shown in the Figure 1, Classification is a relation between Class and Occurrence, Instantiation is relation between Class and Instance, and Extension or Intension is relation between Concept and Class. Constraints on the relationships is applied to restrict on domain, by giving the minimum, maximum, or exact a specified number of instances in concept which can participate in the relation, namely cardinality.

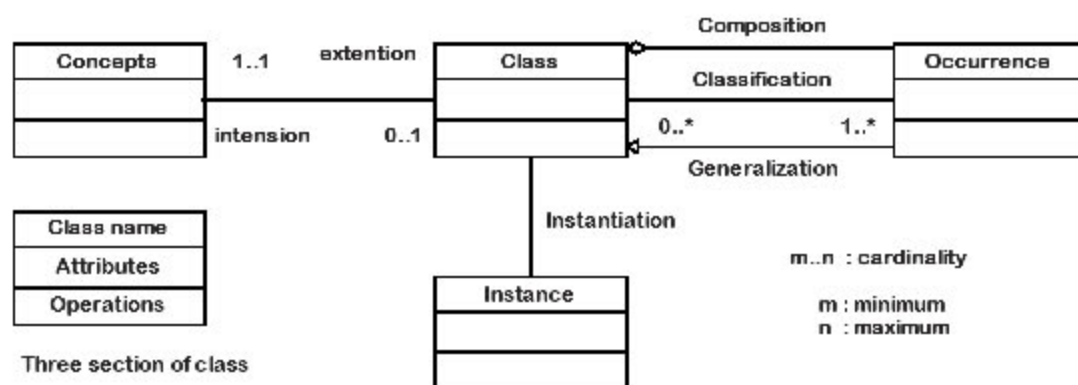


Figure 1: Ontology representation with UML

3. Related Works

Some geoscientists have published ontology in geoscience or earth science domain, whether in the upper ontology and domain ontology. Upper ontology describes very general concepts, whereas domain ontology covers specific domain knowledge. Several examples of upper ontology are Semantic Web for Earth and Environmental Terminology (SWEET) (Raskin, 2006), which covers knowledge of earth system sciences; The North American Geologic Map Data Model (NADM) (North American Geologic Map Data Model Steering Committee, 2004) which provides description, classification and interpretation of geological map features such as Geology Unit, Geology Structure, Earth Materials, Geologic Processes, and Geologic Properties; Geoscience concept models (Richard, 2006) which is an extension of NADM by adding important details and also separation between the geoscience knowledge representation and the geologic map knowledge representation. The domain ontologies that have been developed are Geology Structure Ontology (Babaic et al., 2006), Gravity Ontology (Gates et al., 2007), Igneous Rock Ontology (Sinha et al., 2006), Geology Fractures Ontology (Zhong et al., 2009), Volcanoes Ontology (Fox et al., 2007), and Volcano-Domain Ontology (Pulido, 2009). The two previously mentioned ontologies have the same theme with this paper, i.e. volcano ontology. Volcanoes Ontology (Fox et al., 2007) also discusses on volcanic hazards, but only their effects on atmospheric conditions and its relation to the production of tectonic plate activity. This ontology has three upper level concepts, including volcanic systems, phenomena, and climate, but each concept in the ontology has not yet been represented in detail, and the relation between the concepts have less description in the factual conditions. Volcano Domain Ontology (Pulido, 2009) applies the Self-Organizing Maps (SOM) algorithm to generate clusters of volcanic activity and identify families of important events especially in volcanic seismic activity. The result is classification of the concepts (classes) of seismic event in volcanic seismic activity. Some applications of domain ontology have been implemented in various disciplinary sciences, such as geoscience, biology, medical, and informatics. The application of ontology is described in the following implementations: (1) representation of earthquake source ontology for seismic hazard analysis and ground motion simulation (Zecher et al., 2005); (2) development of GEON (Geoscience Network) including geoscience data modeling and integration, grid system development and visualization via

domain ontologies (Ludäscher et al., 2003); (3) implementation of ontology that automatically captures and integrates detailed knowledge on the cell cycle process by semantic web technologies, and is accessible via the web for browsing, visualizing, advanced querying, and computational reasoning, in addition Cell Cycle Ontology facilitates a detailed analysis of cell cycle-related molecular network components (Antezana et al., 2009); (4) ontology technology for wetland protection domains, and provides a potential alternative tool to the current mainstream methods in knowledge management and information sharing (Jun et al., 2009); (5) ontology for sharing medical images such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), and Magnetoencephalography (MEG) in neuroimaging to explore brain structure and function (Temal et al., 2008).

4. Volcano System Ontology

Volcano features an open form of the earth's surface where magma, gases and the other materials can escape from underneath because of the influence of geological processes, especially volcanism process. Volcanism is various processes and phenomena associated with the discharge of volcanic material like molten rock (magma), pyroclastic fragments, hot water and steam from underneath of volcano into surface of volcano or still beneath the volcano. If the volcanic material reach surface of volcano, volcanic eruption is happen. Volcanic eruption can be accompanied by other phenomena, including earthquakes, debris flow, acid rain, fire, ground deformation, tsunami, air shocks, poisonous gas, and glacial outburst flooding, that is furthermore mentioned as volcanic phenomena. Because of the phenomena potentially take casualties and destroying property in the surrounding area then this phenomenon is called volcanic hazard. Development of volcanic hazard assessment and management requires an understanding of volcano system concept: starting from the theory about the formation of volcanoes; continue with volcanic characteristics based on form and the material composition; the volcanic activities including the trigger factors; the conditions and processes during pre-eruption, syn-eruption, and post-eruption; various product materials from eruptions, and the impact and disasters caused due to volcano activity. Regarding with the term of volcanic system, we propose the upper level volcano system ontology as shown in the Figure 2.

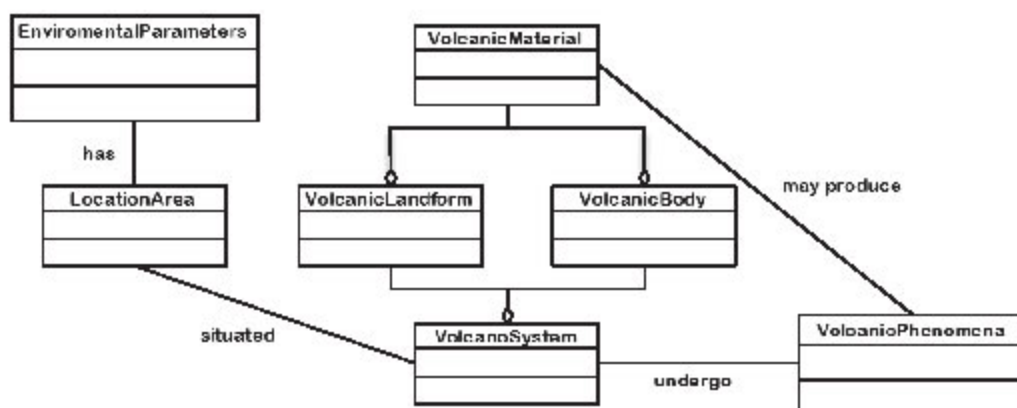


Figure 2: Volcano system ontology

Figure 2 describes that volcano is situated in specific locations and areas that have environmental parameters, including socio economic, geographic, meteorology, hydrologic system, biological environmental, geological setting, and tectonic settings. Volcano is composed of main section, namely volcanic body and the features that affect the volcanoes appearance on the surface, called volcanic landform. In the active period, the volcano system experiences a variety of phenomena as a sign of its activity. Some volcanic phenomena will produce the material as a product of volcanic activity. In the future, these materials will form landform and body of the volcano. Volcano body is composed of cones, magma plumbing, and crater. Generally, the shape of volcano is a cone, although there is also shaped a bit flat. Magma plumbing is a plumbing system consisting of many interconnected pipes or conduits that connect the magma chamber and the vent in the earth's surface. Vent is the place where magma, gases, and the other material escape into the earth's surface. Vent can be a hole or fissure. Magma chamber is a reservoir of molten rock material (magma) beneath the earth's surface, whereas magma conduit is vertical pipes for the passage of magma into the vent. Crater is a circular depression in the ground around the vent caused by volcanic activity (Schmincke, 2004). Volcanic landform is a volcano surface form and location in landscape including its features. Some volcanoes may have several volcanic features such as a lava dome, caldera, and other features. Volcanic landform is characterization of various types of constituent, which depends on the prior eruptive behavior of the volcano. Volcanic landforms have some physical characteristics such as elevation, slope, orientation, rock type, and soil type. The formation of volcanic landforms are influenced by the nature of the extruded materials, the distribution of vents and fissures, volume of outpourings, the duration of volcanism, the ages of volcanic activity

relative to the present and associated stratigraphic units, and the intensity and stage of subsequent erosion activity (Short, 1986). Behavior of volcano is dynamic, furthermore will lead to several volcanic phenomena. Volcanic phenomena can be categorized into three state concepts: pre-eruption, syn-eruption, and post-eruption, shown in Figure 3. The pre-eruption state is dominated by intensively internal processes in the magma and its effect. The magma processes are driven by internal heat sources. Internal heat sources could have occurred because of the radioactive decay, plate movement, plate subduction, or hot plume contact. The overall process is called volcanism and magma is a core of the volcanism process (Schmincke, 2004). The magma process can cause some effect like volcanic seismic, volcanic ground deformation, degassing, and thermal change around volcano surface area. Syn-eruption is a state during the eruption happen in which the materials from the volcano are expelled to the surface. Eruption state has characteristics involving intensity, frequency, distance, volcanic material types, eruption pattern and style, then can be differentiated into some eruption types. Eruption also can be estimated by volcanological properties like dense rock equivalent (DRE) and volcano explosivity index (VEI). Post-eruption is the state occurred after the eruption state. This state is an accumulation of the interaction between the material deposits released during the eruption with the environmental conditions in the volcano area. Debris flow, acid rain, fire, tsunami, air shocks, poisonous gas, glacial outburst flooding, and natural pollution are volcanic phenomena happen at the post-eruption. Volcanic material is the product from volcanic phenomena. Volcanic material can be categorized into two classes of solid and fluid as shown in Figure 4. The solid material usually is rock and primarily contains igneous rock as thrown and ejected rock or ash of various types and size.

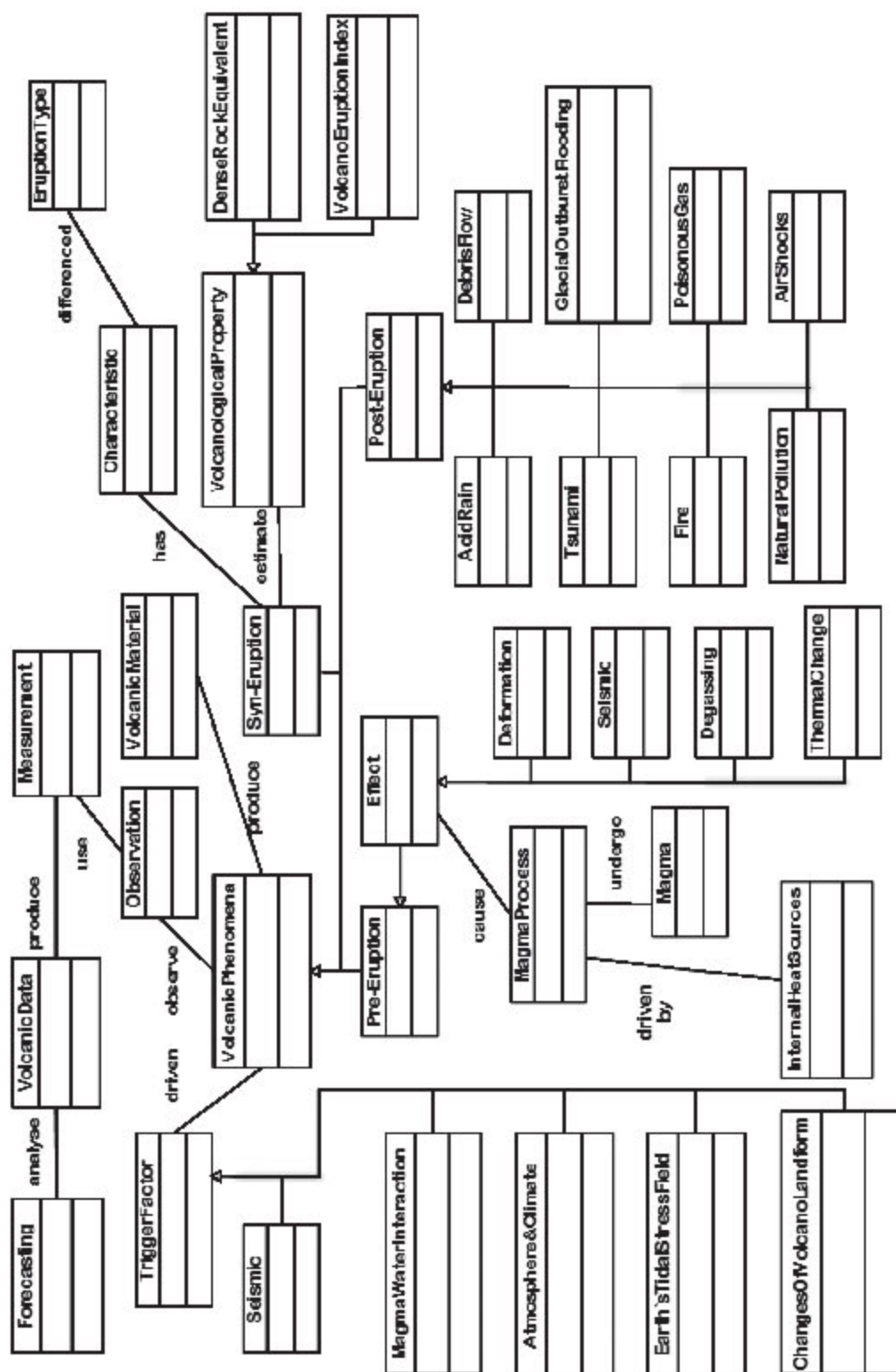


Figure 3: Volcanic phenomena ontology

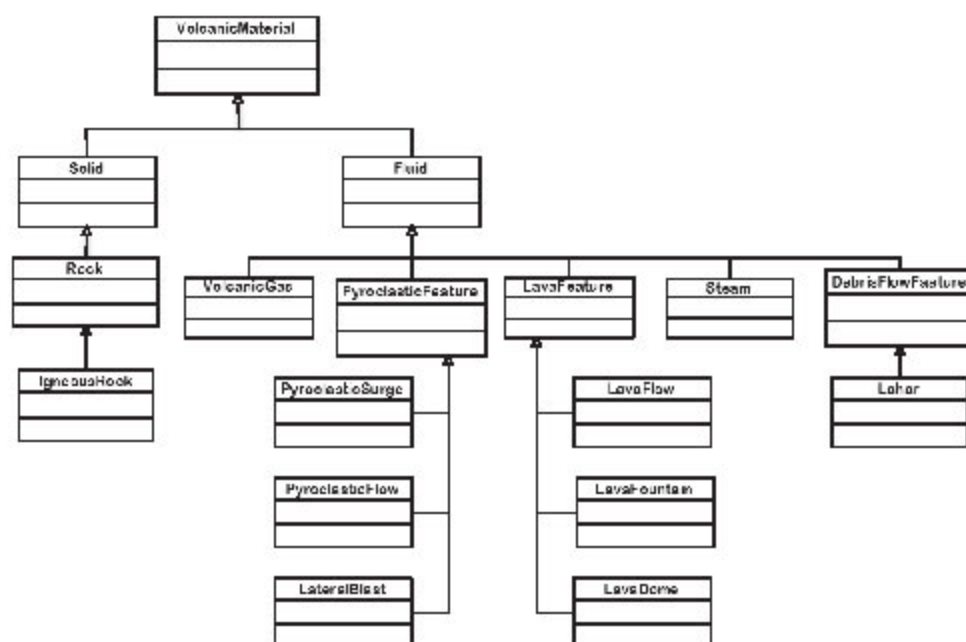


Figure 4: Volcanic material ontology

The fluid materials may be gases such as water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen chloride (HCl), and hydrogen fluoride (HF); pyroclastics flow, surges or lateral blast; volcanic debris flow; hot steam; and lava. Volcanic phenomena are observed by using measurements to get volcanic data. Some methods and techniques are used to analyze the volcanic data in order to be able to forecast the volcanic hazard in the future. Volcanic phenomena are driven by some trigger factors, including seismic, changes of volcanic landform, magma and water interaction, atmosphere and climate, and Earth's tidal stress field (Schmincke, 2004). Magma is molten rock that is found beneath the surface of the Earth. Magma is formed when the upper mantle of the earth melts because of the intensive pressure created by the internal heat source from the centre of the earth. Magma has multi-component and multi-phase mixtures constituted of silicate liquid, crystals and volatile components. The silicate liquid composition is represented by the major elements such as O, Si, Al, Fe, Mg, Ca, Na, K and the remaining minor elements (Rosi et al., 2005). Crystals come either from magma solidification or from surrounding rocks as xenocrystals. Volatiles can be in liquid or gaseous phase depending on whether the system pressure is below or above their saturation pressure. The main volatile components are H_2O and CO_2 , while the subordinate parts are H_2S , SO_2 , HCl , HF , CO , N_2 , H_2 and HBr . Figure 5 describes the magma ontology. Magma migrates upwards through the lithosphere because of the buoyancy and the

pressure of the gas that is dissolved in it. As magma rises, the pressure drops and the gas become less soluble. When the pressure drops low enough, volatile pressure reaches and exceed saturation, some of the gas will come out of solution, forming bubbles by the process called bubble nucleation. The bubbles cause a dramatic decrease in the density of the magma, causing it to rise buoyantly. As the magma rises further, the pressure drops and more gas comes out solution referred to as called as bubble growth. When the magma rise more rapidly, magma become more decompressed, increase of bubble growth and decrease of density, which drives the magma to the surface, where it erupts (Parfitt and Wilson, 2008). The upward acceleration and expansion of the magma gives rise to immense stresses within the magma. If the stresses are larger than the internal strength of the magma, it will cause the magma to disintegrate into the fragments such as ash or pumice (Dingwall, 2001). This fragmentation causes pyroclastics that determined characteristics of the eruption type. Crystallization of magma occurs when magma rises through the conduit. Crystals grow by decompression or decreasing the pressure. Liquid magma composition is changed and magma viscosity increases by increasing crystal content. Viscosity of magma affects the rate of magma movement and type of eruption. High viscosity magma has a low rate movement. Another process that occurs internally in magma is magmatic differentiation. Any process that causes magma composition to change is called magmatic differentiation (Nelson, 2003).

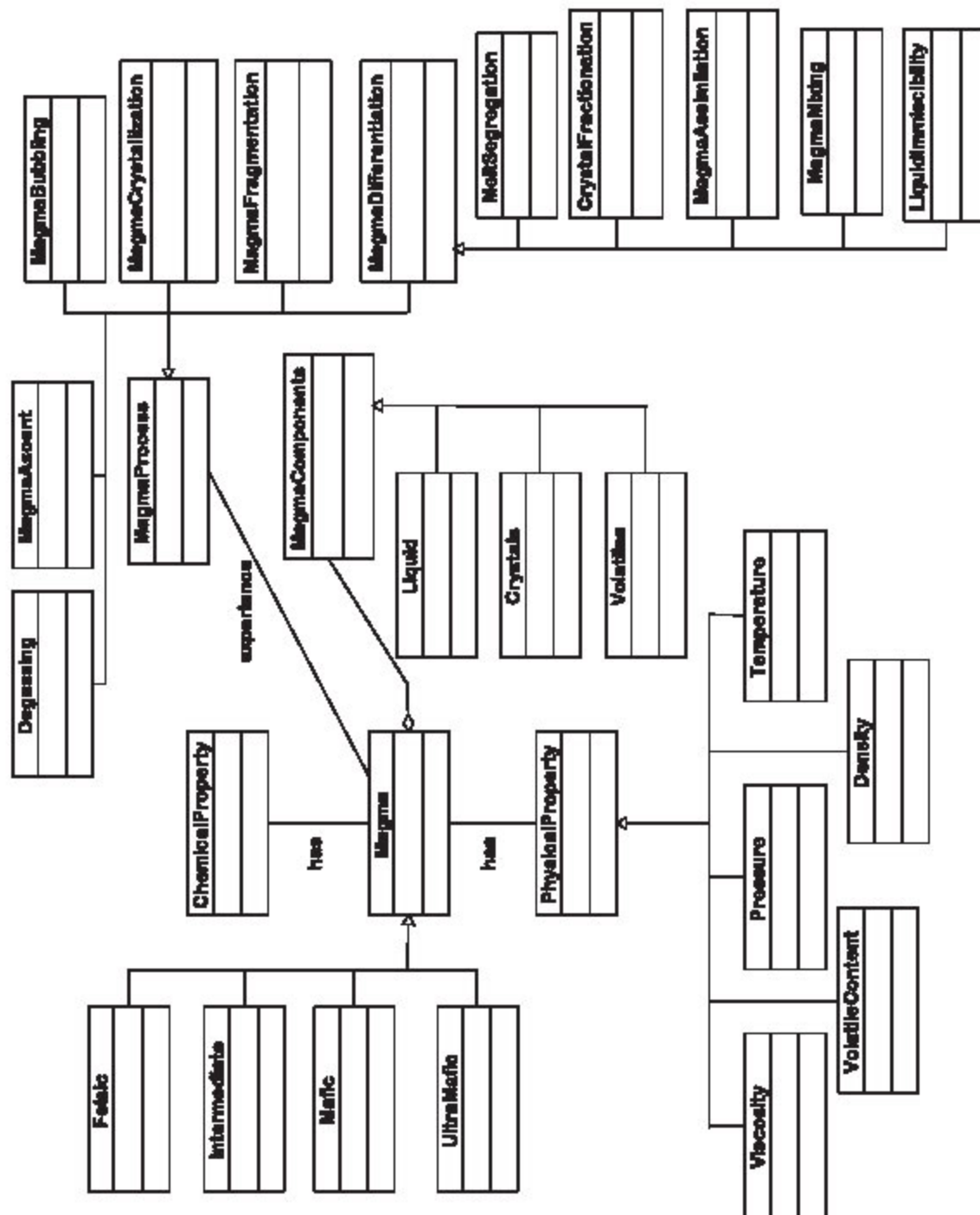


Figure 5: Magma ontology

Melt segregation, crystal fractionation, magma assimilation, magma mixing, and liquid immiscibility in the magma are processes that have been influential in explaining the variation of magma compositions. The processes affect the physical properties of magma which eventually determine the type of eruption (Dohran, 2001). Magma degassing is a term for describing the process of gas exsolution and segregation in the magma (Edmonds, 2008). Magma degassing is a fundamental control on eruption type and magma process. The magma ascent rate is sensitive to gas escape, as the volume proportion of gas affects density, magma compressibility and rheology, resulting in both horizontal and vertical pressure gradients in the magma column to allow gas escape. Magma permeabilities can be higher than wall-rock permeabilities, and so vertical gas loss can be an important escape path, in addition to gas loss through the conduit walls and trapped in soil layer surrounding the conduit. Changes in gas loss can make different types of eruption (Sparks, 2003). Changing rates of magma degassing, including gas composition and concentration released by magma is also used to indicate or as a precursor of an eruption event.

5. Volcanic Hazard Assessment Ontology

Volcanic hazard describes the physical characteristics of an eruption (Blong, 1996), but even when a volcano is not erupting, volcanic hazards such as debris flows or remobilized secondary lahars can still occur. Thus, the extent definition of volcanic hazard becomes as several kinds of event caused by volcanic phenomena that can be potentially danger and harmful to life and property. Volcanic hazard probably occurs within a specified period of time, within a given area, frequency, certain intensity and potentially damage the surrounding environment and its contents. Volcanic hazard assessment provides information on the probable location and severity of dangerous volcanic phenomena and the likelihood of their occurring within a specific time period in a given area. Figure 6 presents the volcanic hazard assessment ontology. Susceptibility area identifies area potentially affected by damage from volcanic hazards. Susceptibility area contains assets that probably exposed to volcanic hazards, are called elements at risk, such as population, building, public services, infrastructures, and economic activities. Currently 500 million people worldwide are estimated to live near active volcanoes (Tilling and Lipman, 1993 and UN/ISDR, 2004). The other sides, the events of volcanic hazards have an ability to destroy the affected areas. The people in this area

expose potentially to volcano hazard, but the fact that not all people who live near active volcanoes are impacted equally. The characteristics of people make their struggles more or less to response the hazards. The characteristics include the demographic, cultural, well-being, economic, physical, and environmental factors. These understandings provide the progresses of vulnerability concept. Initially, vulnerability is defined as weakness (quality) of elements at risk in a susceptible area (UNDRO, 1982 and Birkmann, 2006). This definition is purely in physical terms, but in progress the concept shifts to more interdisciplinary because vulnerability is a product of complex and dynamic interactions of social, economic, and environmental factors (Turner et al., 2003). Vulnerability is resulted by function or combination of processes that forms the degrees of exposure (elements of risk), sensitivity, and the adaptive capacity (resilience). Figure 7 presents the volcanic vulnerability ontology respect to holistic vulnerability factors. Studying of the vulnerability that considers to vulnerability factors will improve the mitigation and preparation of volcanic hazards for the present and future. The implementation of vulnerability in volcanic regions respects to physical factor related the quality of house both of design and material. The implementation involves how to model the failure of masonry walls to the dynamic pressure from pyroclastic flows (Spencer, 2005a) and the vulnerability of four roof types to tephra fall (Spencer, 2005b). Wallenstein et al., (2005) take approach to vulnerability assessment focus on socioeconomic vulnerability factors that affect the ability of an individual to evacuate. Baxter and Ancis (2002) studies influence of environmental factor after volcano disaster release to human health. Lowe et al., (2007) investigates the complexity factors of vulnerability to volcanic hazards, including physical, social-economic, politic, and history. Risk is measure of probability and severity of the adverse effects (Lowrance, 1976), such as harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between the hazards and vulnerable conditions. The realization of volcanic hazards coinciding with a vulnerable situation will lead to a volcanic disaster. Volcanic disaster historically has caused an impact on the surrounding area of the volcano. Damage, victims, and environmental degradation (including considerable changes on geomorphology and land use) are the impact of volcanic disaster. Risk, vulnerability, and volcanic hazard are assessed by identification, characterization, and evaluation.

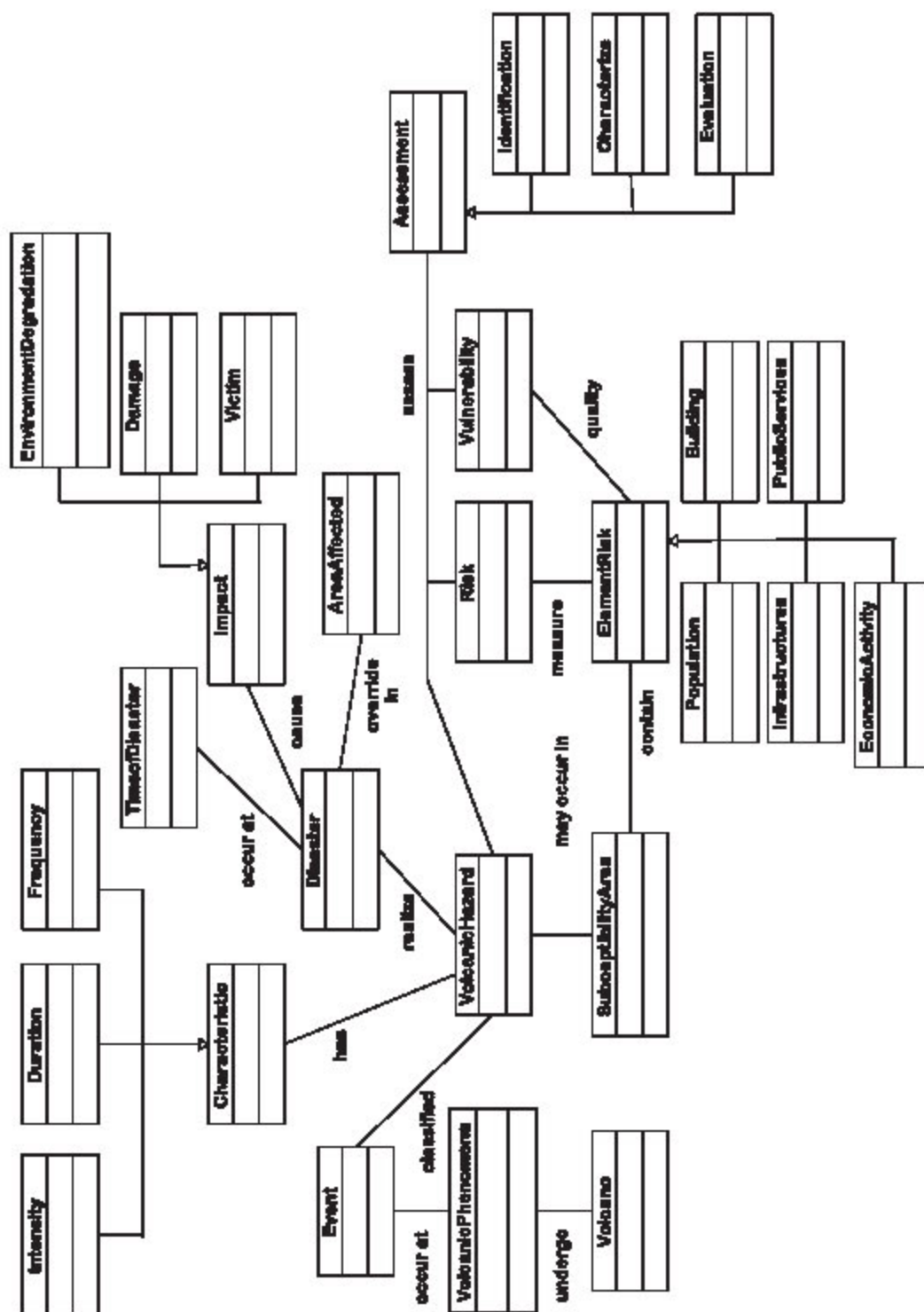


Figure 6: Volcanic hazard ontology

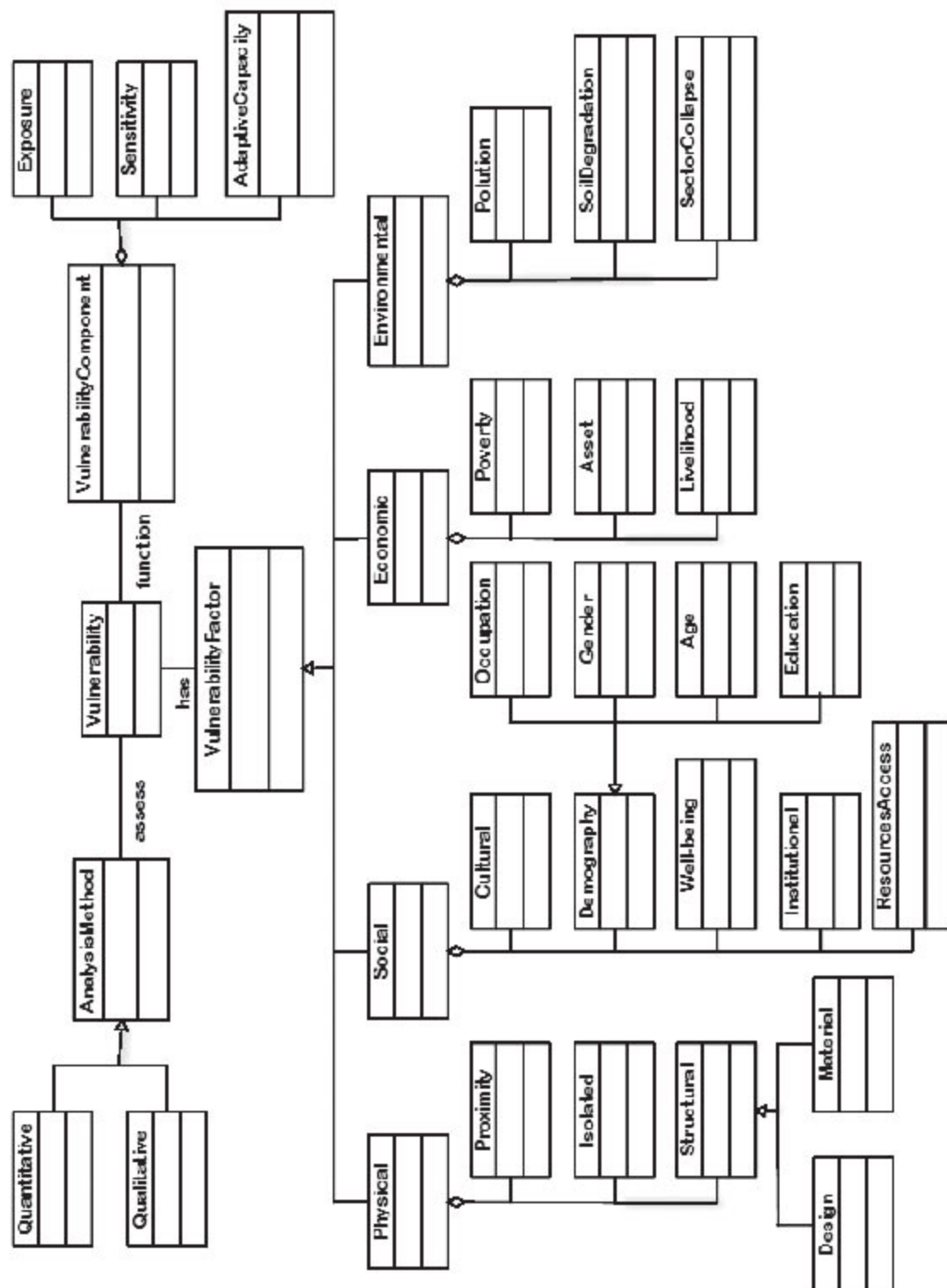


Figure 7: Volcanic vulnerability ontology

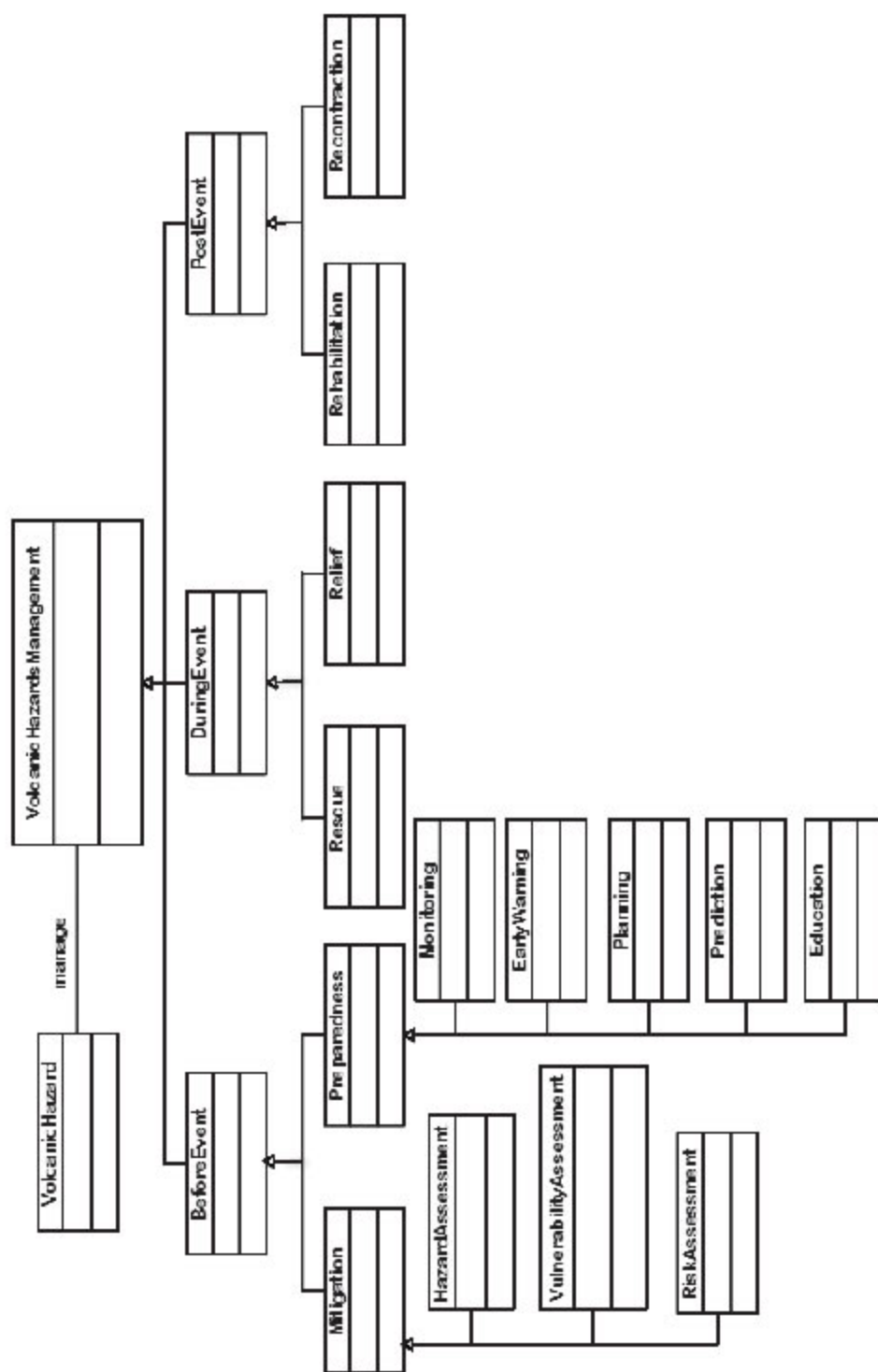


Figure 8: Volcanic hazard management ontology

6. Volcanic Hazard Management Ontology

Volcano hazards management includes all activities, programs and measures which can be taken up before, during and after volcano hazards realized with the purpose to minimize the impact of volcano hazards on people, socio-economic, activity and environment. Figure 8 depicts the volcanic hazard management ontology. Mitigation is effort to limit the adverse impacts of hazards and related disasters. Mitigation can be done by hazard assessment, vulnerability assessment, and risk assessment. Volcanic hazard assessment provides information on the probable location and severity of dangerous volcanic phenomena and the likelihood of their occurring within a specific time period in a given area. Available environmental parameters data, hazard trigger factors, and history records of the volcanic phenomena and its affect heavily needed. Vulnerability assessment will estimate the degree (quality) of element risk that would result from the occurrence of a volcanic phenomenon of given severity. The elements risk includes human population, building, facilities and infrastructure, public service, and economic activities. Risk assessment is an estimate of the probability of expected loss and damage for a given hazardous event. Risk assessment is integration of result hazards assessment and vulnerability assessment. Volcanic hazard assessment is an important step in the volcanic hazard management because this stage is carried out identification and characterization of volcanic hazard by understanding of the process and activities of formation and development of the volcano system. Intensity, the pattern, and range of hazard are determined by the characteristics and processes occurring beneath the volcano system. Preparedness is aimed at minimizing the loss of life and property if volcanic hazard occurs. Preparedness includes public safety information and hazard awareness planning.

7. Conclusions

Volcano system and volcanic hazard assessment ontology is presented in this research. The ontology purpose is to represent volcanic systems and volcanic hazard assessment domain knowledge as conceptual model and knowledge base. This ontology will be helpful for development of applications such as decision support system for volcanic hazards management since volcanic hazards management needs integrated and comprehensive volcanic systems data in order to produce accurate, precise and consistent knowledge about the volcano activity and its effect. Understanding the process and behavior of volcano will be clearer, easier and more complete since

ontology provides the concepts and its structures, its relationships and its meaning that existed in the volcanic systems domain knowledge. This ontology is also used as a rationale to get actual and factual information that can be used as a reference to determine the next steps to anticipate and predict volcanic hazards in the future.

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