Geological Criteria for Site Selection of an LILW Radioactive Waste Repository in the Philippines

Conference Paper · September 2013

DOI: 10.1115/ICEM2013-96127

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Proceedings of the 15th ASME 2013 International Conference on Environmental Remediation and Radioactive Waste Management
ICEM2013
September 8-12, 2013, Brussels, Belgium

ICEM2013 - 96127

GEOLOGICAL CRITERIA FOR SITE SELECTION OF AN LILW RADIOACTIVE WASTE REPOSITORY IN THE PHILIPPINES

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ABSTRACT

In the selection of sites for disposal facilities involving low- and intermediate-level radioactive waste (LILW), International Atomic Energy Agency (IAEA) recommendations require that “the region in which the site is located shall be such that significant tectonic and surface processes are not expected to occur with an intensity that would compromise the required isolation capability of the repository”. Evaluating the appropriateness of a site therefore requires a deep understanding of the geological and tectonic setting of the area. The Philippines sits in a tectonically active region frequented by earthquakes and volcanic activity. Its highly variable morphology coupled with its location along the typhoon corridor in the west Pacific region subjects the country to surface processes often manifested in the form of landslides.

The Philippine LILW near surface repository project site is located on the north eastern sector of the Island of Luzon in northern Philippines. This island is surrounded by active subduction trenches; to the east by the East Luzon Trough and to the west by the Manila Trench. The island is also traversed by several branches of the Philippine Fault System. The Philippine LILW repository project is located more than 100 km away from any of these major active fault systems. In the near field, the project site is located less than 10 km from a minor fault (Dummon River Fault) and more than 40 km away from a volcanic edifice (Mt. Caguas).

This paper presents an analysis of the potential hazards that these active tectonic features may pose to the project site. The assessment of such geologic hazards is imperative in the characterization of the site and a crucial input in the design and safety assessment of the repository.

INTRODUCTION

The International Atomic Energy Agency (IAEA) recommends to all its member states to establish a safe and sustainable solution for long-term management of their radioactive waste. In this regard, the Philippines being a member state, is undertaking a project aimed at locating a near-surface repository for low- and intermediate-level radioactive waste to be accompanied eventually by a co-located borehole repository for sealed sources. Because of the active geological and tectonic setting of the country, a major component of the study is geared towards evaluating and assessing geologic hazards mainly attributed to earthquakes, volcanic activity and mass wasting processes (landslides). This geologic hazard assessment is performed in accordance with guidelines set forth by IAEA (IAEA 1999, 2002) and Philippine codes (e.g. Structural Code of the Philippines in Foz, 2000).

REGIONAL TECTONIC SETTING

The Philippines is located at and near the junction of 3 major tectonic plates, namely; stable Eurasian Plate to the west, northwest-moving Philippine Sea Plate to the east, and northward-moving Indo-Australian Plate to the south (Aurelio, 2000; Queaño, 2006) (**Fig. 1**). The Eurasian Plate is essentially made up of continental crust except on its southeastern margin where oceanic crusts are found in marginal sea basins, including the South China Sea, Sulu Sea and Celebes Sea Basins (Murauchi *et al.*, 1973; Taylor and Hayes, 1980, 1983; Weissel, 1980; Lee and McCabe, 1986; Rangin *et al.*, 1989; Silver and Rangin, 1991). The Philippine Sea Plate is entirely oceanic in nature while the Indo-Australian Plate is composed both of oceanic (Indian side) and continental (Australian side) crusts. As a result of the varied nature of the crusts and the

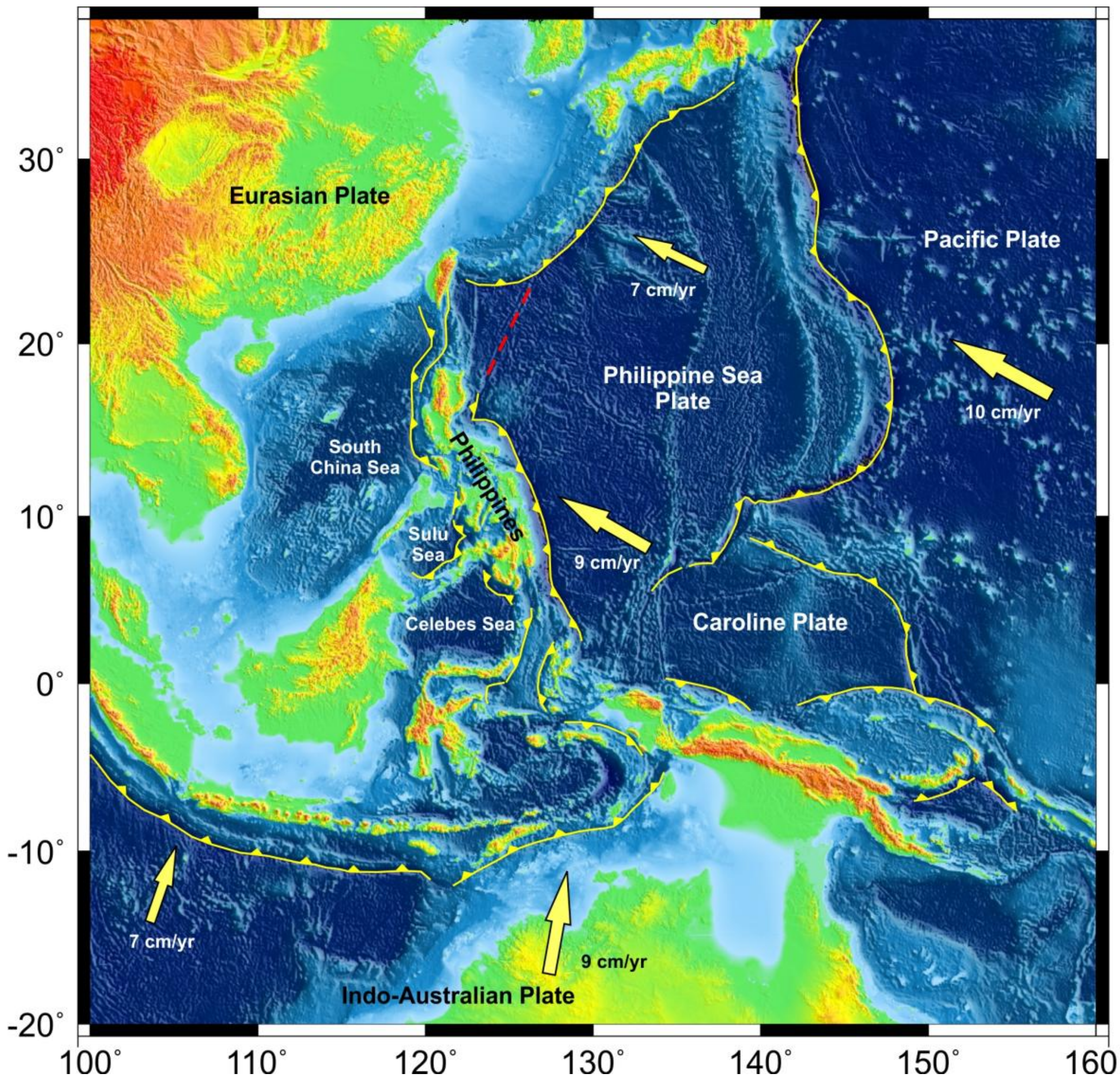


Fig. 1 Regional geodynamic setting of the Philippines in the Asia-Pacific Region. The archipelago is flanked by major tectonic plates, including the stable Eurasian Plate to the west, the NW moving Philippine Sea Plate to the east, and the north verging Indo-Australian Plate to the south. Yellow arrows indicate relative motion of plates with respect to Eurasia (motion vectors adopted from Barrier, 1985). See Acknowledgments for other data sources.

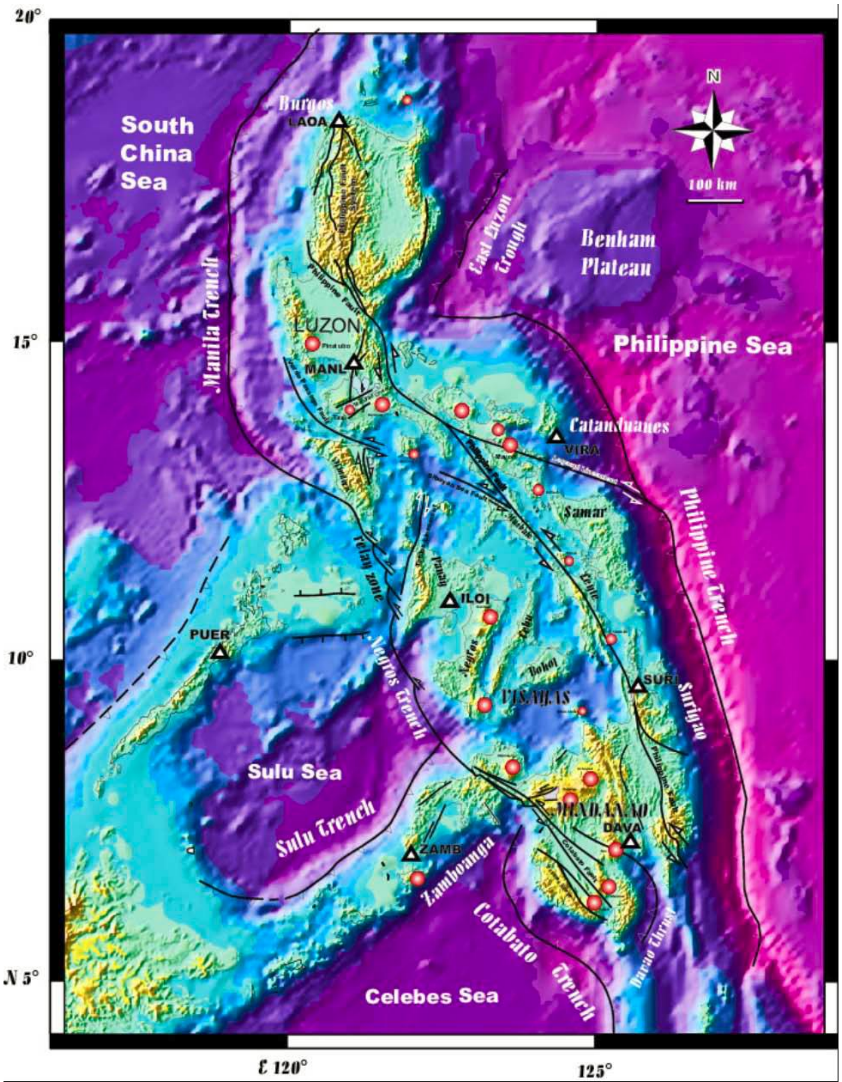


Fig. 2 Tectonic setting of the Philippines showing active subduction systems, active faults and volcanoes (red circles) in and around the archipelago. Modified from Aurelio (2000). See text for discussion.

manner by which these plates kinematically interact, the Philippine region has developed into a complex tri-plate boundary, characterized by active subduction zones and major fault systems. At least six subduction systems surround the archipelago including 4 east-dipping systems on the west (Manila, Negros, Sulu and Cotabato Trenches) and 2 west-dipping ones on the east (Philippine Trench and East Luzon Trough) (Aurelio, 2000) (**Fig. 2**). Inside this double-verging subduction zones are numerous active faults, the most prominent of which is the sinistral Philippine Fault that runs over 1,200 km traversing the entire length of the archipelago (Aurelio, 1992; 2000). This tectonic setting results in the occurrence of frequent earthquakes (about 20 per day of magnitudes 3 or higher) and has produced 23 active volcanoes (PHIVOLCS, 2013).

LOCAL GEOLOGY

The project site is located in the towns of Gattaran and Lallo, province of Cagayan in northeastern Luzon, the biggest island in the Philippines. It is situated on the northern section of the Sierra Madre Range, a north-south trending mountain chain about 200 km long stratigraphically composed mainly of a pre-Cenozoic (Jurassic to Cretaceous) ophiolitic basement, overlain by volcano-sedimentary sequences often intruded by multi-event dioritic to andesitic plutons from the Eocene to the Pleistocene periods. Details of the lithology and petrology of these rock sequences can be found in The Geology of the Philippines, 2nd Edition (Aurelio and Peña, 2010).

At the site, subsurface rocks are mainly basaltic to andesitic volcanic flows and related pyroclastics belonging to Late Oligocene to early Miocene formations with equivalents in the Central Cordillera Range (Aurelio and Peña, 2010). Queaño (2006) identified basaltic rocks in the vicinity that he named Palaui Basalts. These Oligo-Miocene rocks are overlain by Mio-Pliocene volcano-sedimentary deposits of the Awiden Mesa Formation composed mainly of andesites and dacites, and by younger deposits of Mt. Cagua, a solfataric volcano belonging to the Babuyan Volcanic Complex of Aurelio and Peña (2010). Rocks at the site are generally fractured and in certain instances affected by argillic alteration (CDSI, 2006). There are no known mineral deposits within or nearby the project site (MMAJ-JICA, 1989).

MAIN GEOLOGIC HAZARDS

Volcanic Hazards

The project site is located around 42 km southwest of Mt. Cagua (**Fig. 3**), an active volcano considered part of the Babuyan Islands volcanic chain (Aurelio and Peña, 2010). Athough this volcano is located in the northernmost part of Luzon, it falls within the N-S trend of the Northern Luzon (Batanes segment) volcanic centers. The Pleistocene Mt. Cagua volcanic flows, composed mainly of andesites and dacites, impinge upon Miocene sedimentary rocks northeast of the project site. Historical records reveal solfataric activity at Mt. Cagua in 1860 and 1907, prompting the Philippine

Institute of Volcanology and Seismology to classify it as an active volcano (PHIVOLCS, 1997).

Given its relatively far distance to Mt. Cagua, the project site has not been found to be susceptible to the direct effects of lava flow, pyroclastic flow and lahar (CDSI, 2008). However, ashfall and other fine pyroclastic particles are capable of reaching the site in the event of a violent eruption. Experience from the Mt. Pinatubo eruption of June 1991 showed that significant amounts of volcanic material, mostly ash, can reach and deposit at distances of as far as 100 km from the source and may cause significant damage to infrastructure (Bautista *et al.*, 1991; Newhall *et al.*, 1996).

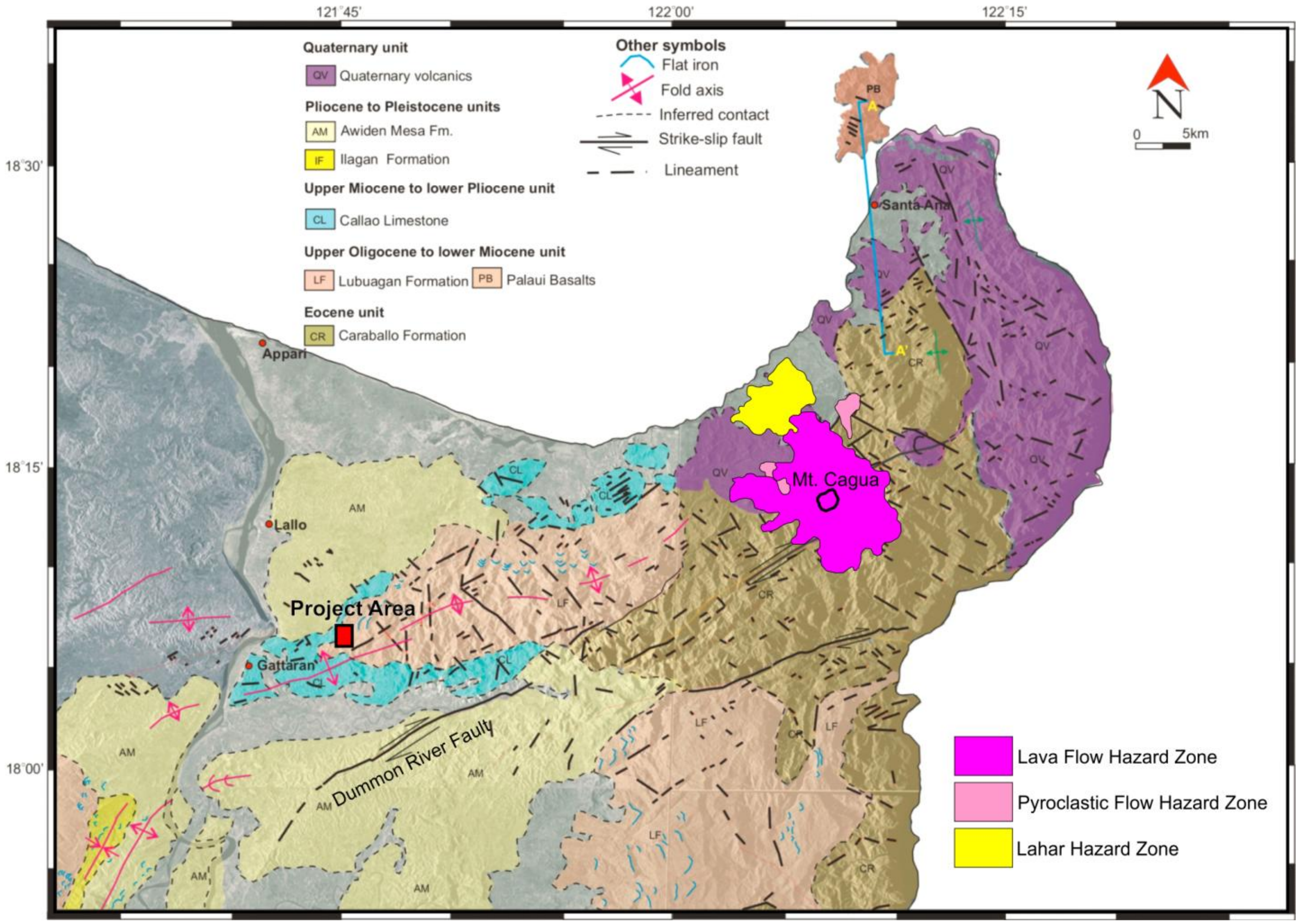


Fig. 3 Volcanic Hazards Map of Mt. Cagua established from PHIVOLCS (1997) data. Base map is geologic map of Queaño (2006). Location of project area and Dummon River Fault also shown. See text for discussion

Landslide Hazards

The project site sits on top of a broad topographic mound named Bantay Kalbo, the local term for “Bald Mountain”, by virtue of its lack of vegetative cover (**Fig. 4**). Bantay Kalbo is plateau-like and relatively flat. On the plateau itself, there are no indications of a landslide history. However, landslide scars are observable on the slopes flanking the plateau. These features are seen to be evident where the basaltic to andesitic bedrock is highly fragmented, fractured and deeply weathered. Exposures close to the creeks at the base of the hill also exhibit hydrothermal alteration, making the slopes vulnerable to erosion.

This situation necessitates the implementation of mitigating measures to ensure the long-term stability of the slopes. The slope design criteria can best be achieved by performing a thorough investigation of the engineering properties of the bedrock including numerical stability modeling, paying close attention to rock strength (or the lack of it) as a consequence of intense fracturing and clay alteration, as well as taking into consideration ground accelerations induced by earthquakes (see below for PGA calculations).

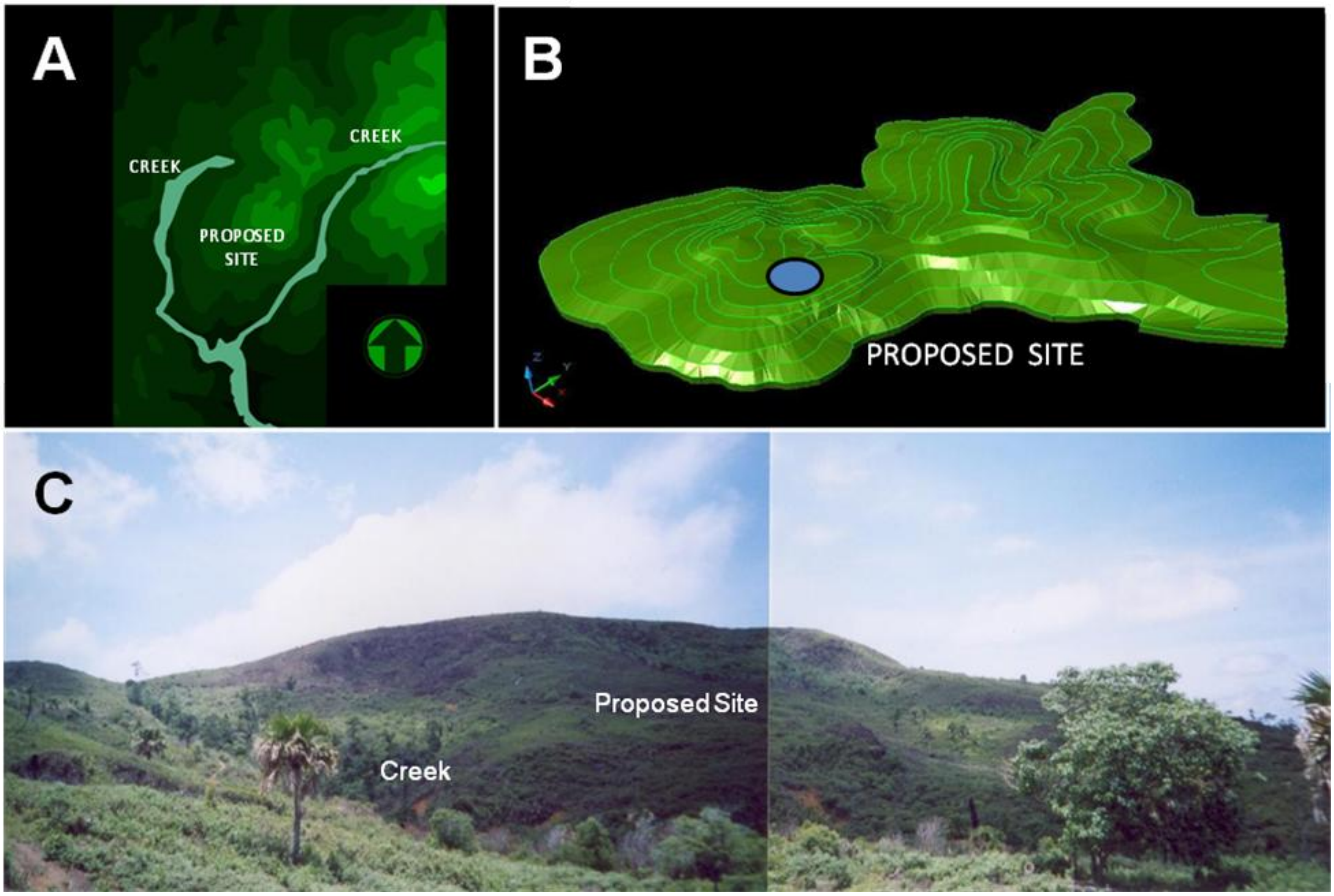


Fig. 4. Topographic map (A) and Digital Terrain Model (B) established from high resolution topographic survey of the project site and vicinity. (C) Panoramic view of Bantay Kalbo looking northeast showing approximate location of proposed project site. See text for discussion.

Seismic Hazard Assessment

Earthquake Generators

Active subduction zones and major faults exist within a 300 km radius of the project site (**Fig. 5**). About 265 km to the east lies the East Luzon Trough, and around 300 km to the west is the Manila Trench. Both are active subduction zones responsible for large magnitude (M>6) earthquakes in recent times. The East Luzon Trough is the bathymetric expression of the subduction of the Philippine Sea Plate underneath northeastern Luzon (Aurelio, 2000). **Figure 6** shows a gentle Wadatti-Benioff zone dipping to the west to depths shallower than 60 km, suggesting that the East Luzon Trough is a young subduction system (e.g. Lewis and Hayes, 1983). Earthquake focal mechanism solutions indicate west-dipping thrust faulting events consistent with a subduction system (**Fig. 6**).

The young subducting slab in the East Luzon Trough is still too short and shallow to produce active volcanism. Although Mt. Cagua appears to lie along the volcanic axis of the East Luzon Trough, several authors associate this volcano, like all the 5 other active volcanoes in the Batanes Group of Islands, with the more mature, east-dipping Manila Trench subduction system located some 300 km to the west (e.g. Yang *et al.*, 1996; Bautista *et al.*, 2001).

In central northern Luzon, earthquakes with depths of focus around 30 km and shallower are associated with the Philippine Fault and its branches. Focal mechanism solutions mostly indicate sinistral faulting (**Figs. 5** and **6**). In 16 July 1990, the eastern-most Luzon segment (Digdig Fault) ruptured for over 100 km producing an Mw=7.7 tremor (Nakata *et al.*,1990; Ringenbach *et al.*, 1991; Velasco, 1996), the strongest instrumentally recorded earthquake along the Philippine Fault System in the last 100 years. The project site is about 70 km to the east of the northeastern branch of this fault system, the East Cordilleran Fault.

An ENE-trending structure, called the Dummon River Fault (DRF) is located to the south of the project site (**Fig. 3**). While the Philippine Institute of Volcanology and Seismology classifies this 65 km-long dextral fault as active, no known historical earthquakes can be associated to it.

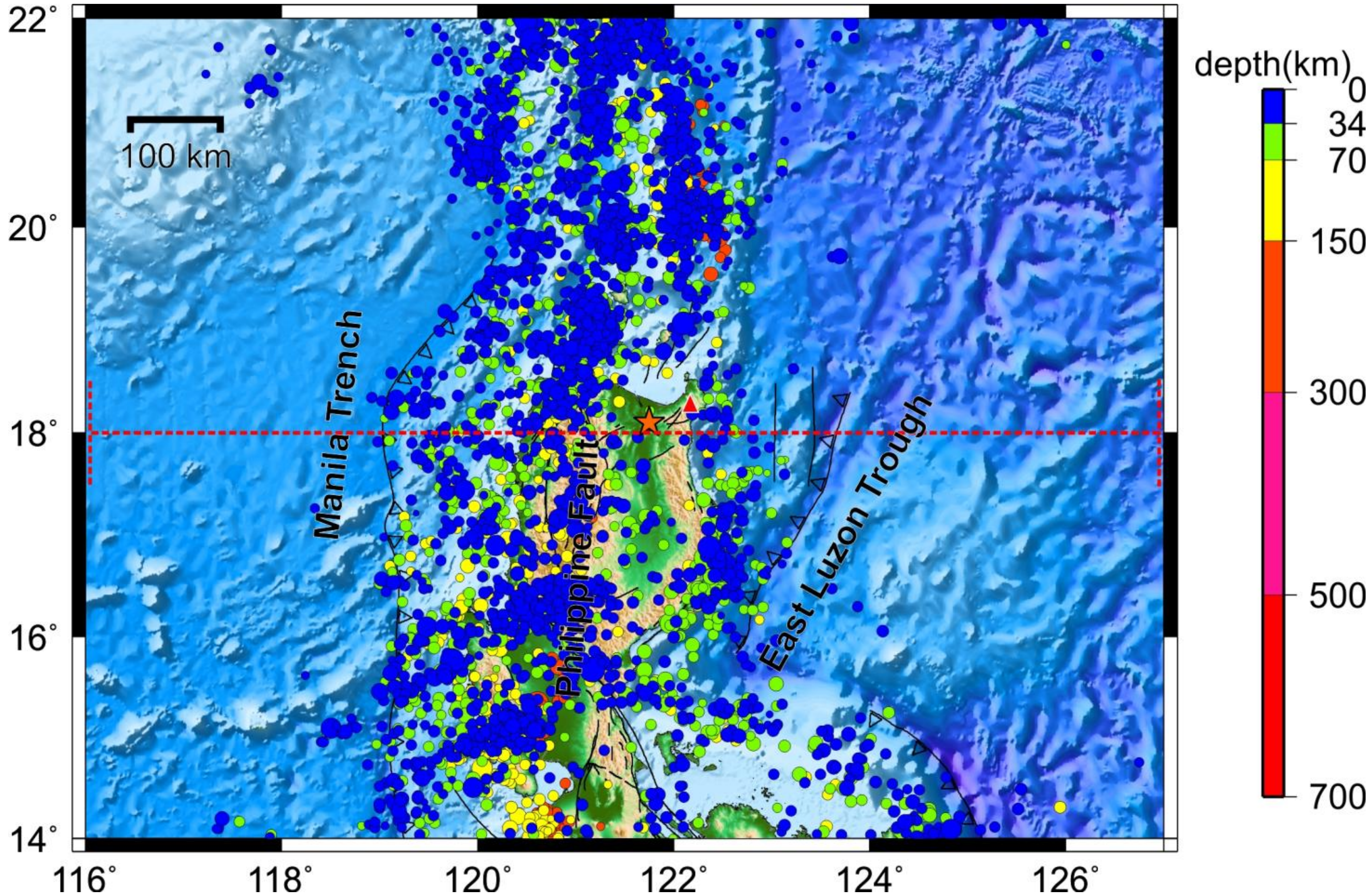


Fig. 5 Seismotectonic map of Northern Luzon showing the main earthquake generators (i.e. East Luzon Trough, Philippine Fault, Manila Trench) and earthquake epicentral location (data up to April 2013). Approximate locations of project site (red star) and Mt. Cagua (red triangle), and trace of seismotectonic section (red dashed line – **Fig. 6**) are shown. Data sources: GEBCO (2009), Jarvis *et al.* (2008), NEIC-USGS and Global Moment Tensor Project. See text for discussion.

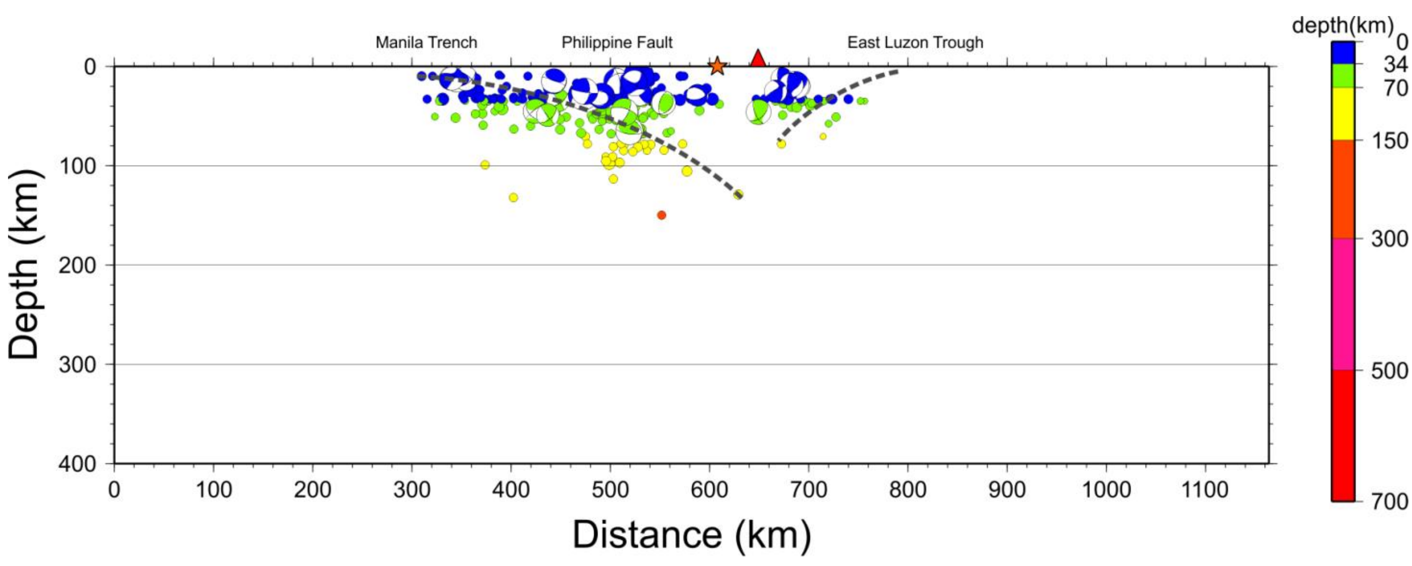


Fig. 6 Seismotectonic section of region shown in **Fig. 5**, showing main earthquake generators (i.e. East Luzon Trough, Philippine Fault, Manila Trench) and earthquake data (hypocenters and focal mechanism solutions as of April 2013). Section bandwidth = 100 km. Approximate locations of project site (red star), Mt. Cagua (red triangle), and trace of subducting slabs (gray dashed lines) are shown. Data sources: GEBCO (2009), Jarvis *et al.* (2008), NEIC-USGS and Global Moment Tensor Project. See text for discussion.

Peak Ground Acceleration at the Site

Thenhaus *et al.* (1994) estimated peak ground (horizontal) acceleration PGA for the Philippines using a probabilistic approach. Their estimates indicate PGA values of less than 0.1***g*** for bedrock, and less 0.2***g*** for soft rock (hard soil) at the vicinity of the project site at 10% probability of exceedence in 50 years. In this study, we compute for deterministic PGA values in order to represent a worst case scenario. We use Wells and Coppersmith's (1994) fault length-to-magnitude empirical relation:

$$\log \boldsymbol{L} = -3.22 + 0.69\boldsymbol{M} \qquad \text{(eq. 1)}$$

where ***L*** is fault length, and ***M*** is magnitude;

a closest fault-to-project site distance ***R*** of 9.6 km, and the attenuation relation of Fukushima and Tanaka (1990) given as:

$$\log \boldsymbol{A} = 0.41\boldsymbol{M} - \log(\boldsymbol{R} + 0.0032 \text{ X } 10^{0.41\boldsymbol{M}}) - 0.0034\boldsymbol{R} + 1.30$$
(eq. 2)

to obtain acceleration values ***A*** expressed in terms of acceleration due to gravity ***g***, at and around the project site in the event of a rupture along the Dummon River Fault. A fault length ***L*** of 65 km corresponds to a maximum magnitude of ***M*** 7.3, suggesting a PGA value of 0.27***g*** for bedrock and 0.48***g*** for soft rock at the project site (**Fig. 7**). Soft rock PGA values may be applicable to areas where fracturing and alteration are intense. These PGA values are notably elevated, especially within the context of a nuclear waste facilities where acceleration values of as low as 0.1***g*** should already be given serious attention (IAEA 1999, 2002).

The more significant tectonic features including the East Luzon Trough (0.03***g***) and the Philippine Fault (0.12***g***) produce weaker PGA values at the site, since they are situated much farther away (**Fig. 8**).

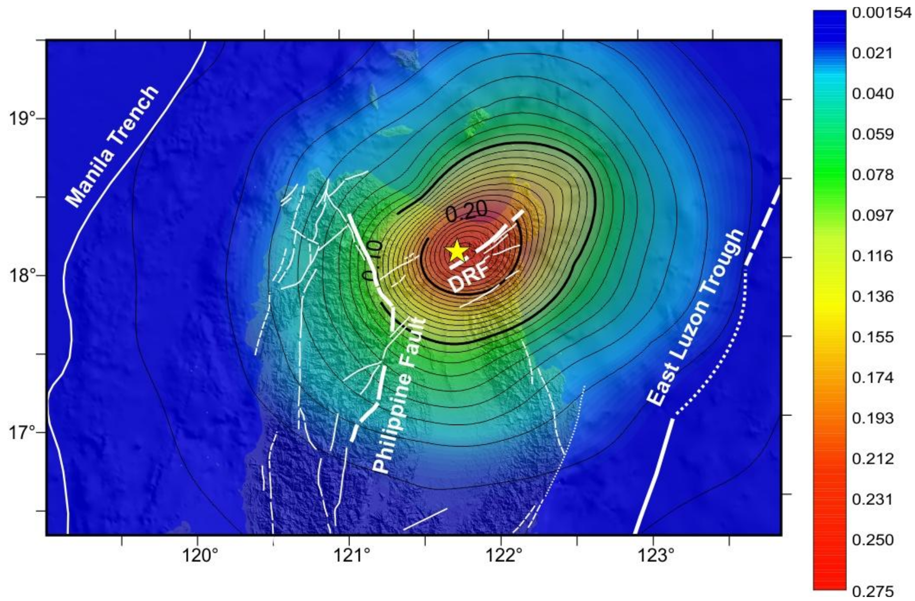
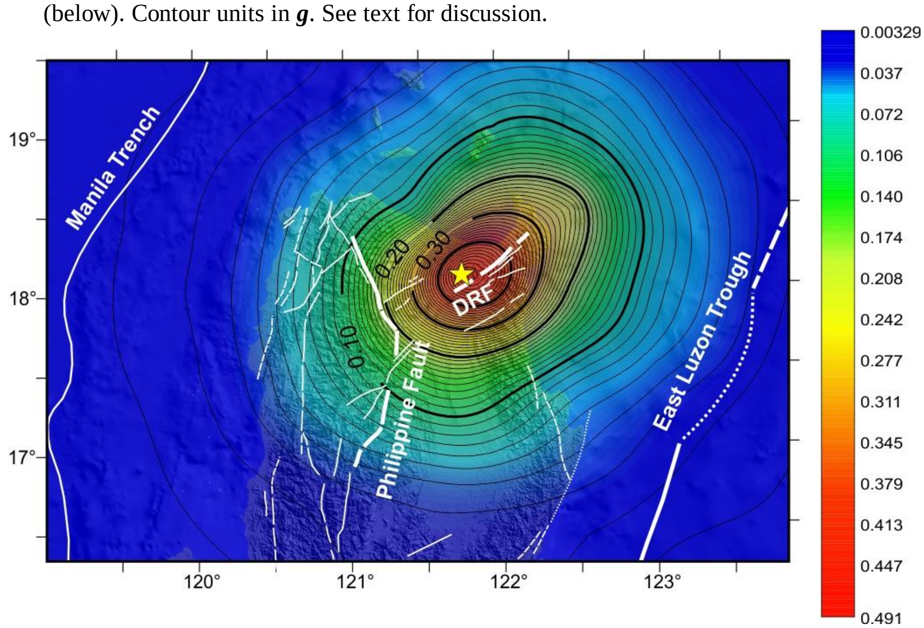


Fig. 7 Deterministic Peak Ground Acceleration (PGA) values computed at the project site using a hypothetical M 7.3 earthquake along the Dummon River Fault, on bedrock (above) and fractured/hydrothermally altered rock (below). Contour units in ***g***. See text for discussion.



CONCLUDING REMARKS: CONSIDERATIONS FOR SITE DESIGN

This paper shows that the major geological sources of instability of the project site are earthquakes, mass movements and to a lesser degree, volcanic activity. The design criteria to be adopted should take into consideration, the following; 1) ground acceleration values in the vicinity of 0.27***g*** for bedrock and 0.48**g** for fractured and hydrothermally altered rock that need to be recomputed in the context of a Factor of Safety appropriate for critical facilities such as a radioactive waste disposal facility (FS $\geq$ 2.0); 2) proper engineering design to address landslide hazards that may be triggered either by earthquakes or

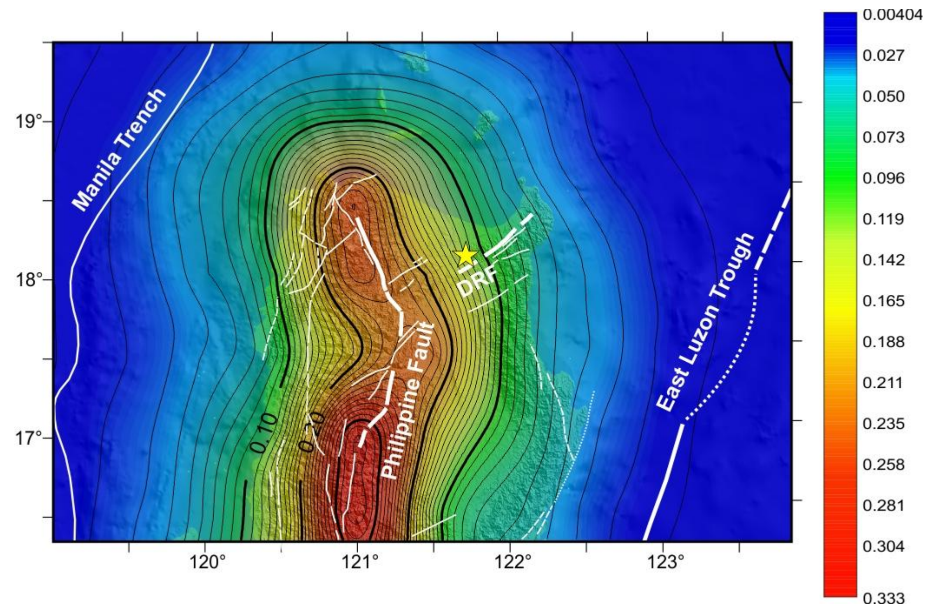
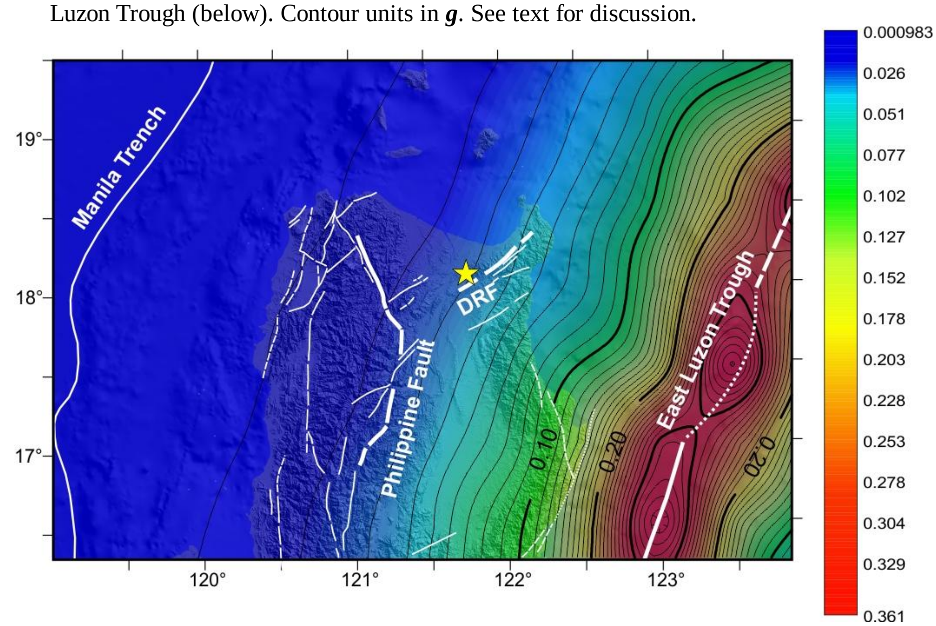


Fig. 7 Deterministic Peak Ground Acceleration (PGA) values computed at the project site in bedrock using a hypothetical M 8.0 earthquake along the East Cordillera branch of the Philippine Fault (above), and along East Luzon Trough (below). Contour units in ***g***. See text for discussion.



rainfall; and 3) possibility of eruption of Mt. Cagua within the operational control life of the facility.

ACKNOWLEDGMENTS

M. Aurelio would like to thank the Philippine Nuclear Research Institute for allowing to present and publish this paper. The International Atomic Energy Agency is acknowledged for the technical and financial assistance extended to the project. Most figures (maps and sections) were generated using the Generic Mapping Tools of Wessel and Smith (1995). Map data sources include GEBCO (2009) for bathymetry, Jarvis *et al*. (2008) for SRTM land topography, and NEIC-USGS and Global CMT Project for earthquakes.

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