POSTER SESSION:

Energy

Native Hydrogen: A Prospect Fuel for the Philippine Energy Transition

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The Paris Agreement of 2015 under the United Nations Framework Convention on Climate Change (UNFCCC) has provided for a target of not exceeding 1.5oC increase of global temperatures from the pre-industrial levels, which necessitated all countries to reduce their carbon emissions from fossil fuels. Numerous approaches have been done, including renewable energy, nuclear, ammonia and hydrogen. The production of hydrogen is becoming part of the big discussions in the energy transition, but not much on native hydrogen. There are studies conducted as far back as three decades ago and the exploration and development of native hydrogen is just starting to pick up. Hydrogen gas is a mineral gas with a high energy density, longer storage periods and occurs naturally in geological environments, such as serpentinized ultramafic rocks at mid ocean ridges, and land-based ophiolitic massifs and can be associated with methane.

The Department of Energy (DOE) has realized the role that native hydrogen will play in the energy transition given the geological setting of the country which may be host to native hydrogen and will be providing the policy and regulatory framework needed to attract investments in the exploration, development, and production of native hydrogen. As a start-up activity, the DOE collated all previous studies and literatures related to native hydrogen occurrence, studies and locations of the different ophiolitic belts in the country, previous gas seeps locations investigated and evaluated, and then it was analyzed using a Geographic Information System (GIS). Preliminary results shows that there are gas seeps locations that coincide within or near ophiolitic belts which may be further investigated using geophysical techniques, geological mapping, sampling and laboratory analyses and drilling.

Key Words: Native Hydrogen, Geologic Hydrogen, Energy Transition, Philippines

POSTER SESSION:
Techniques, AI, Machine Learning

Investigating the use of image segmentation and machine learning in the textural analysis of rocks and their potential industry applications

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The textures and composition of rocks hold clues on their provenance, depositional processes, transporting medium, porosity, and permeability. The volume of components of rocks is typically visually estimated in the outcrop and microscopic scaler using a comparator chart and then plotted on ternary diagrams for identification. This method can be tedious and subject to the observer's bias. This study investigates the use of image segmentation and machine learning as a possible alternative to visual estimation. This method involves the use of 2D images of rock as input data for a pixel-based approach to volume estimation. The images are processed in the Trainable Weka Segmentation Plugin of Fiji, an open-source image analysis software, to create grain boundary maps using the in-house Random Forest algorithm, a supervised machine learning classifier. Further image segmentation using the Watershed segmentation technique is done to obtain a more defined grain boundary map where textural parameters such as mean grain size, grain shape, sorting, elongation ratio, and clast-to-matrix ratio are obtained.

To investigate the potential of image segmentation and machine learning techniques, two types of samples were used for this study. The first type consists of outcrop images of the conglomerate unit of Lagdo Formation, southwest Panay. This conglomerate unit consists of granule to cobble-sized clasts enclosed in coarse-grained sand-sized, well-indurated, and hard matrix. The hard and well-indurated characteristics of the conglomerate made it challenging to conduct 3D morphological and grain-size measurements of the clasts using calipers or sieving methods. The measurements from Trainable Weka Segmentation were compared to the manual handcrafted measurement done on Fiji software by a human expert. The similarities in the results from both methods indicate the potential use of image segmentation and machine learning as tools for future sedimentological analysis of 2D images despite the limitations and challenges of obtaining dimensions from rudaceous conglomerate units.

The second set of input image data are photomicrographs of sedimentary and volcanic rocks. Machine learning models are created to produce probability maps of rock components as observed and annotated during petrographic analysis. This is an ongoing study but machine learning models created will be presented as an overview. This study can have potential applications in the energy sector, environmental science, mining, and hydrology.

Keywords: machine learning, image segmentation, grain size analysis, petrography, conglomerate

Navigating Complexity: The Role and Significance of Probe Hole Drilling in the Re-Orientation of the Tunnel Alignment

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Tunnel construction presents multifaceted challenges that require comprehensive evaluation to ensure the safety, efficiency, and long-term stability of the underground structures. Nevertheless, the possibility of encountering water ingress from river crossings with shallow rock cover is inevitable along with unfavorable ground condition due to fault zones resulting to poor rock mass classes. This paper discusses the significance of probe hole drilling as the cornerstone for the re-orientation of the tunnel drive/alignment, focusing on the Tigerway Decline Access Development Project at Agusan Del Sur, Philippines.

Using the Furukawa Double Boom Jumbo Drill, two long probe holes were drilled near the tunnel crown the to gather data on: (1) Borehole Geometry; (2) Geological and Geotechnical Properties; and (3) Drill Performance.

A special case of ground support system and tunnel realignment was developed to mitigate the risk of tunnel instability while streamlining construction time, enhancing personnel and equipment safety, reducing support requirements, and eliminating the need for Pre-Excavation Grouting (PEG). The cost savings resulting from the resulting approach was likewise significant.

Keywords: Probe Drilling, tunnel, Engineering Geology, NATM (New Austrian Tunneling Method)

Combined Ground Penetrating Radar and Electrical Geo-Resistivity Survey in underground utility condition assessment and Anthropocene upper surface characterization at Sta. Mesa, Manila

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An assessment of active underground utility facilities was undertaken last June-August 2023 to determine their current conditions as part of upgrading and maintenance to improve the delivery of services to the end users. The introduction of combined Ground Penetrating Radar (GPR) and Electrical Geo-Resistivity (ERT) Surveys were implemented as part of a targeted approach to identify the relative location of the utilities geographically, as well as assess the characteristics and conditions of the overburden material and any undisturbed original bedrock material within the study area. The upper surface overburden has indicated significant reworking and the presence of variable type of debris, confirmed by following excavation activities and background historical evaluation. The target utility and conditions based on the geophysical methods were similarly confirmed after the excavation works.

Development of a 3D electromagnetic (EM) mapping system for geological exploration

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We designed the QEm electromagnetic mapping system to capture transient EM waves and detect the perturbations between the mutually-perpendicular components. The hardware module records the multi-parametric EM waves while the software module takes Maxwell's equations to chart transient perturbations in the various waveforms. We extended Caignard's equations used in magnetotellurics into the different components and created 3D electromagnetic images of the underlying Earth materials. The results suggest that multi-component EM data can be used to create 3D maps of the underground akin to full-waveform geophysics.

Preliminary tests indicate that the system is robust, and able to faithfully record at rates up to 1KHz with 24 bits data resolution. Time synchronization and geographic position are in high precision using GPS; battery power sustains the system for days and can be extended using solar recharging. Data quality is high, allowing signals to be stacked for improved S/N. The QEm functions both as passive and active systems. Active mode uses pulsed square-wave signals then received by the QEm sensors which can be exploited for induced polarization mode of acquisition. Passive mode allows recording over a period of hours and data is stacked to enhance imaging of deeper levels.

Results comparing the 3D QEm data with conventional 2D resistivity profiles is encouraging, suggesting potential in the search of groundwater or metallic materials. Being nodal, the QEm system has low environmental footprint and allows the data resolution to be adjusted to spatial constraints that cabled system cannot overcome. Being very portable, lightweight and self-powered, the logistics required for deployment is much reduced compared to conventional cabled resistivity systems. More tests are being conducted for various exploration targets, while hardware features and data processing procedures are being refined to optimize the system. Patent protection is underway through DOST.

Keywords: 3D electromagnetic surveys

Aiming Higher: an update on the applications of small remotely piloted aircraft in the disaster risk reduction activities of the DOST-PHIVOLCS from 2019 to 2023

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For over a decade, the Department of Science and Technology – Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS) has been using small remotely piloted aircrafts (RPAs) in its disaster risk reduction (DRR) activities. With the advancements in RPA technology over the past four years from 2019 to 2023, the Institute has also broadened the use of RPAs in a variety of applications. These were achieved with fabricated fixed-wing RPAs used for longer flight missions and off-the-shelf quadcopters with assembled payloads.

RPAs have been instrumental in data collection for earthquake-related studies. These include documenting and monitoring landslides after earthquakes, mapping elements-at-risk, mapping boulders transported by tsunami events, and validating the Google Earth Engine-derived mangrove extents.

DOST-PHIVOLCS also expanded the applications of RPAs in volcano research and monitoring. RPAs were used in sampling water within active volcano crater lakes, gathering data to generate high-resolution digital elevation models (DEM) for lahar modeling, mapping volcanic fissures, and monitoring and estimating volcanic deposits during eruptive events.

In terms of mainstreaming the technology, DOST-PHIVOLCS has conducted capacity-building workshops on quadcopter RPA operations to make the technology more accessible to internal and external stakeholders who are also engaged in DRR.

With the developed methodologies, DOST-PHIVOLCS has been able to enhance its data collection, improve its existing procedures, and provide the necessary information and services for better-informed decision-making. As RPA technology advances, DOST-PHIVOLCS will endeavor to improve its developed methodologies and find more ways to apply RPAs in its DRR activities.

Keywords: hazard mapping, volcano monitoring, earthquake, capacity building, innovation

Utilization of small remotely piloted aircrafts (RPA) in water sampling on active volcano crater lakes in the Philippines

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The Philippines hosts a number of active volcanoes that have crater lakes. The Department of Science and Technology – Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS) regularly collects water samples from these crater lakes to monitor their volcanic activity and model their hydrothermal systems. To lessen the exposure of the Institute scientists to hazards from entering the crater of these active volcanoes, especially during times of heightened volcano activities, remotely piloted aircrafts (RPA) capable of collecting water samples and analysing the physico-chemical conditions of crater lakes were developed.

Small quadcopter RPAs were equipped with payloads that included a high-density polyethylene sampling bottle (developed by Terada et al., 2018), a lightweight water temperature sensor and pH meter, a microcontroller board, and a camera. The developed RPAs first underwent test flights for payload capabilities and endurance checks. During the actual water sampling, the RPAs were manually controlled to collect water samples in predetermined sampling locations in the crater lakes. Afterward, the samples were taken to the laboratory for geochemical analysis to determine changes to the crater lake water composition.

The developed method was first successfully applied to the Taal Volcano Main Crater Lake and the Amacan Crater of the Leonard Kniaseff Volcano, and will be replicated in other active volcanoes with crater lakes. While the method already serves as a safer and more efficient alternative to the traditional water sampling techniques, it is also being refined with the advancements in RPA technology, enhancements to signal and data transmission, and improvements to low-cost and lightweight sensors.

Keywords: remotely piloted aircrafts, Taal Volcano, Leonard Kniaseff Volcano, Arduino, sensor development

Geologic controls of submarine groundwater discharge (SGD) in a hydrothermally active region in Mabini, Batangas through acoustic imaging

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Submarine groundwater discharge (SGD) is a significant pathway of materials into the ocean. Nutrient inputs from SGDs are comparable to or can even exceed those from rivers. SGDs, although prevalent in shallow waters, are typically difficult to detect and thus challenging to map. Mapping is essential in estimating the potential magnitude of the influence of SGD and identifying the factors that control the distribution and nature of SGDs. Different methods have been employed to identify the occurrence and map SGDs, from chemical tracers and isotopes to geophysical tools such as electrical resistivity and acoustics. This work utilizes low-cost GPS-fish finders, which use multifrequency down imaging and side scan imaging to image the substrate and the occurrence of SGD along the eastern-southeastern coast of the Calumpan Peninsula, Mabini, in Batangas. The study site is considered a hydrothermally active region, which contributes to the bubbly or gaseous nature of the SGD. A total length of 65-km line survey data was acquired from the 6.5-km long study site. Both bubbly or gaseous and non-gaseous SGDs can be imaged. Sparse bubbly SGDs, where bubbles rise from the sea floor over widely-spaced points, are sporadically distributed throughout the study area and in any substrate type. Effusive, closely-spaced bubbles resembling a curtain rising from the seafloor, called curtain bubbly SGDs, are common in areas underlain by sand and where lineaments can be projected offshore. They can also be widespread where limestone outcrops are found on land. Spring bubbly SGDs, where intense degassing accompanied by copious water discharge from a small area on the seafloor, can be found where lineaments converge offshore and where sandy to sandy-gravelly substrates abut against outcrops. In some cases, non-gaseous springs appear to emanate from decimeter-wide vents along bedding planes. Parabolic water column anomalies emanating from the seafloor but with no trains of reflectors rising to the surface, suspected to be non-gaseous or water-rich SGD, are typically co-located in the zones with the other types of bubbly SGDs. The occurrence and nature of SGDs in the study site can be attributed to the geology of the area, such as the permeability of the coastal aquifers and lithologies found onshore and the presence of structural features such as faults, fractures, and bedding planes.

Keywords: submarine groundwater discharge (SGD), acoustics, fish finders, Mabini

Enhancing Shear Wave Velocity (Vs) Mapping using Elitist Genetic Algorithm through the HVSRInv Program

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The measurement of the average shear wave velocity for the upper 30 meters (Vs30) of the horizontally stratified soil layers is a crucial factor in assessing earthquake hazards due to its correlation with the amplification factor. Site amplification can infer the effect on ground motion of different geological conditions which can help structural engineers, urban planners, and local government units in their hazard mitigation plans. Geophysical surveys, such as Refraction Microtremor (ReMi) and borehole logging, are some of the methods for determining Vs30, but they can be labor-intensive and demanding. A more convenient and time-efficient way of generating a Vs30 map and obtaining shear-wave velocity profiles from geophysical data contributes to a more streamlined seismic hazard analysis.

Several studies investigate other possible techniques to map Vs30.One of these developed the HVSRInv, a MATLAB-based graphical user interface for inversion and forward calculation of horizontal-to-vertical spectral ratio (HVSR). This study adapted their interface and generated Vs30 profiles through HVSR inversion using the HVSRInv software. The elitist genetic algorithm was applied to the HVSR data obtained from Leyte Province to estimate the thickness, density, and damping ratio of the layers. The inferred Vs30 can then be used to compute site amplifications which can be integrated into the seismic hazard analysis.

The inferred shear-wave velocities are compared with those acquired from actual ReMi surveys to assess the validity of the HVSR approach. Power-law regression was also used to compare the calculated Vs30 and site period to assess whether the approach can serve as a supplementary data source for Vs30.

Keywords: HVSR Inversion, Shear Wave Velocity, Elitist genetic algorithm

Machine Learning-Based Assessment of Liquefaction Susceptibility in South Cotabato, Philippines

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The phenomenon of soil liquefaction, observed during seismic events, presents a substantial threat to urban areas, necessitating precise assessment methods for hazard mitigation. This research introduces an innovative approach, employing machine learning algorithms (i.e., *Decision Trees*, *Random Forests*, *Logistic Regression*, *Support Vector Machine*, and *Neural Networks*) to evaluate liquefaction susceptibility. This method bypasses the complexities of parameter calibration and normalization, resulting in a robust assessment compared to traditional simplified procedures. The resultant model delivers a binary classification, where 1 signifies liquefiable soil, and 0 denotes non-liquefiable soil.

Utilizing a training dataset derived from geotechnical investigation reports in Metro Manila, key input variables include *groundwater table elevation*, *SPT N-value*, *soil type*, *fines content*, and *Atterberg limits* (liquid and plastic). The output variable represents liquefaction assessment, employing the National Center for Earthquake Engineering Research (NCEER) method as the basis. Following the development and rigorous validation of the model, its predictive capabilities are applied to the input data of geotechnical investigation reports of South Cotabato, Philippines. Model performance and reliability were assessed using statistical parameters such as *accuracy*, *sensitivity*, *specificity*, *positive predictive value*, and *negative predictive value*.

The successful application of the model in South Cotabato highlights its potential to predict the liquefaction susceptibility that compares favorably to widely used existing methods. Thus, this research underscores the potential of machine learning for improved liquefaction susceptibility assessment and recommends its wider adoption in seismic risk evaluation.

Keywords: machine learning, liquefaction, SPT

Role of lithology and geologic structures to the drainage morphometry of Carrascal watershed, Surigao del Sur using Principal Component Analysis

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Carrascal Watershed is located in the Municipality of Cantilan and Carrascal, Surigao del Sur, Philippines. It is divided into 49 sub-watersheds with a total area of 167 square kilometers and characterized by a dendritic drainage pattern. The watershed is underlain by ultramafic, metamorphosed sedimentary, and clastic sedimentary rocks- transected by a NW-SE trending thrust fault. Principal component analysis (PCA) is a statistical analysis used for narrowing many parameters into specific and most important parameters for the correlation with the other variables. In this study, PCA was utilized for determining and comparing the lithologic and structural controls on the hydro-geomorphic parameters of the watershed. A LiDAR Digital Elevation Model (DEM) was utilized in ArcMap 10.4 as an input data for watershed delineation and characterization. Morphometric calculations grouped into three morphometric aspects (linear aspect, aerial aspect, and relief aspect) are used to characterized the drainage morphometry of the watershed and for the correlation to the geologic structures and lithology. Preliminary results focus on the linear aspect and yields a bifurcation ratio (Rb) value of 1.5891, suggesting that the geological structures highly influence the drainage network of the watershed. A mean stream length (Rl) of 856.331 km, considered short, indicates that the watershed has high relief and steep slopes. A high drainage density (Dd) value of 5.12 suggests that, generally, the watershed is underlain by impermeable rocks that result in sparse vegetation and high relief of the basin, resulting to increased erosion and runoff. The DEM was also used for lineament extraction. Preliminary findings showed that there is a dense accumulation of lineament structures in the southeastern portion of the watershed. This suggests the presence of numerous faults and fractures in the area. The findings and insights derived from the analysis of this study can enhance our knowledge about the geomorphology and dynamics of the watershed. The study has the potential to improve river management practices, including risk reduction management of the watershed.

Keywords: Morphometry, Principal Component Analysis, Digital Elevation Model

Streamline the Shoreline: Application of CoastSat Toolkit in Automated Extraction of Shoreline in the Philippines

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The Philippines has one of the longest coastlines in the world; hence, more communities are exposed to coastal hazards such as erosion, sea level change, storm surges, and tsunamis. Regular monitoring of the shoreline pattern is crucial in mitigating the impacts of coastal hazards, especially in recent years where natural and anthropogenic processes have intensified coastal modifications. However, most studies on coastal hazards rely on manual digitization of shoreline which prolongs the process of mapping, especially when it comes to tsunami hazard assessment. In this study, we tested the efficiency of the emerging open-source AI-based CoastSat toolkit in automating the process of shoreline extraction and compared its performance with the actual shoreline data derived from images captured by DJI Phantom 4 Pro RTK.

CoastSat is an open-source and well-documented Python-enabled tool developed by Vos and others (2019) to monitor the time-series shoreline evolution of select beaches in Australia. Although the toolkit has a built-in shoreline detection algorithm, the classifier was re-trained to be more familiar with the pixel features of select beach areas in the Philippines. The coastal areas of Calauag, Quezon was defined as a test site. Publicly available Landsat 8 TOA satellite images were used as input data which were downloaded via the Google Earth Engine API package of CoastSat. The data were pre-processed using the workflow of cloud masking, downsampling, and pansharpening to improve spatial resolution. A reference shoreline was manually digitized on the interactive GUI to guide the shoreline extraction algorithm. The pixels were then classified into four classes (sand, water, white water, other land features) using the supervised learning algorithm and Multilayer Perceptron Neural Network. Modified Normalized Difference Water Index (MNDWI) calculation was performed to constrain the boundary between the sand and water pixels. Manual adjustments on the Otsu's thresholding algorithm were made to increase the efficiency of shoreline detection. The shoreline data was generated using the iso-valued contour computed through Marching Squares algorithm. The CoastSat capabilities allow users to filter out the best images that will be fed in the classifier before batch shoreline detection.

Visual inspection of the output shoreline overlain on the reference satellite image revealed the successful shoreline position digitization of Calauag, Quezon. The algorithm performed best in delineating the shoreline boundary in mangrove and beach areas. However, it falsely classified pixels in areas adjacent to river inlets and in fish ponds where shorelines were drawn as the interface between the water and embankments. The extracted shoreline data was also validated against the millimeter-scale accuracy of the drone images of select areas in the target site. The CoastSat-derived shoreline using Landsat 8 images yielded a shoreline close to the high-resolution shoreline output of drone photos. The accuracy of the classifier also increased as more training data from the Philippine beaches

were being inputted to the training model. The capability of the CoastSat algorithm in extracting shoreline provides an opportunity to fast-track the process of shoreline extraction in relation to coastal hazards. Further assessment of its performance can be tested in other coastal areas in the Philippines with morphodynamic settings.

Keywords: CoastSat, automatic shoreline extraction, supervised learning, coastal hazard mapping, tsunami

A Geostatistical Approach for Generating a Seismic Microzonation Map of Ormoc City, Leyte

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A vital step required by provisions in modern building codes is the determination of seismic site classification to determine the expected seismic design forces for the structure. One concept employed to look into seismic site classification in big cities is microzonation. Microzonation is the delineation of a region into different areas based on the variation in seismic hazard potential. Slope, topography, soil characteristics, and subsurface conditions are all important parameters in microzonation; microzonation maps with respect to the variation of each of these parameters are prepared and combined to determine the area's earthquake hazard potential.

The DOST-GIA ACER Program, in its effort to improve existing methodologies currently being used, has adopted a geostatistical approach for generating microzonation maps, where the baseline model is based on time-averaged shear wave velocity over the top 30 m (Vs30) combined with a joint model of Vs30 derived from slope and geology. Vs30 data obtained from existing borehole data as well as refraction microtremor surveys conducted in the City of Ormoc, Leyte were used to analyze the Vs30 versus slope trends per surficial geologic unit to observe if there is any probable interaction between slope and geologic terms. Linear regression was used on the Vs30 data to compute for the dependent variables regarding the geologic Vs30 medians, slope, and cross-term coefficients to generate the joint model. The geostatistical interpolation method kriging-with-a-trend is used to incorporate the residuals between the joint model and measured Vs30 data for further refinement of the model. Unlike stand-alone proxies like geology or slope models, this method takes advantage of both the slope and geology trend's predictive potential while also efficiently reverting to ordinary kriging near-measured data to attain consistency with the measured data. The developed relationship between Vs30, slope, and geology allows for a code-based seismic site classification throughout the city. A site classification map adopting the National Earthquake Hazards Reduction Program/International Building Code (NEHRP/IBC) classification scheme is provided in this study.

Keywords: Vs30; site amplification; topographic slope; geology; kriging

Generation of Landslide Susceptibility Map using Frequency Ratio (FR) and Analytical Hierarchy Process (AHP) in the Mineralized Areas of Benguet Province and Volcanic Areas of Southern Luzon, Philippines

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Landslides are one of the most destructive geohazards in the Philippines, claiming lives, destroying infrastructures, disrupting biodiversity, and interrupting traffic, especially in mountainous areas with limited road networks. To manage the adverse effects of landslides, the conduct of Landslide Susceptibility Mapping is an important mitigation tool to warn people of the landslide hazards in their area and the risk that it may pose to their communities.

Thus, this study generated Landslide Susceptibility Maps (LSM) for areas of different geological characteristics: the mineralized areas of Benguet province and the volcanic areas of Southern Luzon. There are eight (8) causative factors of landslides considered in this study for each of the geological areas. These factors include elevation, slope, soil, geology, faults and lineaments, distance from roads and rivers, and aspects for volcanic areas while mineral alteration factor was added for mineralized areas of Benguet. The factor data layers were reclassified into five categories, from very low (1) to very high (5) susceptibility to landslide. Using the frequency ratio method, the correlation between historical landslide occurrence and the classification of each causal factor was calculated. The classification with the highest frequency ratio value was reclassified into very highly susceptible (5) while the least into very low susceptible (1) zones. To achieve the weights to be used for the weighted overlay analysis of the factor data layers, the Analytical Hierarchy Process (AHP) developed by Goepel (2018) was used. Each of the causative factors was rated by 11 experts composed of five (5) geologists, four (4) foresters, and two (2) engineers. These were consolidated into final weights for each geological area as inputs for the generation of LSMs. The results of the study, particularly the LSM, will be useful in developing disaster management protocols for the Local Government Units (LGUs). Additionally, the consolidated weights using the AHP would be useful in generating LSM for areas with similar geological characteristics.

Keywords: Landslide, Landslide Susceptibility Map (LSM), Analytical Hierarchy Process (AHP), Frequency Ratio (FR)

LIGTAS: An Interactive Web-based National Landslide Database through Crowdsourcing: Harnessing Citizen-Science for Landslide Monitoring

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Landslides pose a significant threat to human lives, infrastructure, and the environment. Timely and accurate landslide monitoring is crucial for effective disaster management and mitigation strategies. Landslide monitoring methods, such as remote sensing and ground-based sensors, are often expensive, limited in coverage, and require expertise. To overcome these limitations, the concept of crowdsourcing and citizen science has emerged as a promising approach to gather large-scale data efficiently and cost-effectively. The project "Landslide Investigations on Geohazards for Timely Advisories in the Philippines (LIGTAS)" developed an interactive web-based National Landslide Database through website development and ArcGIS online web-mapping platform to engage the public in data collection and reporting of landslide events. The database serves as a centralized repository for landslide-related information, including date and time of landslide occurrence, exact locations, and triggering factors.

The developed web-based landslide monitoring system employs a combination of mobile application, web platforms, and social media platforms to facilitate community involvement. Citizens are encouraged to report landslide events by submitting geotagged photos, descriptive information, and real-time rainfall data through the LIGTAS landslide reporting platform. These reports undergo a data validation process to ensure data reliability. The final output is a National Landslide Database, which serves as a valuable source of information for researchers, government agencies, and local government units for real-time landslide monitoring and early warning systems. By harnessing the collective power of citizen science, the database facilitates the identification of landslide-prone areas in the Philippines such as the mineralized areas of Benguet and volcanic terranes of Southern Tagalog and Bicol Region.

Keywords: Landslide, Citizen science, Crowdsourcing, Interactive web-based National landslide database.

Tectonic Geomorphology of the Philippine Fault in Agusan-Davao Basin, Eastern Mindanao, Philippines using new high-resolution data

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Eastern Mindanao located south of the Philippines has experienced destructive historical earthquakes (M>7) in the past. Most recently, a Mw 6.0 earthquake struck the province of Davao de Oro last 01 February 2023. This was followed by a sequence of moderate-sized earthquakes with magnitudes ranging from Mw 4.6 to Mw 5.9 last 06-07 March 2023. Current active faults in Eastern Mindanao are mapped using 1:30,000 aerial photographs taken in 1950s and 1979 and were plotted in 1:50,000 topographic maps. Upon the availability of newly acquired high resolution images, we have refined the active fault traces in Eastern Mindanao by integrating the results of aerial photographs, Light Detection and Ranging - Digital Elevation Model (LiDAR-DEM, 1m x 1m spatial resolution), and Interferometric Synthetic Aperture Radar - Digital Elevation Model (IFSAR-DEM, 5m x 5m spatial resolution) interpretations. Morphotectonic analysis unveiled more accurate and additional traces of the Philippine Fault. Interpreted tectonic landforms associated with active faulting in Eastern Mindanao are offset streams, fault scarps on recent deposits, triangular facets, linear valleys, fault saddles, backscarps, pressure ridges, and basins. The transtensional interaction, observed through the left-steps of the segments of the Philippine Fault, dominates the Eastern Mindanao and forms wide basins and valleys in Davao de Oro and Agusan Marsh area. Detailed and high resolution active faults map of the Philippine Fault can be beneficial in disaster mitigation planning and seismic hazard assessment. This study provides valuable information that can enhance the understanding of the earthquake generation potential of the Philippine Fault segments and their tectonic implications.

Keywords: Philippine Fault, LiDAR, IfSAR, Aerial Photographs, Agusan-Davao Basin

POSTER SESSION:
Social License to Operate

Participatory Resource and Landscape Services Mapping of an Upland Mining Community: Case Study on Barangay Ampucao, Itogon, Benguet

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Long-term sustainable management of mining areas entails a better understanding of human-environment interaction, including environmental impacts, land use, and landscape services among local communities. The study area, Barangay Ampucao in Itogon, Benguet, has long been a mining community hosting a sixty-five-year-old large-scale mining company and several small-scale gold mining. In this research, participatory mapping and focus group discussion were conducted to characterize the human-environment interactions of an upland mining community in the Philippine context through a community-drawn resource map outlining their natural, economic, and social resources. Sketch maps were digitized using QGIS 3.22.8 and analyzed for hotspot analyses using kernel density estimation. Results show that Barangay Ampucao has a mixed-use landscape with upland farming, family-operated livestock raising, large-scale Cu-Au mining, scattered small-scale gold mining activities, and a tourist eco-hiking trail. Landscape services enjoyed by the Ampucao community from their environment include freshwater, fuel, food, geological resources, spiritual values, aesthetics, and social relations. Spatial patterns of the landscape services show general clustering where the sitios (neighborhoods) are located. Identifying and mapping the community's local spatial knowledge are critical inputs to sustainable management of mineral-rich areas, policy guides for mixed-used natural resources management, and final mine decommissioning and rehabilitation plans.

Keywords: participatory mapping, landscape services, mining community

Resiliency of the National Museum in the Face of the COVID-19 Pandemic: Engaging the Public in Geosciences Through Digital Means

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The cultural sector was one of the most affected by COVID-19 in 2020. The majority of cultural institutions were forced to shut their doors, leaving museums and galleries with an unclear future. Despite the challenges and confinement posed by the pandemic, the National Museum of the Philippines has remained steadfast and has continued to fulfill its core functions and mandates by creating new ways to connect the public with its exhibitions and programs through its digital presence.

This paper explores the methods employed by the Geology and Paleontology Division (GPD) of the National Museum of the Philippines in utilizing virtual and online platforms to conduct programs and activities that are helpful in the appreciation of geosciences. The GPD produced more digital and online content to educate and engage the public with their temporarily inaccessible collections, especially in the appreciation of Philippine Fossils. The online contents resulted in increased digital engagement with the online platforms of the museum. This remarkable engagement from the public paved the way for the creation and publication of GPD's *Fossils: Records of Prehistoric Life in the Philippines* book, which the public can view for free on the museum's website.

The increase in digital engagement is one of the most far-reaching consequences of COVID-19, and it opened more opportunities for the National Museum to create a new and unique way to promote and access its exhibitions and collections.

Keywords: Social Media, Geology, Paleontology

Promoting Geosciences: The National Museum of the Philippines' Approach to Curating Captivating Geological Exhibitions

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The National Museum of the Philippines (NMP) is the premier repository and custodian of the Philippines' cultural, historical, and natural heritage. A part of its vast collections is the National Geological and Paleontological Collection which is composed of over 28,000 pieces of rocks, minerals, fossils, petroleum products, and geological tools of national and international significance. This collection is being managed by the Geology and Paleontology Division (GPD).

In fulfilling its mandate as an educational, cultural, and scientific institution, the GPD has curated several geological exhibitions in its central office, and in other regional offices in Batanes, Rizal, Bicol, Cebu, Iloilo, and Negros Island with the goal of fostering broader public awareness and interest in the field of geology.

This work focuses on the different methods undertaken by the GPD in curating and enhancing exhibitions that aim to elevate the public's engagement and interest in geosciences. Moreover, it puts emphasis on the visitor-centric approach of the museum in providing services that are well-matched with the needs and expectations of museum goers. An overview of the different geological exhibitions all over the Philippines and other GPD programs will also be highlighted in this work. Finally, this will also present the efforts of the GPD in strengthening its relevance in the expansion and promotion of geosciences and in the service of the Filipino people.

Philippine Participation in the International Earth Science Olympiad (IESO): Benefits and Challenges

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The International Earth Science Olympiad (IESO) is one the 14 commonly recognized international Science Olympiads. The Philippines was involved in planning for its inception before it finally commenced in 2007 and even hosted the 2nd IESO held in Manila and Bicol in September 2008. This was the first time that the Philippines hosted an international Science Olympiad.

Since 2007 until its most recent participation in 2019, the Philippines garnered 1 gold, eight silvers, 18 bronzes, 1 honorable mention during the 3rd IESO in Taiwan, aside from the awards earned in the International Team Field Investigaion (ITFI) and Earth Science Project (ESP). Fortunately, a number of IESO Olympians end up taking an Earth Science course (BS Geology, in particular) – Paul Yang-Ed (2008, Bronze medalist), Emmanuel Codillo (2009, Honorable Mention), Christopher Jan Landicho (2011, silver medalist), and Eugene Toribio (2017, silver medalist). Mr. Codillo even topped the 2016 Geology Board Exam and just recently (2023) finished his PhD in Geology at Massachussetts Institute of Technology. Dr. Federico De Jesus was the youngest participant (13 years old) when he won bronze during the First IESO held in South Korea in 2007. He recently got his PhD in Molecular Medicine. Jan Francois Severo (2018, bronze medalist) graduated summa cum laude in Materials Engineering in UP Diliman this year.Most of them have testimonies to share as to how their participation in the Olympiad had influenced their career path.

Other benefits of IESO participation, aside from development of human resources in the Earth Sciences, are public awarenes of Earth Sciences, provision of appropriate training for Earth Science teachers (e.g. BU-RCSMED initiatives), geotourism especially when the 2nd IESO was held in Manila and Bicol and during Earth Science camps at Mirisbiris Garden (owned by Dr. Chris Newhall) where final selection and training are conducted.

Just like the other international science Olympiad participation in the Philpines, the government does not appropriate funds for participation in IESO. Funding support usually comes from various sources which are basically funds raised by the institution in charge. For instance, Mathematical Society of the Philippines for International Math Olympiad (IMO); Ateneo De Manila University for International Biology Olympiad (IBO), and Bicol University-Regional Center for Science and Mathematics Education Development (BU-RCSMED) for International Earth Science Olympiad (IESO). Often lack of funding prevented the participation in IESO, just like in 2012 to 2016. In other countries, the government plays a vital role in supporting olympiad participation. For instance, the Ministry of Education Malaysia (MOE) is the highest governing body in charge of all national science Olympiads in Malaysia. MOE allocates funding and appoints agencies to handle the science olympiads (Azmi, 2023)

Training is also an issue. Most trainings were conducted by volunteers, like some faculty from the National Institute of Geological Sciences, UP-Institute of Environmental Science and Meorology, Bicol University-RCSMED, and experts from PAGASA, Astronomical League of the Philippines (ALP) and others.

Science olympiads play an important role in the development of scientific talents and giftedness and contribute in building up the science capital of the Philippines. And in relation to the GEOCON theme for 2023 – Investing on human resources contributes significantly in ensuring our natural resouces are properly managed by decision and policy-makers who put premium and importance to, or appreciation of, Earth Science principles and science-based ideas.

Keywords: International Earth Science Olympiad, public awareness, geotourism, scientific talents

POSTER SESSION:
Environment

Vegetation diversity as a factor in carbon sequestration and storage: Examples from the ultramafic forests in Palawan, Philippines

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Aboveground biomass represents the second-largest carbon reservoir, accounting for an estimated 15-30% of carbon stores in various forest ecosystems. However, in ultramafic forests, a distinctive group of plants known as metallophytes thrives. These plants are renowned for their ability to flourish in soils containing exceptionally high concentrations of undesirable metals and limited soil moisture. Research has shown that a combination of soil properties, climate, and water availability leads to the development of relatively stunted vegetation, with the tallest trees rarely exceeding 20 meters in height.

To assess the carbon storage potential of metallophyte aboveground biomass, we conducted a floristic study in two distinct types of ultramafic formations on Palawan Island. The selection of these two sites was based on their differing land uses. Our observations revealed that Bataraza exhibited higher species diversity, boasting a total of 18 tree species within a one-hectare study plot, while Puerto Princesa City had only 12 species. However, in terms of diameter at breast height (dbh), Puerto Princesa City's ultramafic area featured trees with a wider average dbh of 14.84 cm, as opposed to Bataraza's 12.64 cm. Notably, *Syzygium leucoxylon* had the largest dbh value of 46 cm in Puerto Princesa City, while *Casuarina equisetifolia*, with a dbh of 39 cm, was the tallest in Bataraza.

Our data demonstrated that the aboveground biomass in Puerto Princesa City was higher, despite the area hosting a limited number of tree species. Further analysis of soil carbon content indicated that Puerto Princesa City's ultramafic soils contained 99.05 tons/ha, while Bataraza's soils reached 85.68 tons/ha. Considering the combined contribution of aboveground biomass and soil carbon, our study suggests that Puerto Princesa City's ultramafic formations have greater potential for sequestering atmospheric carbon. These findings underscore the importance of preserving and conserving the remaining species within the area, making this research a pivotal basis for conservation efforts.

Keywords: aboveground biomass, diversity, metallophytes, soil carbon, ultramafics

The role of geology and physical properties in soil organic carbon storage: Examining ultramafic and karstic forests in Palawan, Philippines

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Soil organic carbon (SOC) is influenced by various factors including vegetation inputs, soil depth, soil moisture, lithology, soil formation, and other environmental parameters. Consequently, forest vegetation, particularly in ultramafic and karst soils, is also largely controlled by the underlying parent materials. This study evaluated the SOC stock and the physicochemical properties of soils influenced by bedrock lithologies such as ultramafic and karst in Puerto Princesa City and Bataraza, in Palawan. The SOC content in ultramafic soils ranges from 4-7 % in the topsoil (0-20 cm depth) to 3-5 % in the subsoil (21-50 cm) while topsoil SOC content in karstic soil range from 5.10-6.24 %. Consequently, soil organic carbon stocks in ultramafic soils from Puerto Princesa City is 99.05 tons/ha while Bataraza has 85.68 tons/ha, while the karstic soil in Bataraza has 74.27 tons/ha. This shows that ultramafic soils has relatively higher potential to sequester and store large amounts of carbon. On the other hand, the hierarchy of different physicochemical variables were established using Kruskal-Wallis test for nonparametric variables while Pearson R Correlation test was used for parametric variables. Results showed that soil texture had the greatest influence on organic carbon storage while soil pH was the second most influential parameter. Soil porosity, bulk density, and particle density were the least influential parameters, respectively. Other factors such as land use, land cover, and tree species will be considered in terms of their effects in SOC sequestration.

Keywords: Carbon stock, carbon sequestration, soil physico-chemical properties

Assessment of soil organic carbon from various land use types within the Agno River Basin, Philippines

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The organic carbon stored in the soil is significantly influenced by land uses and soil management practices. This study quantified and compared soil organic carbon (SOC) within the Agno River Basin under different land uses, namely; open forest, agricultural land, brushland, and grassland. A total of 29 samples were taken at depth 0 - 20 (topsoil) cm and 21 - 50 cm (subsoil) using soil auger. Moreover, to measure the bulk density (BD) of the soil, undisturbed core method and gravimetric method were used. The SOC content, on the other hand, utilized Walkley-Black procedure. The results showed that BD and % SOC decreased with depth, wherein low BD and high % SOC were observed at 0 - 20cm, while high BD and low % SOC were observed at 21 - 50cm depth. However, larger SOC stock was observed in the subsoil layer compared to topsoil layer with computed 68.93 and 56.92 ton/ha, respectively. Comparison between different land uses showed that lower BD (i.e., 1.27 g/cm³ from the topsoil and 1.34 g/cm³ from the subsoil) were observed in areas under open forest while higher BD, 1.40 g/cm³ from the topsoil and 1.44 g/cm³ from the subsoil, were observed in areas with of grassland and brushland land covers. Relatively high % SOC were observed in brushlands while grasslands and agricultural lands have relatively low % SOC. The computed SOC storage (in ton/ha) decreased in order of brushland >open forest> agricultural land> grassland. The study showed that SOC stock is significantly different with soil depth and across land use types in ARB. Thus, vegetation is considered as one of the important factors for SOC storage.

Key words: soil carbon storage, soil depth, land use, land cover

Phenotypic Characterization of Heavy Metal-Tolerant Proteobacteria Isolated from the Soil Along the Agno River Basin

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Anthropogenic activities (i.e. agricultural, domestic, industrial, as well as geogenic processes) contribute to the Heavy metal (HM) accumulation within the Agno River Basin (ARB). One of the impactful land uses of ARB is mineral extraction. HMs from mining activities accumulated in soil and mine tailings up to an alarming concentration poses a great threat on both the aquatic and terrestrial ecosystems. In microorganisms, some HMs are vital cofactors for metalloproteins and enzymes, but when they reach beyond threshold it could affect its growth, morphology, and biochemical activities. Among the HMs that could be hazardous at high concentrations are Hg, Pb, Cd, As, Zn, Ag, Cr, Cu, Ni, Fe, and Co, which are predominant on mine tailings. These HMs alter the biomass, diversity of microbial communities, cycling of elements, and cause inhibitory effects on microbes via blocking the essential functional groups. Other microorganisms have developed several mechanisms, like bioaccumulation, in order for them to tolerate HMs and could adapt and survive under metal-stressed conditions caused by effluents of mining. HM-tolerant bacteria belonging to phylum Proteobacteria are Gram-negative that shows extensive metabolic diversity. The main objective of the study is to isolate, characterize, and identify HM-tolerant proteobacteria from the collected soils along the Agno River Basin in Northern Luzon, Philippines. In this study, the soil collected from the 29 sampling sites (from the provinces of Benguet, Pangasinan, Nueva Ecija, and Tarlac) along the ARB were subjected to microbiological analysis correlated with the soil geochemical properties. The HM-tolerant proteobacterial strains that were isolated and identified are promising potential bioremediators. This study could serve as a baseline data and information on future bioremediation studies.

Keywords: heavy metal (HM)-tolerant, Proteobacteria, multiple metal resistance (MMR) technique, *16S rRNA* gene sequencing

Relationship of symbiotic mycorrhizal fungi and soil properties from rhizospheres in Upper Agno River Basin (Philippines)

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Soil is a mixture of mineral and organic matter, considered one of the most valuable natural resources. Thus, assessing the soil condition in an area is essential due to soil influences in other environmental processes. One of which is the presence of mycorrhizal fungi in the soil, which has an important function for plant growth, especially when soil nutrients are limited. This study determines the soil's physical properties and the symbiotic mycorrhizal fungi within the Upper Agno River Basin. The soil's physical properties include texture, pH, color, bulk density, particle density, and porosity that uses a hydrometer method, potentiometric method for pH determination, Munsell soil color chart, and undisturbed core and approximation methods, respectively. Mycorrhizal analysis used the procedures provided by Brundrette et al. (1996). Soil samples were taken from depths of 0-20 cm and 21-50 cm for each sampling site with a total of five sampling sites. The results show that the soils mostly have sandy loam and sandy clay loam textures. Notably, the soil pH of the samples ranges from 4.9 to 6.83, which signifies that the soil types contain ideal pH for plant growth. For bulk density, the values range from 1.01 g/cm³ to 1.58 g/cm³ while particle density values range from 2.38 g/cm³ to 2.63 g/cm³. Mycorrhiza samples from the study sites were inoculated in the laboratory wherein soil samples collected were combined with sandy planting medium and were planted with Bahia grass species. The seedlings were planted in December 2022 and harvested in June 2023. After the harvest, the length, fresh and oven-dry weight of shoots and roots, and the spore counts were measured while visual estimation of fungi on roots was done. Results showed that the highest average value for shoot length was 55.33 cm while the highest average values of fresh and oven-dry weight were 12.95 g and 7.71 g for the shoots, and 37.84 g and 14.57 g for the roots. The highest average from mycorrhizal spore count is 612 from sample GS5 RZ2. Identification of the mycorrhiza species among the different sampling sites will also be carried out.

Keywords: soil physical properties, pH, bulk density, particle density, symbiotic mycorrhizal fungi, spore count, root colonization

Geochemical characterization of mine wastes in the Philippines for the possible recovery of valuable elements: Towards circular economy in mining

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Mining wastes can have significant environmental impacts in the Philippines since these may contain high concentrations of potentially toxic elements (PTEs). However, mining wastes may be reprocessed because they often have significant amounts of potentially valuable elements. In this study, several mine wastes, in the form of waste rocks/soils and tailings, were characterized using X-ray Diffraction (XRD) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analyses to determine the concentration and occurrences of different strategic elements. Geochemical results show that Rapu-Rapu VMS legacy mine wastes still have high concentrations of Ag, Cu, Pb, and Zn; Barlo VMS mine waste rocks have elevated Au, Ag, and Cu values; tailings from a porphyry-Cu mine in Benguet and from artisanal mines in Camarines Norte have high Cu and Au contents; and mine wastes of a Ni laterite mine in Zambales have elevated Co and Sc contents. In contrast, waste rocks from legacy mines in Camarines Norte and Palawan and tailings from an active mine in Benguet have low concentrations of valuable elements. The increase in demand for these critical raw materials and new developments in a more sustainable recovery of economic metals could turn these mine wastes into valuable products towards achieving a circular economy in the Philippine mining industry.

Keywords: mine waste, tailings management, valuable elements, sustainable development, circular economy

Mineralogical and Geochemical Occurrence of Mercury in Mine Tailings from Abandoned Mercury Mine in Palawan: Implications in Environmental Impact

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One of the legacy mines in the Philippines, a mercury mine in Puerto Princesa City in Palawan Island, was operated by the Palawan Quicksilver Mines Inc. (PQMI) from 1953 to 1976. The tailings left behind was processed through calcination and was allegedly dumped in the jetty port in Honda Bay and surrounding villages. In this paper, the mineralogy and geochemistry of Hg is analyzed from sediments of three alleged mine waste dumping areas surrounding PQMI, namely, from the Honda Bay Wharf (HBW), from Sitio Matahimik (SMK; the village 300 meters away from former open pit site) and from the Puerto Princesa City Landfill (PPCL). Based on grain size analysis, the sediments with size less than 63μm show the highest mercury concentration reaching up to 885 ppm in SMK. Through automated scanning electron microscopy energy-dispersive X-ray spectroscopy (SEM-EDS) analysis of composition, Hg is found to occur in mercury sulfides (HgS, cinnabar) surrounded by ferric oxide minerals and silica for all sampling sites. The cinnabar grains from both SMK and PPCL are relatively large (10μm size) and do not contain visible zoning, indicating that no processing had occurred while grains from HBW are smaller (<2μm) and broken in textural form. It is inferred that the "mine wastes" dumped in SMK and PPCL are the low-grade ore materials that did not pass the cut-off grade while those in HBW are the calcined ores. From these findings, it was confirmed that the finer grain size fractions that are more prone to inhalation through dust are concentrated with cinnabar minerals. Meanwhile, lower HgS amount in HBW occurring within goethite phases assures low biotoxicity of the metal provided it is not reacted with acidic water. This study contributes to the current knowledge in abandoned mine tailings in the Philippines and its implications in mine environmental safety.

Keywords: abandoned mine, cinnabar, mercury, Palawan

Enhancement of Groundwater Monitoring within the Lower Bulacan Province

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Recent studies conducted within the Lower Bulacan Province has indicated a significant progression of saline water intrusion inland, beginning to affect municipalities that were previously do not have reports of increasing salinity in their groundwater supply. Significant groundwater extraction has been historically identified as one of the primary causes of this condition, aggravated by the increased urbanization across the province and delays in migration to alternative water resources to provide supply. The early and strategic placement of monitoring wells will provide concerned local water utility agencies, local government units and national government agencies with future data to determine the progression of this condition in order to establish updated policies and functional measures to address this impact to the overall water supply of Lower Bulacan, as well as provide a strong basis in the development of other water resources available to the region.

POSTER SESSION:
Natural Hazard

Long-term Subsidence Analysis in Marilao, Bulacan Spanning 6 Years of GPS Data

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Results are presented for the GPS data analysis of the Marilao site, MAR2, which is part of the Valley Fault System (VFS) network. The VFS is a 100 km long active fault that transects several areas in Metro Manila and nearby provinces. The VFS network was established in 2016 by DOST-PHIVOLCS and National Cheng Kung University (NCKU) to monitor the deformation and behavior of the fault system using GPS data. The Marilao site, MAR2, is located in Marilao, Bulacan, a town that is experiencing severe flooding due to land subsidence and also, possibly, sea level rise.

The GPS data from MAR2 were processed using the Bernese 5.2 software and referenced to the Eurasian Plate. The interseismic GPS results between 2016 and 2022 show that MAR2 has a horizontal velocity of 71.62 mm/yr and an azimuth of N294°, indicating that it is moving westward relative to the Eurasian Plate. The time-series also shows that MAR2 has a vertical displacement of -361.3 mm from February 2016 to August 2022, which translates to 55.58 mm/yr of subsidence.

The results warrant identifying the causes of subsidence and developing a long-term comprehensive plan to mitigate its effects. Future actions would include the need to improve spatial resolution by adding more GPS stations in order to fully understand the extent of the subsidence within the area.

Keywords: GPS, Bulacan, Marilao, subsidence

Surface Rupture along the Creeping Leyte Segment of the Philippine Fault: The 2023 M_S 5.3 Leyte, Leyte Earthquake

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On January 15, 2023, a magnitude (M_S) 5.3 earthquake with a depth of 1 km struck the northern Leyte region in the Philippines. The mainshock and aftershock hypocentral locations and focal mechanism indicate that the earthquake originated along the northern end of the Leyte segment of the Philippine Fault, a well-established creeping fault. Evidence of fault creep was vividly documented from the ongoing displacement of cultural features in the affected area, particularly in Leyte, Leyte. A field investigation was carried out to examine the characteristics of this seismic event. Despite the relatively low magnitude, the earthquake produced an 8-kilometer segmented surface rupture, oriented along N25-30W. We measured a maximum left-lateral displacement of 1.5 cm. The observed surface rupture length exceeds the expected length, while the recorded maximum displacement aligns with its magnitude based on empirical relations. This surface rupture marks the first documented occurrence of such a phenomenon along the Philippine Fault associated with an earthquake with M<6, particularly along a creeping fault segment. Globally, earthquakes with magnitudes as low as this one (<6) have a minimal probability of rupturing the Earth's surface. However, the extreme shallowness of the Leyte event provides a crucial explanatory factor for its surface rupture occurrence. The difference between the fault's long-term slip rate and its creep rate, as derived from prior studies, suggests the presence of a slip deficit as the likely trigger for this earthquake rupture event. Additionally, Coulomb stress analysis indicates a notable stress increase in the area following the occurrence of the 2017 M_W 6.5 Leyte Earthquake, situated to the south of the 2023 earthquake event. This unprecedented seismic event not only sheds light on the dynamic behavior of the Leyte segment of the Philippine Fault but also serves as a reminder of the seismic risks associated with creeping faults. The study offers invaluable insights into the complex nature of this fault and underscores the paramount importance of continuous monitoring of such faults.

Keywords: surface rupture, creeping fault, low-magnitude earthquake, slip rate

The MOVE Faults: Measurements of Velocities of Earthquake FAULTS in the Philippines Using GNSS

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The MOVE Faults (Measurements Of Velocities of Earthquake Faults in the Philippines) is a Philippine government-funded project that aims to measure the velocities and describe the mechanical behavior of the active faults in the Philippines using GNSS.

The use of GNSS in the Philippines started in 1991 as the GPS project, a result of the collaboration between PHIVOLCS and two French institutions – Université de Paris VI and Institut Géographique National under the Republic of the Philippines-France Collaborative Project on Seismotectonics.

In 1996, PHIVOLCS collaborated with the Institute of Earth Sciences - Academia Sinica of Taiwan (IESAS) to establish the Philippine GPS campaign network in Central and Northern Luzon. The collaboration is still ongoing, with the entire Luzon network composed of around 50 Continuously Operating Reference Stations (CORSs).

In 2008, PHIVOLCS, in collaboration with National Cheng Kung University of Taiwan (NCKU) under the RP-Taiwan Project, installed 10 CORSs along the Valley Fault System (VFS). Two years later, 8 CORSs were installed in Mindoro Island under the same project, with the objective of studying the collision between Palawan and the Philippine Mobile Belt. In more recent years, the same collaboration yielded the densification of the VFS network into 27 CORSs comprised of 4 dual and 23 single frequency receivers, as well as the eventual establishment of 20 CORSs in Samar and Leyte, 8 CORSs in Masbate, 2 CORSs in Romblon, 2 CORSs in Mindanao and 1 in Palawan.

In 2009, a grant from the Department of Science and Technology Grant-In-Aid project led to the acquisition of new GPS receivers, the reoccupation and rehabilitation of old GPS networks along the PFZ and the study of crustal deformation patterns of the Cotabato-Sindangan Fault, a 300-km long active fault cutting across northwest to southeast of Mindanao.

In the past 5 years, PHIVOLCS has installed 23 CORSs in Visayas and Mindanao with real-time monitoring of displacement and velocity capabilities. At present, more than 300 GPS campaign sites and CORS are installed all over the country, devoted to the study of crustal deformation patterns along the PFZ and other minor yet potentially active faults in the country.

Keywords: GPS, PHIVOLCS, collaborations, Philippine Fault

GPS Motions Associated with the 2022 July and October Northwest Luzon Earthquakes

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The Northwestern Luzon earthquakes, consisting of the M7.0 event on 27 July 2022 and the M6.4 on 25 October 2022, were investigated using Global Positioning System (GPS) data collected from measurements in Luzon prior and after the events.

Analysis of interseismic GPS data from 2000 to 2022 showed that site velocities vary from 72.72 mm/yr to 85.87 mm/yr, based on a reference point, S01R, located in Taiwan on the Eurasian Plate. The azimuths associated with these velocities ranged from N284° to N288°.

Co-seismic horizontal displacements associated with the two earthquakes were also calculated. Displacements measured at a point located 0.4 km east of the middle of Abra River Fault are 194 mm and 42 mm for the 27 July earthquake and the 25 October earthquake, respectively. On the other hand, the point located 0.2 km west of Vigan-Aggao Fault was displaced by 10 mm and 30 mm during the 27 July and 25 October earthquake, respectively. The cumulative co-seismic displacements near Abra River Fault and Vigan-Aggao Fault are 235 mm and 29 mm, respectively, following the two seismic events.

Moreover, the integration of four Velocity and Displacement Autonomous Solution Engine (VADASE) enabled stations of National Mapping Resource and Information Agency (NAMRIA) into the GPS network facilitated measurements of near real-time co-seismic displacements ranging from 14 mm to ~73 mm for the 27 July 2022 M7.0 earthquake. These stations are located from 130 - 440 km from the epicenter. The integration also made possible the detection of ground shaking in other parts of Luzon at least 45 seconds following the event.

Keywords: GPS, Northwestern Luzon earthquake, co-seismic displacement

GPS Motions Associated with the 2020 and 2023 Masbate Earthquakes

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Global Positioning System (GPS) data collected from continuous and campaign measurements were used to estimate the long-term interseismic surficial velocities and co-seismic displacements associated with two significant earthquakes in Masbate Province, the M6.6 and M6.0 events on 18 August 2020 and 16 February 2023, respectively.

The interseismic GPS results between 2004 and 2020 show that the velocities of sites vary from 23.39 mm/yr to 55.79 mm/yr and have azimuths ranging from N291.63° to N310.56°, relative to the Eurasian Plate. Results also show that the relative motions across the Philippine Fault in Masbate are 22.100 mm/yr and 11.064 mm/yr.

Measurements associated with the August 2020 earthquake showed that the largest horizontal displacement is 447.5 mm towards N137.61°. The total co-seismic displacement was measured at least 620 mm along the fault, consistent with the approximate horizontal displacement measured by the PHIVOLCS Quick Response Team (QRT) members.

Similarly, data from the GPS survey following the Mw 6.0 16 February 2023 earthquake show predominantly parallel displacements to the Philippine Fault. Two points, located east of the fault, demonstrate NW-directed movements of 116.1 mm at N327.65° and 51.2 mm at N326.16°. Two points west of the fault have horizontal displacements of 92.3 mm towards N138.58° and 65.1 mm towards N145.40°, respectively. In general, most of the points west of the fault moved in a southeasterly direction resulting from elastic rebound. The total co-seismic displacement succeeding the earthquake in 2023, is at least 200 mm.

Keywords: GPS, Masbate earthquake, co-seismic displacement

Impacts of the 16 February 2023 M$_w$6.0 Masbate Earthquake

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At 2:10 AM (local time) on 16 February 2023, a magnitude (M$_w$) 6.0 earthquake struck the province of Masbate. The epicenter had a focal depth of 10 kilometers and was located offshore along the Masbate Pass, 11 kilometers southwest of Batuan. Based on epicentral location, aftershock distribution, and focal mechanism solution, the earthquake was generated by the Masbate segment of the Philippine Fault. The maximum ground shaking was felt at PHIVOLCS Earthquake Intensity Scale (PEIS) VI (very strong) in areas near the epicenter in Masbate Island and Ticao Island. The DOST-PHIVOLCS Quick Response Team conducted a field investigation to assess and map the earthquake's geologic impacts and effects to structures. An approximately 28-meter-long ground rupture was mapped in Brgy. Suba, Dimasalang based on eyewitness accounts, since the manifestation of the rupture has already been effaced by heavy rains during the time of visit. The residents notably recalled observing the rupture in the same area 20 years ago, during the 15 February 2003 M$_s$ 6.2 Masbate earthquake. Liquefaction caused differential settlement in swampy areas and lateral spreading along the coast of Dimasalang, Masbate. Roadcut landslides were observed in the municipalities of Uson, Batuan, and San Fernando. Multiple tension cracks pointing in the same direction of failure were documented in a zigzag road located in San Fernando. Damaged structures, categorized based on damage severity and building type, were also documented in 42 barangays in Masbate. Assessments revealed that older structures and those constructed using substandard materials were more susceptible to damage. Considering the frequency of earthquakes in the province, the 16 February 2023 M$_w$ 6.0 event is a timely reminder to continue building efforts on disaster preparedness, mitigation, and response.

Keywords: Masbate, Philippine Fault, earthquake impacts

Tectonic Implications and Impacts of the 2023 Ragay Earthquake Swarms

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From 07 June 2023, Ragay, Camarines Sur has been experiencing an earthquake swarm. Approximately 155 associated earthquakes were recorded, 50 of which were felt. The highest magnitude recorded by the Philippine Seismic Network for this earthquake swarm is M_W 4.4 which occurred on 07 June and 19 August, both were felt at PHIVOLCS Earthquake Intensity Scale (PEIS) V (Strong) in the municipality of Ragay, Camarines Sur. Despite being categorized as light earthquakes, structural impacts were still noted in the vicinity of Ragay. Source faults associated with the earthquake swarm have no clear surface manifestations. However, seismicity distribution and the focal mechanism solutions derived from PHIVOLCS SWIFT-CMT of earthquakes with Magnitude 4 and above indicate a possible strike-slip motion with a southwest-northeast trend. The seismicity distribution of the 2023 earthquake swarm also shows a similar seismicity distribution with the 2021 Ragay earthquake swarm events. These events suggest deformations within a crustal transtensional fault system bounded by an unnamed fault traversing the municipalities of Goa and Libmanan, Camarines Sur to the north, and the Legazpi Lineament to the south.

Keywords: earthquake swarm

Accelerated Tsunami Modeling of the East Luzon Trough on Calauag, Quezon

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Developing accelerated and accurate tsunami assessments is a must for ensuring the safety of coastal communities. To achieve that, current tsunami hazard mapping methodologies should be enhanced by utilizing high-resolution data to produce more accurate hazard maps, thus contributing to improvements in assessment methods, including speed, accuracy, and reliability of hazard maps, and the development of early tsunami warning systems in response to tsunami events. The computational performance and features of two widely-used tsunami modeling software, COMCOT and JAGURS, were analyzed by modeling with multiple high-resolution bathymetries on a computer with hardware capabilities of a 32Gb RAM, i9-12900 CPU @2.9GHz MSI Notebook. The study area selected is the municipality of Calauag in Quezon Province. The East Luzon Trough was considered as the tsunamigenic earthquake generator in the simulation due to its proximity and potential to affect the study area. No historical tsunami event in the study area is associated with the mentioned earthquake source, so the accuracy and comparison of the tsunami simulations to real-life scenarios cannot be ascertained.

In an attempt to obtain the highest resolution possible, this study compared the two tsunami models in terms of wave data (i.e. height and arrival time) and hardware capabilities (i.e. elapsed time and storage requirement) upon execution on five levels of nested grids with an increasing spatial resolution (15, 5, 5/3, 5/9, and 5/27 arcseconds) derived from two datasets. Thus, a total of four scenarios were modeled in this study - JAGURS-1, JAGURS-2, COMCOT-1, and COMCOT-2. JAGURS-1 and COMCOT-1 refer to the dataset using GEBCO bathymetry and elevation data (SRTM15+), while JAGURS-2 and COMCOT-2 refer to stitched nearshore bathymetry derived from Sentinel-2 and IfSAR DEM. Open multi-processing (OpenMP) libraries in the source code for both models were also utilized upon compilation for faster data processing.

Differences in wave heights and arrival times were observed between the models and datasets. The first series of waves arrived at Brgy. Dapdap 69 to 82 minutes into the simulation with wave heights ranging from 1.27 to 1.64 meters (JAGURS-1), 1.36 to 1.80 meters (COMCOT-1), 1.30 to 1.56 meters (JAGURS-2), and 0.95 to 1.69 meters (COMCOT-2). Notable maximum wave heights were recorded in the GEBCO dataset in the most populated barangay, Brgy. Poblacion, at 2.33 m using JAGURS and 2.32 m using COMCOT. Wave height differences between models across all datasets were at most 0.3 m. However, the difference in wave heights between datasets of varying native resolution was relatively higher, which is at most 1 m. Longer computational time ranging from 49 to 55 hours and larger storage requirements up to 130Gb were required for COMCOT to execute, unlike JAGURS which only needed 19 to 23 hours to finish and 50Gb of space.

Keywords: Tsunami simulation, COMCOT, JAGURS, Comparative Analysis

Revisiting the 1976 Magnitude 8.1 Moro Gulf Earthquake and Tsunami: The East Side Story

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The infamous 1976 Moro Gulf earthquake and tsunami is said to be one of the most disastrous events to ever occur in the Philippines. On August 17, 1976, at 00:11 AM (local time), a magnitude 8.1 quake jolted Mindanao Island. The quake's epicenter was traced offshore of the Moro Gulf, along the shallow portion of the subducting slab of the Cotabato Trench. Maximum ground shaking experienced by the affected areas nearest the epicenter reached Rossi-Forel (RF) VII. This great earthquake generated a devastating tsunami that left thousands of casualties, displaced families, and millions of pesos worth of damages. Documentation of the impacts was concentrated on the structural damages and tsunami inundation of populated areas such as Pagadian and Cotabato cities. This paper attempts to reconstruct the tsunami impacts specifically on the eastern side of Moro Gulf where tsunami height and inundation were highest by documenting the narratives from eyewitnesses and field verification.

Field investigations in the municipalities of Kiamba and Maitum of Sarangani Province; Palimbang, Lebak, and Kalamansig, Sultan Kudarat; Datu Odin Sinsuat, Maguindanao del Norte; and Cotabato City present new evidence of tsunami impacts. The maximum tsunami height reached about 15 meters and inundated more than 700 meters from the coast. Two to three series of waves were also documented. With the limited investigators and road accessibility issues they had after the event, researchers could not cover the areas primarily affected by the tragic 1976 Moro Gulf earthquake and tsunami, leading to undocumented tsunami data and accounts of survivors.

Keywords: tsunamigenic earthquake, eyewitness account, narratives, DANAS Project

Narrative Accounts and Reconstruction of the 1992 Manay Earthquake and Tsunami

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Two earthquakes with magnitudes 7.1 and 7.5 jolted southeastern Mindanao, 26 minutes apart on 17 May 1992. These earthquakes caused strong ground shaking, destructive tsunamis, and damage to residential houses in the coastal municipalities of Manay, Cateel, Baganga, Boston, Caraga and Tarragona, Davao Oriental Province. To better understand and document the impacts and observations of these earthquakes, we have conducted in-depth interviews in Sitio Bonga, Brgy. Poblacion, Manay where a 6-m high tsunami was reported. This study is part of the DANAS: Earthquake, Tsunami, Volcano Disaster Narratives for an Experiential Knowledge-based Science Communication (DANAS Project), a DOST-GIA funded project that aims to properly document past significant events and document earthquake survivors' experiences using their local languages.

Sitio Bonga, Brgy. Poblacion, Manay, with more than 15 houses, is located in a cove where tsunami amplification is possible and has been confirmed by the tsunami survivors. Narrative analysis of interviews indicates that the 1st and 2nd earthquakes have generated tsunamis with a maximum height of 6 meters and an inundation of about 200 meters. Survivors also identified more than one wave and recession of the sea level after the shaking. Liquefaction manifested as sand boil and fissuring and earthquake-induced landslides were described during the interview. No casualties were reported in this area, they evacuated after the 1st earthquake and tsunami wave, except for a young girl tragically engulfed by the tsunami. The story of this young girl has helped us reconstruct what happened during and after the tsunamigenic earthquake, collaborated with other survivors and tsunami modeling done in previous studies.

Keywords: narrative analysis, earthquake survivors, tsunamigenic earthquake, local language, DANAS Project

A Narrative Analysis of Eyewitness Accounts During the 2019 Cotabato-Davao del Sur Earthquake Series

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In October and December 2019, five (5) magnitude > 6 earthquakes shook the provinces of Cotabato and Davao del Sur and vicinity. These earthquakes were felt at a maximum of PHIVOLCS Earthquake Intensity Scale (PEIS) VIII (very destructive) and caused damage to residential houses and infrastructures. Geologic impacts include earthquake-induced landslides, rockfalls, tension cracks and liquefaction manifested as sand boil, lateral spread and sand fissures. To better understand how affected communities perceived and described these events, we have documented survivor interviews in their respective languages. Our objective is to gather and analyze how they describe their experiences, specifically on the geologic impacts they have witnessed. This study is part of the DANAS: Earthquake, Tsunami, Volcano Disaster Narratives for an Experiential Knowledge-based Science Communication (DANAS Project), a DOST-GIA funded project. A purposive sampling was employed and we have documented the narratives of 16 earthquake survivors located strategically and have experienced firsthand the geologic impacts.

Most of the respondents identified the exact date of the strongest ground shaking and described a vertical movement that coincided with maximum magnitude and their proximity to the epicenter. They have words and descriptions in their languages (Cebuano) to describe different geologic impacts such as ground shaking (*uyog, tay-og, yuta nga nagbalod-balod, tabyog, labyog, yugyog, ningkurog, nag untol-untol*), landslides (*yuta nga nabulandos, naglimin-limin ang yuta, yuta nga nahunlos, nihandos nga yuta*), rockslide (*naligid na bato*), tension cracks (*liki, nangalaka, buhaga sa yuta, murag gipang-ungaran sa baboy halas*), terracettes (*gitadtad ang porma sa yuta, bukid nga murag ni-abili*), and liquefaction (*nagbugwak na tubig, nibuswak nga lapok*) by sand boil (*yuta nga nangaliki dala balas ang sirit, nagbuwa na balas*) and lateral spread (*murag gidaro, liki-liki*). Despite experiencing this series of earthquakes that occurred four (4) years ago, the respondents demonstrated a remarkable ability to differentiate each event. Substantial damages incurred have been aggravated by successive seismic events thus being discerned by the survivors as the single most destructive earthquake event.

Keywords: narrative analysis, local language, geologic impacts, DANAS Project

Seismic Hazard Analysis in a highly seismically active country: A case example in the Leyte Province, Philippines

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In a highly seismically active country such as the Philippines, Seismic Hazard Analysis (SHA), either deterministic (DSHA) or probabilistic, is an important undertaking for assessing ground shaking hazards or other earthquake-induced hazards. Through SHA, ground motion parameters such as the Peak Ground Acceleration (PGA) and Spectral Acceleration, which are used when designing critical structures, are obtained. The main considerations in conducting a SHA for an area or site are: (1) the modelling of seismic sources, (2) the selection of applicable ground motion prediction equation(s) (GMPE), and (3) the site amplification factors. Each consideration requires a thorough review to ensure acceptable SHA results.

In SHA, characterizing seismic sources is one of the biggest challenges because of limited availability of seismicity and field-validated geological data. In this research, DSHA is explored and conducted on selected sites in the Leyte Province which is transected by the Philippine Fault. Various seismic sources within 100km from Leyte Province were characterized. Several GMPEs were also considered and tested.

The OpenQuake engine, an open-source software by the Global Earthquake Model Foundation, was mainly utilized in running the analyses to test its capabilities for SHA and on generating seismic hazard maps. Considering that many recent GMPEs are integrated in the OpenQuake engine, and its user interface is simple, it can be a powerful tool for SHA. This research is implemented by the DOST-PHIVOLCS under its ACER program, and if results are proven satisfactory, then the methodologies developed in this research may be implemented to other provinces in the Philippines.

Keywords: SHA, PGA, DSHA, GMPE, Openquake engine

Seismic Hazard Analysis Application for Calculating and Visualizing Ground Motion Parameters at User-Defined Geographical Locations

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Technologies such as geographic information systems like Quantum GIS and ESRI's ArcGIS, and computational systems like MATLAB and GNU Octave can assist in processing extensive earthquake events and seismic sources for seismic hazard analysis. However, none of the aforementioned tools can perform every necessary function, and switching across different applications and formats can be a tedious process. Aside from the impracticality, handling large datasets manually can also lead to challenges with efficiency and accuracy, and introduce a higher probability of uncertainty. These challenges can be critical when dealing with hazard information as these can potentially affect data-driven decision-making in disaster mitigation. With this in mind, developing a software that can process all this data at once can prove to be more efficient and user-friendly.

The SHADE Project developed a Python-based software to aid in the seismic hazard assessment of the Philippines. The application features an interactive map that is seamlessly integrated, utilizing earthquake catalogs and fault parameters of established predefined points, essential for computing Spectral Acceleration (SA) and Peak Ground Acceleration (PGA) of specific locations. By utilizing this map, users have the ability to choose specific points and access SA (at 0.2s and 1.0s), PGA values, and the hazard curves for the chosen location. The application simplifies the process of ascertaining PGA and SA values, as users simply need to select a point on the map, with the results being automatically generated, eliminating the need for manual analysis and calculations. This streamlines the assessment of potential hazards in the area, providing a more dependable and efficient approach for individuals.

Keywords: SHA, PGA, SA, Python-based application

Earthquake Damage Prediction Analysis Based on Different Magnitude Scenarios: A Case Study at Caraga State University, Butuan City, Philippines

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Seismic ground shaking affects the strength of buildings and structures, which can result in the devastating impacts associated with earthquake occurrences. With the high vulnerability of the Philippine Island Arc to earthquakes, developing innovative approaches for assessing seismic hazards is imperative to measure potential impacts and losses if an earthquake occurs. The primary focus of this study is to provide damage prediction estimates for Mw 5.2, Mw 7.4, and Mw 7.9 earthquake scenarios at the Caraga State University campus. The nearest active fault in the area is the Surigao Segment of the Philippine Fault, which is capable of generating a Mw 7.4 earthquake. The study utilizes the intensity prediction equation of Allen and co-authors (2012) and the average shear-wave velocity measurement of the upper 30 meters of soil layer (Vs30) in the area as a site correction term for the intensity calculation. The study also takes into account the additional damage that may be caused by liquefaction and employs the global geospatial liquefaction model (GGLM) of Zhu and co-authors (2015) for calculating liquefaction probability. The calculation of the building damage ratio for each scenario utilizes vulnerability curves to express the building damage ratio as a function of the measured intensity in the Modified Mercalli Intensity (MMI) scale. Preliminary analysis of the in-situ conditions also suggest that the study area is likely to experience strong ground-shaking since it is overlain by unconsolidated sedimentary deposits and classified as a Site Class E area, characterized by a low, less than 180 m/s, Vs30 value. The study presents an integrated approach to determine and measure the potential impacts of an earthquake, ultimately providing a new approach to seismic hazard assessment and reinforcing the preparedness and mitigation initiatives of the most seismically active areas in the country.

Keywords: Earthquake damage prediction, vulnerability curve, building damage ratio, liquefaction probability, Philippine Fault Zone

The catastrophic April 2022 Baybay City landslides in Leyte, Philippines: characteristics, triggering conditions, and implications for hazard assessment

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Multiple catastrophic landslides triggered by Tropical Storm Agaton (internationally known as Megi) occurred last April 2022, mainly affecting Eastern Visayas, particularly Leyte. At least 125 confirmed deaths and 161 affected households were reported in 5 barangays in Baybay City, namely, Bunga, Can-ipa, Kantagnos, Mailhi, and Maypatag. While Tropical Storm Agaton was in the Philippine Area of Responsibility (PAR), PAGASA-Visayas State University Agrometeorological Station recorded the highest 24-hour cumulative rainfall value at 536.2 mm on April 10. The 90-hour cumulative rainfall reached 996.8 mm, which is more than nine times the normal rainfall of Leyte in April (110.3 mm). Heavy and sustained rainfall from Tropical Storm Agaton caused a rapid increase in pore water pressure, triggering these landslide events. The five major landslides in Baybay City were characterized through satellite imagery, unmanned aerial vehicle survey, field mapping, and material sampling. Landslide materials were found to be volcanic cohesive soils from the weathering of the pyroclastic bedrock. Slopes along the Anobang-Lobi mountain range, like that of Bunga, Kantagnos, and Mailhi, were preconditioned by adversely oriented and southwest-dipping bedding planes. The failures resulted in translational slides along the daylighting bedding planes, while in other areas, it ranged from debris slides to avalanches. The different geologic factors and extreme meteorological conditions contributed to the simultaneous landslide events on a regional scale in Baybay City. Understanding how these factors affect the landslide events will help in future landslide hazard assessments and risk reduction activities in the area.

Keywords: rainfall-induced landslides, Baybay City, Tropical Storm Agaton, landslide hazard assessment

Spatial distribution of co-seismic landslides triggered by the 2023 February to March Davao de Oro earthquake series, Philippines

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The 2023 February to March Davao de Oro earthquake series induced hundreds of co-seismic landslides in the mountainous region of Davao de Oro and other nearby provinces in Eastern Mindanao. The February earthquake had a magnitude (M_W) of 6.0 and the March earthquake series had a magnitude range of M_W 4.2 to 5.9. Manifestations of mass movement due to ground shaking such as tension cracks and landslides (rock falls and shallow, disrupted slides) affected both artificial and natural slopes. These mass movements resulted in partially damaged structures and partial to total road blockage. The occurrence of co-seismic landslides affected the municipalities of Compostela, Monkayo, Montevista, New Bataan, Nabunturan, Maragusan, Mawab, and Maco. This study aims to evaluate the spatial distribution of co-seismic landslides and identify the correlation between their occurrence with geologic, pedologic, seismic, and topographic parameters.

The Department of Science and Technology - Philippine Institute of Volcanology and Seismology Quick Response Team (DOST-PHIVOLCS QRT) conducted field mapping and interpretation of aerial images acquired through the utilization of remotely piloted aircraft to determine the distribution of slope deformations and landslides. Hazard assessment, landslide inventory, and site observation were carried out for the areas affected by the earthquakes. The team mapped a total of 107 landslides and 80 tension cracks attributed to the 2023 February to March Davao de Oro earthquake series.

Based on the preliminary analysis of data gathered on the field, most of the landslides and tension cracks occurred within the slope range of 15 to 20 degrees, categorized as undulating to hilly slope based on the Bureau of Soils and Water Management (BSWM). These landslides manifested within the elevation range of 600 to 699 meters above sea level (masl) while most of the tension cracks occurred within 200 to 299 masl and 1000 to 1099 masl. Regarding the lithology of affected locations, majority of the landslides occurred in areas dominated by sandstones, shales, and conglomerates, while tension cracks were mostly observed in terrains dominated by sandstones, shales, and conglomerates, quartz diorite, and dacitic and/or andesitic plugs. Information regarding the lithology of the province was based on the lithological map from the Mines and Geosciences Bureau (MGB). Using the soil map from the BSWM as reference for pedologic information, the result suggests that most of the landslides and tension cracks occurred in areas dominated by sandy clay loam, notably the Camasan sandy clay loam.

The co-seismic landslide inventory for the 2023 February to March Davao de Oro earthquake series was compared to the latest earthquake-induced landslide hazard model produced by the institute following Newmark's sliding block analysis. The model predicted

the occurrence of landslides with an accuracy of ~95%, with most of the landslides occurring in areas under the "moderate hazard" classification. The landslide inventory and hazard model results can be enhanced by adding comprehensive landslide interpretation using available satellite images. Utilizing satellite images for landslide identification and interpretation can fill the spatial gaps left by the limitations of both field and RPA surveys. The landslide inventory for the 2023 Davao de Oro earthquake events, together with the analysis conducted versus multiple parameters, will improve the completeness of the overall co-seismic landslide inventory of the Philippines and the accuracy of the earthquake-induced landslide hazard models produced by the Institute. This will benefit stakeholders by helping them enhance their disaster resilience towards earthquake-induced landslide hazards.

Keywords: Newmark's sliding block analysis, remote sensing, remotely piloted aircrafts

Assessment of the Geology, Geomorphology, and Anthropogenic Factors of Landslide affected areas in Kananga, Leyte from the 2017 Magnitude (Ms) 6.5 Earthquake using Spatial Statistics

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At 4:03 PM on 06 July 2017, a 2-km deep, strong earthquake with magnitude (Ms) 6.5 struck the island of Leyte. Ormoc City and Kananga, Leyte experienced intense ground shaking, registering at PEIS VIII (very destructive) on the PHIVOLCS Earthquake Intensity Scale (PEIS). The said earthquake triggered various hazards, including earthquake-induced landslides (EILs), which resulted in serious damage to property. Understanding the spatial distribution and influencing factors of these EILs are vital for effective disaster risk management. However, there is a lack of accessible studies examining the spatial distribution and influencing factors of EILs specifically related to this event in Kananga, Leyte. Numerous methods have been developed to study EILs and their influencing factors. Such methods include numerical modeling, remote sensing, and spatial statistics. Numerical models use geotechnical data to simulate the conditions of a slope failure. Yet, these models are quite site specific and costly. Remote sensing provides an accessible means of evaluating the spatial distribution of EILs but may not provide insights into the underlying influencing factors. Spatial statistical modeling finds the relationship between EILs and their influencing factors. It can also be used on a regional scale for landslide hazard and susceptibility mapping.

In this study, we combined remote sensing techniques and spatial statistics to analyze the 2017 earthquake event. It aims to evaluate the spatial distribution of landslides to understand the event-based characterization on the basis of the influencing factors (geomorphological, geological, hydrological, and anthropogenic). Manual landslide inventory was done in Google Earth Pro to delineate EILs related to the 2017 earthquake event using historical satellite imagery. Spatial statistical tools from ArcGIS Pro software were then used to analyze the influence of the factors (geomorphological, geological, hydrological, and anthropogenic) to the distribution of EILs. Spatial statistics show clustering of EILs at areas with higher elevation, relatively steep slopes, and with close proximity to faults (2-8 km). The resulting EIL statistical analysis is instrumental in creating landslide susceptibility maps and aiding stakeholders in allocating resources for critical areas vulnerable to earthquake-induced landslides.

Keywords: Earthquake-Induced Landslide (EIL), Remote Sensing, Spatial Statistics

Structural and Lithological-based Assessment in the Anao-aon Quadrangle of Surigao Del Norte for Earthquake-induced Landslide Susceptibility Map using Remote Sensing and Geographic Information System

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Landslide events are a case of cascading hazard in which earthquake can be the triggering factor. This causes extensive damage and pose significant risks to the affected area. The investigation of the relationship between structural and lithological characteristics of the Surigao Segment and the occurrence of landslides in the Anao-aon Quadrangle triggered by the 2017 Surigao Earthquake aids in elucidating causative factors of the earthquake induced landslide. The study employs Remote Sensing (RS) and Geographic Information System (GIS) techniques to produce a Landslide Susceptibility Map (LSM), utilizing the statistical method Weight of Evidence (WoE) and Analytical Hierarchy Process (AHP) for weighting and ranking of parameters. Parameters utilized in this study comprise of the geological parameters which are the structural and lithological factors (lithology, distance to epicenters, distance to fault zone, and etc.), and Digital Elevation Map (DEM) which are slope, elevation, lineaments, etc. The parameters are integrated by GIS software to analyzes the influence of variables on the likelihood of landslide occurrence post-earthquake landslides. The preliminary results of this research focused on data gathering and processing of remotely-sensed data and converting datasets into a GIS-ready thematic layers. This includes the inventory map (10 initial mostly shallow-seated translational landslides distributed to barangays: Magtangale (2), Banbanon (1), Bonifacio, Silop (1), Mabua (1), Punta Bilar (1), Anumar (1), Laurel (1), and San Isidro (1) from the report of PHIVOLCS) for validating the accuracy of LSM. The findings of this research, once completed, will contribute to the understanding of the complex interplay between the conditioning and triggering factors focused on the structural and lithological controls of earthquake-induced landslide. The creation of LSM will aid in disaster preparedness and risk mitigation efforts which helps authorities and policymakers in making informed decisions, ultimately enhancing the resilience of communities in earthquake-prone areas.

Keywords: Remote Sensing, GIS, Earthquake-induced Landslide, Susceptibility Map, Surigao Del Norte

Spatial Patterns and Hillslope Preconditioning Factors of Landslides Triggered by the 2019 Mw 6.1 Central Luzon Earthquake, Philippines

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The 2019 Mw 6.1 Central Luzon Earthquake (Philippines) triggered numerous shallow landslides in the towns of Floridablanca (Pampanga) and San Marcelino (Zambales). Although the ground shaking is the primary driving force in coseismic landslides, the contributions of preconditioning factors such as lithology, slope, and aspect are also important to analyze to determine the susceptibility of the area. Thus, we examined the influence of topographic and lithologic preconditioning slope characteristics, along with the triggering seismic event, on the distribution of landslides within the 25 km x 50 km study area centered in Floridablanca and San Marcelino. By conducting landslide inventory using satellite imageries (3-m resolution Planetscope satellite images, Google Earth), we assessed the correlation between landslides and preconditioning factors. The triggering event was modeled as a peak ground acceleration (PGA) scenario using the Intensity Measure Relationship (IMR) Model (OpenSHA software). We then obtained the relative contribution of the factors to the spatial distribution of landslides using landslide ratios and discriminant analyses.

The results indicated a correlation between landslide distribution and lithology, with the highest weight factor (WF) at 6.17 based on discriminant analysis. The Quaternary volcanic deposits have the highest landslide frequencies (LF) and landslide ratios (LR) (pyroclastic flow deposits: 66.1% LF, 33% LR; and volcanic plugs and domes: 28.2% LF, 14.0% LR). In contrast, older units, particularly those from the Zambales Ophiolite Sequence, exhibit minimal landslide occurrence (5.7% LF, 2.9% LR). Slope angle has the second highest WF at 1.52, with high landslide occurrences (65.0% LF, 32.0% LR) between slope angles of 20° to 50°. Interestingly, this range matches the internal friction angle values for pyroclastic deposits. However, landslides in the Quaternary plug deposits at slope angles lower than their expected internal friction angle suggest that factors beyond the internal friction angle caused instability. One possible factor is the presence of discontinuities such as joints and faults. In addition, the highest peak ground acceleration values of 0.40 to 0.35 g correspond to the vicinity of Mount Tapungso volcanic plug and Mount Cuadrado volcanic dome where LR values are high. This exemplifies the positive correlation found between landslide density and PGA values, emphasizing the role of higher shaking intensities in triggering landslides. However, the study also revealed that landslides occurred in lower PGA ranges (0.25 – 0.20 g) within the 1991 pyroclastic flow deposits characterized by high LF and LR (22.3% and 11.2%, respectively). The results underscore the significance of considering specific preconditioning factors in landslide hazard assessment and land-use management planning.

Keywords: Coseismic landslides, preconditioning, distribution

Semi-Automated Landslide Detection using Object-based Image Analysis for the 06 July 2017 Magnitude 6.5 Leyte Earthquake

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Typically triggered by earthquakes and extreme weather events, landslides are recognized to be one of the most catastrophic natural hazards in the world, resulting in multiple casualties, destruction of properties, and business interruption, among others. Immediate recognition of landslides after a disaster is essential in evaluating the consequent hazards and risks present in the affected area. Landslide mapping can be carried out accurately through site investigation and manual interpretation of high-resolution aerial imagery. However, these conventional methods are usually hampered by the unavailability of aerial photos and the physical inaccessibility of the affected site. To address these issues, recent studies assessed the applicability of remote sensing utilizing satellite products in landslide detection. The introduction of semi-automated remote sensing techniques using Object-Based Image Analysis (OBIA) accelerates the process of landslide delineation and provides a good alternative for an efficient landslide hazard analysis. In contrast to traditional pixel-based methods, OBIA clusters homogenous pixels into meaningful image objects through segmentation and employs a classification process to distinguish varying feature classes.

In this study, a semi-automated method of landslide detection using OBIA is proposed to delineate the landslides that occurred during the 06 July 2017 Magnitude 6.5 earthquake in Leyte, Philippines. It aimed to generate a landslide inventory using historical high-resolution satellite images covering Ormoc City and its neighboring municipalities. The performance of the semi-automated landslide inventory was verified by comparing its output to the ground-truth data and manually delineated inventory using a confusion matrix. The accuracy assessment reveals that the proposed method was able to conservatively map landslides induced by a high-magnitude earthquake event, thus making it a practical substitute for manual landslide mapping especially in inaccessible regions.

Keywords: landslide inventory, object-based image analysis

Anthropogenic Factors Leading to Slide Reactivation

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Mass wasting, a fundamental geomorphological process, refers to the downhill movement of Earth materials, including soil, rock, and debris. This natural phenomenon plays an ongoing role in shaping the Earth's surface. Several critical factors and triggers can initiate mass movement, encompassing material properties, topography, geologic structures, and the impacts of human activities. The consequences of mass wasting are profound, with significant geological, environmental, and societal implications, including landslides, road closures, property damage, loss of life, and environmental disruptions.

Within the picturesque Benguet Province, all the conditions necessary for mass wasting are met. In Sitio Tangke, nestled in Brgy. Ampucao, Itogon, Benguet, an old landslide has been identified and is under continuous monitoring by ISRI since 2020. The geometry and dimension of the mapped slumping block that is gradually moving northwest at an annual rate of 0.75 cm. The block spans 370 aerial meters from crown to toe, with a substantial elevation drop of 230 meters and a width of 250 meters. The terraces of the slide are inhabited, with over 80 houses primarily engaged in illegal small-scale mining (SSM) activities.

The presence of structures such as houses and SSM processing plants situated along the slope, coupled with the active small-scale mining on the mid- and lower slopes, aggravates slope instability, potentially catalyzing the reactivation of the pre-existing landslide.

Landslide monitoring and early warning in the Philippines: a case study of rainfall-triggered landslides in Iloilo Province during 2022 Severe Tropical Storm Paeng

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The Philippines is highly susceptible to catastrophic landslides due to its mountainous terrain and geographic location. To mitigate the landslide risk in the country, the Dynaslope Project, a research program under the Department of Science and Technology – Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS), has developed a cost-effective early warning system for deep-seated landslides (EWS-L) through sensor technology and community participation. Ground-based monitoring instruments, including subsurface tilt sensors and rain gauges, were installed to measure underground movement and rainfall, respectively. At-risk communities also regularly monitor surficial ground movement through installed surficial markers and observation of manifestations of ground movement. Community-sourced and sensor data are then analyzed to generate accurate early warnings and disseminated to the affected localities to enable proper responses.

In October–November 2022, rainfall brought by Severe Tropical Storm Paeng triggered nearly concurrent landslide events in three Project sites in the Iloilo Province, particularly in Brgy. Boloc in Tubungan, Brgy. Inabasan in Maasin, and Brgy. Marirong in Leon. During the event, critical ground movements were evident in the forms of critical subsurface movement and the manifestation of cracks, localized slope failures, and damaged structures. Peak one-day (~130 mm) and three-day (~250 mm) cumulative rainfalls preceded these ground movements by at least six hours. These rainfall amount to 50.8% and 97.7%, respectively, of the normal monthly rainfall (256 mm) in Iloilo in October. In other words, a month-worth of rain was poured in three days to trigger critical ground movements.

Observed critical ground movements necessitated the issuance of the highest landslide alert level, which indicates that a deep-seated landslide may be imminent and that the households at risk must evacuate. While a major landslide did not eventually happen during the event, households within the identified hazard zones were successfully evacuated; these affirm that the landslide early warning activities implemented by the EWS-L represent some degree of success. Nevertheless, the continuing activity of the landslides and the likely occurrence of rainfall triggers suggest that the complete failure of the slopes is bound to happen in the future, proving that the EWS-L is even more necessary.

Keywords: landslide monitoring, landslide early warning system, sensor technology, community participation

Rainfall threshold for the initiation of shallow landslides along the Benguet-Nueva Vizcaya Road, Benguet

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NIGS

Rainfall threshold has been utilized to predict when a landslide will likely occur during a significant rainfall. This is crucial in the development of landslide early warning systems especially for rainfall-induced landslides.

We utilized 30 rainfall-induced landslides along Benguet–Nueva Vizcaya Road in Bokod from a total of 54 landslides that occurred during the years 2015 to 2021. These landslides and their associated landslide-triggering rainfall characteristics, the cumulative event rainfall (E, in mm), normalized cumulative event rainfall (EMAP) and duration of rainfall event (D, in hrs), were examined, and used to generate an E–D threshold and an EMAP–D threshold at the 5th, 20th, and 50th quantiles to signify different warning levels. We empirically derived rainfall thresholds of 8.70 mm in a 24-hr period or 77.90 mm in a 240-hr period, for the initiation of shallow landslides along the Benguet–Nueva Vizcaya in Bokod. This is based on the generated 5th quantile E-D threshold, $E = 0.427D^{0.95}$. We propose a Warning Zone = $\{(D, E, CR_{15}) \mid E > \alpha D^{\gamma}, CR_{15} > 64\ mm\}$ for the initiation of landslides in the Benguet – Nueva Vizcaya Road. These rainfall thresholds were used in conjunction with antecedent rainfall as its effect to landslide occurrence becomes more significant beyond the 15-day cumulative rainfall (CR_{15}) of 64 mm. The proposed warning zone system may guide the local government in their decision making related to evacuation or closure orders for the Benguet–Nueva Vizcaya Road in Bokod prior to heavy rainfall events.

Determination of liquefaction distance limits using case histories in the Philippines

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Empirical equations of magnitude-liquefaction distance relations were established using the updated historical liquefaction database of the Philippines which contains more than a thousand liquefaction case histories caused by 90 earthquake events from 1619 to 2023.

In this study, the liquefaction case histories were first filtered in terms of the farthest distance from the epicenter or the earthquake generator, the assigned location quality, and the liquefaction probability ranking. Using the remaining data set, linear least squares method was applied to generate the bounding curves that best fit the data points. Correlations between earthquake magnitude (in M_S and M_W), the farthest distance from the epicenter, and the earthquake generator were then established. Lastly, these equations were compared with existing bounding curves developed by other authors that are specific to their study region or worldwide.

The empirical equations which are applicable to the Philippine setting can be used to determine the potential extents of liquefaction caused by an earthquake. This information can be utilized in hazard mapping and modeling, and can ultimately be used for earthquake disaster preparedness, mitigation, and response.

Keywords: liquefaction, linear least squares method, magnitude-distance relations

Application of the Global Geospatial Liquefaction Model (GGLM) in the Philippines

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Predicting the spatial extent of earthquake-triggered soil liquefaction is important for rapid response, risk estimation, and disaster mitigation planning. Liquefaction hazard's potentially large impact on current infrastructures in urban areas along coasts and lowlands further highlight the importance of liquefaction prediction to the Philippines. Wide-scale and damaging liquefaction occurred and was extensively mapped after the Mw 7.7 July 1990, Mw 7.0 July 2022, and Mw 6.4 October 2022 earthquakes in Northwestern Luzon. In this study, we compare the documented liquefaction accounts from these three significant events to the widely used Global Geospatial Liquefaction Models (GGLM) by Zhu et al. (2015, 2017), specific to the Philippines. The model builds upon the use of various globally available geospatial proxies to quantify the likelihood of liquefaction occurrence. These include predictors on soil density (e.g., Vs30, elevation, topographic slope, roughness), soil saturation (e.g., distance to nearest water bodies, water table depth, mean annual precipitation, aridity index), and ground shaking parameters (e.g., peak ground acceleration, peak ground velocity). Significant to the application of this method to the Philippines is the use of high-resolution (~5 meters) geospatial datasets complemented with site-specific geotechnical data from Standard Penetration Tests. Results from this study will be used as precursor to our final goal, which is to derive the optimal empirical model from the generated predictors that is more appropriate for the Philippines. The target goal will be illustrated by producing preliminary liquefaction probability maps in provinces without detailed liquefaction hazard maps such as Sorsogon and South Cotabato provinces.

Keywords: liquefaction, GGLM

Geotechnical Investigations and Liquefaction Potential Assessments in Ilocos and Abra, Philippines Post-2022 Earthquakes

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The 27 July 2022 Mw 7.0 and 25 October 2022 Mw 6.4 earthquakes have caused widespread liquefaction in Northwestern Luzon, Philippines, specifically affecting the provinces of Ilocos Sur, Ilocos Norte, and Abra. Most liquefaction manifestations have occurred in lowland areas as lateral spreads, ground fissures, ground subsidence, sand boils, and structure settlement. Detailed investigations were conducted using various geophysical and geotechnical equipment such as Screw Driving Sounding (SDS), Refraction Microtremor (ReMi), and Three-Component Microtremor (3CMt) on selected sites with liquefaction manifestations for soil characterization post-earthquake events. Sediment sampling on the upper few meters of the sites was also done using hand auger. Quantitative analyses were also performed to assess the liquefaction potential of these sites. The tests revealed that shallow water levels and loose sandy sediments, coupled with strong ground shaking, greatly contributed to liquefaction occurrence. Grain size analysis of samples indicated that the sediments are typical for most liquefiable soils. Furthermore, the results displayed strong positive correlations, with ReMi shear wave velocity (Vs) trends aligning with SDS N-values. Soil cover estimates from the 3CMT site period also closely matched actual SDS penetration depths. Liquefaction potential indices (LPI) derived from these tests further corroborated this assessment, with a range of low to high liquefaction potential across the sites. These findings suggest that to varying extents, the sites remain susceptible to liquefaction emphasizing the hazard posed by future seismic events.

Keywords: liquefaction, SDS, ReMi, 3CMt, LPI

Ashfall Modeling of Scenario Eruptions of Hibok-Hibok Volcano, Camiguin Island, Philippines

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Volcanic eruptions are a persistent geological hazard with diverse manifestations, including ashfall, posing significant risks to human populations and the environment. The focus of this research is on ashfall modeling and forecasting of the Hibok-hibok volcano, an active volcano on Camiguin Island, Philippines. The island hosts several volcanoes, making ashfall modeling crucial for hazard assessment and mitigation. Despite its historical activity, the Hibok-hibok volcano remains a subject for ongoing comprehensive eruption data research. This study aims to simulate ashfall dispersal using the Ash3D model, utilizing data from the 1948-1953 eruptions and scenario events (USGS, 2021). The PVAHA framework, initially proposed by Bear-Crozier et al. in 2016, was utilized. The scope of this investigation encompassed the geological setting of the volcano, its historical eruption events, and the various volcanic hazards it presents, including lava flows, lahars, and pyroclastic flows. Initial findings show that for a plume height of 12.6 km asl and 0.015 km3 DRE volume, ash deposit thickness of 1mm would reach the northernmost part of Mindanao and neighboring islands of Visayas. The outcomes of this study significantly contribute to disaster preparedness, aviation safety, and the advancement of scientific knowledge about volcanic hazards in the Philippines, particularly in the region of Hibok-hibok volcano.

Keywords: Ashfall modeling, Ash3D, Hibok-hibok, Camiguin

Characteristics of the June 1897 Mayon Volcano eruption interpreted from the stratigraphy of the Basud River Channel, Santo Domingo, Albay

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The June 1897 eruption of Mayon Volcano claimed around 350 lives and caused extensive damage to properties, making it its second most devastating eruption next to the infamous 1814 Plinian event. Historical accounts described the peak of the eruption characterized by "thick and immense" eruption column and large quantities of eruptive materials cascading down the slopes of the edifice. Flows travelled distances of 9-11 km away from the crater, even reaching the seas of Albay in Santo Domingo. Most of the products of the eruption were deposited along the Basud River located at the eastern flank of the volcano. This study focuses on the stratigraphy of Basud River to unravel the eruptive events and processes.

Field mapping and stratigraphic analysis show that the June 1897 eruption started with the emplacement of a several-m-thick pyroclastic flow unit which contains very dense cauliflower bombs, followed by an explosive phase depositing 20-60-cm thick tephra fall layer interpreted to be Plinian in origin. The tephra fall layer consists of lapilli-sized (1-2 cm) andesitic juvenile and lithic fragments and is overlain by 20-30-cm thick surge deposits. It was succeeded by the emplacement of pyroclastic flows. Two types of pyroclastic flow deposits were distinguished: bomb-rich and lithic-rich facies. Bomb-rich pyroclastic flow deposits contain abundant and large cauliflower bombs with maximum size of 4.5 m. Lithic-rich pyroclastic flow deposits are dominated by boulder-sized volcanic lithic fragments that are either evenly distributed across the whole unit or occur as concentration zones or lithic trains within the flow units. A second Plinian phase of the eruption was recognized from a 30-cm thick upper Plinian fall unit which marked the beginning of the deposition of a series of pyroclastic flows. Lahar deposits occur between the pyroclastic flow units as hydrothermally altered and indurated units, which are interpreted as hot lahars. Reworked deposits vary in character ranging from stream flows to debris flows which predominantly comprise the downstream deposits near the coast. The observed pattern of the June 1897 eruption does not correspond to any other known eruptive sequence of Mayon Volcano. The two Plinian layers at the beginning and midway of the sequence are different from the 1814 eruption characterized by only one Plinian tephra layer. The June 1897 pyroclastic flow deposits are distinct because of the unusually large cauliflower bombs and the long runout distance.

Keywords: volcano-stratigraphy, Mayon Volcano, Basud River, pyroclastic flows

Seismic Imaging (Vp, Vs, and Vp/Vs) of Crustal Structure and Magmatic Plumbing System Beneath Kanlaon Volcano, Philippines

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Kanlaon Volcano, located on Negros Island, Philippines, is one of the most active volcanoes in the country with a recorded history dating back to 1866. It has intermittently erupted, primarily in phreatic bursts, on at least 30 documented occasions. Recent study, using precise earthquake relocation and waveform correlation have documented the occurrence of deep long-period earthquakes. These deep seismic events, characterized by their recurring nature, suggest a non-destructive source within the volcano's depths. Current research points to the movement of volcanic fluids as the probable cause behind these phenomena. These deep earthquakes appear to interact with or affect the shallower earthquakes based on their spatio-temporal relationships. To fully understand its magmatic plumbing system and the processes that modulate its activities, we conducted 3D tomography study, which is the first for the volcano, using the 16 seismic stations of the Kanlaon Volcano Seismic Network and nearby stations of the Philippine Seismic Network. Our dataset consisted of a wide range of earthquake depths, that allowed us to image in higher resolution the subsurface structure of the volcano. In this study, we present our preliminary tomography analysis. Our results show distinct distribution of seismic wave velocities (Vp and Vs) and the Vp/Vs ratio, providing critical insights into the intricate magmatic plumbing system of Kanlaon Volcano.

Keywords: 2020 Taal Volcano eruption, volcano seismology, seismic signal classification, volcanic unrest

Classification and Analysis of the Seismic Activity of the 2020 Taal Volcano Eruption

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Volcanic unrest often generates numerous seismic phenomena, each producing distinct seismic signals that convey invaluable information on underlying volcanic processes. The precise classification and analysis of these volcanic earthquakes, therefore, play a critical role in volcano monitoring and early warning. This study focuses on identifying and categorizing seismic signals associated with the 2020 Taal Volcano eruption, from the onset of seismic unrest in March 1999 until the lowering unrest status to Alert Level 1 on March 2020. Our goal is to elucidate the attendant processes from magma ascent to eruption and develop a conceptual model of the magma plumbing system underlying Taal. We describe and analyze seismic activity through spectral analysis of the waveforms generated. Spectral analysis revealed a gamut of earthquake types that include VTs (volcano-tectonic), LFVQs (low frequency events), hybrid and explosion-type earthquakes, and banded and monochromatic tremors, each of which originated from distinctive magmatic processes. These results reflect the changing conditions in the magmatic and conduit systems that yielded information critical to timely and accurate information on the eruption of Taal. Finally, we present the crucial role played by seismic observations in the formulation of recommendations that could apply to future eruptions of the volcano.

Keywords: 2020 Taal Volcano eruption, volcano seismology, seismic signal classification, volcanic unrest

POSTER SESSION: ECONOMIC GEOLOGY

Characterization of barite deposits in Mabilog na Bundok, Lobo, Batangas, Philippines

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The Philippines hosts two geological existence of Barite which can be found in Mabilog na Bundok, Lobo in Batangas and in Mansalay, Oriental Mindoro. Barite deposits in Lobo are located along a structure considered as a dilational jog genetically associated with the subduction of the Manila trench, imitating the Macolod Corridor extensional setting. Scientific papers about barite attributes have contributed to geologic studies in the past; however, it lacks of studies concerning the characterization of barite deposits, specifically in the Philippines. USGS identified four major types of barite deposit in the world which are: (1) bedded-sedimentary, (2) bedded-volcanic, (3) Vein, cavity-fill, and metasomatic, and (4) residual. The immediate objective of this research project is to characterize the barite deposits within the vicinity of Brgy. Mabilog na Bundok, Lobo, Batangas. The study focused on identifying specific characteristics of barite, specifically the mesoscopic textures. Furthermore, the collection of samples was done within the one-day fieldwork. The samples were characterized based on the textures and associated minerals observable in hand samples. The results showed that the barite deposits within the area of Barangay Mabilog na Bundok, Lobo in Batangas were characterized as hydrothermal-type barite deposits based on the analysis of the collected rock samples according to their textural characteristics and mineral assemblages. Furthermore, the strong influence of hydrothermal processes on the formation of the barite deposit within the area sequentially characterizes the deposit belonging to the vein, cavity-fill, and metasomatic type. Mesoscopic characteristics such as quartz textures, the presence of vugs, and the mineral assemblages as shown on the samples display attributes relating to low, intermediate, and high sulphidation epithermal system deposits.

Keywords: barite, barite deposits, mesoscopic textures, vein cavity-fill and metasomatic type

Understanding and utilization of siliceous – silica minerals within local market demand, at Bugallon, Pangasinan, Central Luzon, Philippines

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The presence of Siliceous - Silica mineralization in Bugallon, Pangasinan, Central Luzon Island, Philippines, is characterized in two forms: 1) Silica in fragmental form - the pervasive and widespread Siliceous from erosional weathering of Quartz, and 2) Silica in rock form - the localized Silica massive bull quartz from faults and swarms of pegmatite dikes as local faultings. The presence of Silica mineralization follows on the Porphyry Type model, with pervasive argillic to advance argillic alteration of up to 1Km depth.

The presence of Silica mineral resource is almost 80%, or 657.6hectares of the total 822hectares, mineral rough resource estimate is 32,880,000cu.m. and 40,113,600MT using density at 1.22 (MEASURED), and a running rough mineral reserve estimate of 26,304,000cu.m. and 32,090,880MT (MEASURED) at 80% quarriable materials on 5m depth as studied in one of Mineral Production Sharing Agreement (MPSA). This study is being conducted in order to field assess the Silica mineral presence and how this raw material could be properly utilized given the market demand, and help and sustain different industries with the local market as priority.

SIENNALYN GOLD MINING CORPORATION
COPPER – GOLD DEPOSIT

Gregorio S. Hutalle, Jr.

SIENNALYN GOLD MINING CORPORATION

The Siennalyn Gold Mining Corporation (SGMC) has an approved MPSA, with MPSA No.: 076-97-IX, Date Approved: October 8, 1997, Area: 4,116 Hectares, for 25-year contract, renewable for similar period for Gold–Copper. It is located at the Municipalities of R. T. Lim, Titay, and Ipil in the Province of Zamboanga Sibugay, Western Mindanao, Philippines. It has an initial estimated resource of 854,000 tons of copper and 500,000 ounces of gold. There is a great opportunity for bringing up the deposit to a world class category in terms of quantity and quality. The area has also a promising content of energy elements.

At present, SGMC is processing its Application for Renewal of the MPSA and already submitted to the MGB Central Office for approval. Accordingly, the company has applied for NCIP-FPIC and is now halfway on the process.

SGMC believes that the Copper–Gold Deposit (CGD) could be developed, and its operations commence soon as the funders are just waiting for the SGMC MPSA eventual renewal. Once the CGD is on the economic mainstream, SGMC could contribute to the economy of the country, and help alleviate the living conditions of the local peoples, the peoples on the surrounding communities, and the Filipino as a whole.

Ore characterization and liberation potential of the Carmen quartz-pyrite-gold veins, Mankayan Mineral District, Philippines

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The Mankayan Mineral District (MMD) in northern Luzon is a well-studied and economically significant mineral district in the Philippines. A combination of numerous structures and suitable stratigraphic units allow the MMD to host a wide variety of hydrothermal deposits. Previously, three (3) mineralization styles were recognized in the MMD: porphyry coppers, enargite-replacement epithermal veins, and carbonate-base metal epithermal veins. A recent addition is the mineralization of the quartz-pyrite-gold (QPG) veins characterized by the Northwest, Carmen, and Florence deposits.

This study focuses on using mineralogical analyses to describe the occurrence and textural relationships of ore-gangue minerals in the Carmen QPG vein and delineate their mineral associations and potential for liberation. The major gangue mineral is quartz exhibiting an interlocking texture of euhedral to subhedral grains ranging from 0.400-0.001mm. Some quartz grains float in massive enargite veins or pyrite crystals. Ore microscopy results, confirmed by Scanning Electron Microscopy (SEM) and Mineral Liberation Analysis (MLA) data, reveal the modal mineralogy of the following minerals: quartz (SiO_2) – 48.71%; enargite (Cu_3AsS_4) – 40.29%; pyrite (FeS_2) – 9.18%. Other minerals present in trace amounts include tetrahedrite ($Cu_{12}Sb_4S_{13}$) – 0.57%; chalcopyrite ($CuFeS_2$) – (0.51%); bornite (Cu_5FeS_4) – 0.05%; chalcocite (Cu_2S) - 0.05%; covellite CuS – (0.05%). Hessite (Ag_2Te) and gold-silver tellurides are also present but do not contribute to the overall modal mineralogy. Hessite grains are locked in enargite (84.39%) and quartz (15.60%) with grain sizes of 3-14μm while Au-Ag tellurides are locked in enargite (77.5%), quartz (20.67%), and pyrite (1.83%) with grain sizes of 3-8μm. Future analyses will include inductively coupled plasma mass spectrometry (ICPMS) to determine bulk rock and trace element geochemistry and correlate these with the mineralogy. Ore processing will be attempted to evaluate the liberation potential of the major ore minerals from the gangue.

Keywords: Mankayan, epithermal, liberation, MLA

Genesis of the Kematu Au-Ag epithermal deposit, Tboli, South Cotabato Philippines

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The Kematu Au-Ag deposit, located in Tboli, South Cotabato, contains an inferred mineral resource of 2.4 million tonnes at 5.5 g/t gold and 21 g/t silver. The deposit is spatially and genetically correlated with the Pliocene to Pleistocene volcanism, regional extension, and local trans-tensional faulting. The mineralization is in the form of veins, breccia, and disseminations, and is hosted in the andesite porphyry and tuffaceous sandstone of the Parker Volcanic Complex. The major east-west trending veins range from 0.3 to 1 m thick and are dominantly composed of quartz, adularia, calcite, and clay. Ore minerals and sulfides present are electrum, sphalerite, galena, pyrite, chalcopyrite, and tetrahedrite-tennantite. Electrum is observed as inclusions in pyrite, with approximate compositions of 75 wt.% Au and 25 wt.% Ag. Textures present are pseudobladed quartz, rhombohedral adularia, massive calcite, and drusy quartz. The first two are indicative of boiling conditions, whereas the rest are formed from the slow cooling of fluids in open space. Alteration assemblage is composed of chlorite, illite, and albite, formed from neutral pH conditions. FeS content of sphalerite ranges from 0.1 to 1 mol%. Microthermometric measurement of fluid inclusions in sphalerite and calcite yielded homogenization temperatures (T_H) of 230-280 °C and 250-260 °C, respectively. Salinity values acquired from the same minerals acquired a range of 6-10 wt% NaCl eq. The FeS content and T_H values indicate an intermediate sulfidation state fluid. Sulfur isotope values ($\delta^{34}S_{CDT}$) range from 0.1 to 1.9 ‰ for pyrite, and -5.3 to 0.5 ‰ for galena, sphalerite, and chalcopyrite, suggesting a magmatic and homogeneous source of sulfur. The regional geo-tectonic controls, mineralization style, mineralogy, mineral chemistry, and sulfur isotope compositions suggest an intermediate sulfidation epithermal type.

Keywords: epithermal, Kematu deposit, intermediate sulfidation

Mineralogical characterization of refractory gold ore in the Bonanza vein, Maco gold deposit: Insights from petrography, geochemistry, and mineral liberation analysis (MLA)

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Recently, economically treatable gold ore is increasingly becoming depleted, necessitating the development of mineral processing methods for more complex and refractory ores. Refractory gold ores, which cannot be extracted through conventional processes (e.g., gravity concentration or direct cyanidation), often contain gold in forms such as submicroscopic or invisible gold, gold within carbonaceous sulfide ores, and most commonly, gold encased within sulfide minerals. Due to ore variability and complexity, mineralogical ore characterization becomes a crucial step in developing more cost-effective, optimized, and environmentally friendly mineral processing procedures to enhance recovery and yield of gold extraction.

In the Philippines, several gold deposits are host to refractory gold ores. This includes the NW-trending Bonanza-Sandy epithermal gold veins of the Masara Gold District in southeastern Mindanao. This study focuses on mineralogical characterization of the Bonanza epithermal gold ore using petrography, geochemistry, and SEM-based mineral liberation analysis (MLA). The objective is to evaluate gold speciation, grain size, liberation, exposure, mineral associations, and the presence of potentially harmful gangue components relevant to gold extraction processes.

Ore microscopy and X-ray diffraction (XRD) results revealed a predominant occurrence of sulfides such as pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS), with pyrite being the most abundant, and gangue components consisting mainly of quartz (SiO_2) and calcite ($CaCO_3$). Scanning electron microscopy (SEM), further confirmed the presence of these minerals, and additionally identified the presence of gold and silver tellurides mainly hosted in the pyrite. Moreover, data from mineral liberation analysis (MLA) indicated that the ore is primarily composed of pyrite (52.74wt%), quartz (28.36wt%) and chalcopyrite (5.83wt%), with minor amounts of gold (0.00718wt%). Gold was mainly in the form of Au-Ag tellurides (77.27%), followed by electrum (12.57%) and native gold (8.87%), in which 80% of the grains have a size smaller than 12 microns. Occurrence of these gold minerals is largely associated with pyrite (66.22%) and pyrite-chalcopyrite-sphalerite (23%), with the gold commonly locked on the sides of the minerals, although a smaller proportion exists as free grains (8.22%).

Inductively coupled plasma mass spectrometry (ICPMS) for trace element geochemistry, mineral chemistry using electron probe microanalysis (EPMA), and sequential extraction will be further conducted to characterize the ore.

Keywords: ore characterization, Masara Gold District, MLA

Mineral assemblage and mineral chemistry of the Dinapigue nickel laterite deposit, Isabela, Philippines

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Nickel laterite deposits around the world are now being studied for their potential to hold significant amounts of critical metals such as Co, Sc, and rare earth elements (REEs). Through laterization, these elements can be concentrated within the laterite profile. In the Philippines, nickel laterites form from the weathering of ophiolitic suites. In particular, the weathering of the ultramafic rocks of the Isabela Ophiolite produced the Dinapigue nickel laterite deposit.

Representative samples were obtained from the different horizons of the laterite profile. The mineral assemblage of the deposit was obtained through the use of petrographic analysis, ore microscopy, and X-ray diffraction (XRD). In addition, Scanning Electron Microscopy – Electron Dispersive X-ray Spectroscopy (SEM-EDX) and Laser Ablation – Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) were done to determine the mineral chemistry of the observed mineral phases.

Petrographic analysis of the bedrock samples show two distinct bedrock lithologies from which the studied laterite profiles developed: lherzolite and dunite. The lherzolites are characterized by the presence of olivine, orthopyroxene, clinopyroxene, spinel, and serpentine. The dunite bedrock on the other hand is composed of mostly olivine, spinel, and serpentine. Ore microscopy of the saprolite horizon samples show the occurrence of serpentine and garnierite with relict chromian spinel and magnetite. In the limonite horizon, Mn-oxyhydroxides were observed. Observed peaks from XRD analysis also show similar mineral assemblage, with additional peaks from hematite and goethite.

Mineral chemistry analysis show preferential concentration of critical metals towards certain mineral phases. In the bedrock, Co partitioned more towards the olivine from the lherzolite. Sc and REEs on the other hand were more concentrated in the clinopyroxene. Within the laterite profile, Co and REEs were significantly enriched in the Mn-oxyhydroxides.

Keywords: laterite, critical metals, Dinapigue, lherzolite

Rare Earth Elements (REE) potential of the Karst Bauxite deposit in Paranas, Samar, Philippines: Insights from mineralogy and geochemistry

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Rare Earth Elements (REEs) have gained attention in recent years due to their role in the global shift towards sustainable and environmentally friendly technologies. These elements are essential in the production of various advanced technologies, including rechargeable batteries, mobile phones, electric vehicles, and renewable energy systems. Given their importance and the limited global REE supply, the identification of alternative REE sources has become vital for many countries worldwide. One promising possibility for REE enrichment is in bauxite deposits, which are residual accumulations resulting from extensive weathering of rocks rich in alumino-silicate minerals, a phenomenon that predominantly occurs in tropical and humid climates.

In the Philippines, several bauxite reserves are located on the island of Samar, including the deposit in Paranas being managed by Alumina Mining Philippines Inc. This bauxite deposit is classified as a karst bauxite deposit since the bauxite profile is hosted in the limestone depressions between karst hills. This study employs mineralogical and geochemical techniques to characterize REE enrichment in the karst bauxite deposits of Paranas, Samar. X-ray diffraction results reveal the common minerals that occur in bauxite: boehmite $AlO(OH)$, gibbsite $Al(OH)_3$, goethite $FeO(OH)$, anatase (TiO_2), lepidocrocite $FeO(OH)$, and cristobalite (SiO_2). The Mineral Liberation Analyzer (MLA) provided insights on the modal mineralogy of bauxites, although some mineral phases were not identified due to the amorphous nature of the soil. The weight percent (wt%) of the following minerals and soil phases identified are: AlOFe (96.89%), AlSiO_Fe (2.12%), Quartz (0.32%), AlO (0.22%), FeO_Ti (0.19%), FeO (0.17), Fe(Al)O (0.06%), Anatase (0.01%), Ilmenite (0.01%), and Ulvospinel (0.01%). X-ray fluorescence and inductively coupled plasma mass spectrometry results indicate the abundance of Al_2O_3 (44%) and Fe_2O_3 (24-25%). On the other hand, the trace elements, cobalt, scandium, yttrium, lanthanum, cerium, and neodymium are significantly enriched compared to other trace elements. The initial concentrations are up to 300 ppm in total. Furthermore, initial Bayer leaching experiments conducted by the study revealed that the REEs are concentrated in the residue after leaching of the aluminum. This indicates the potential to produce REE as byproducts from the bauxite residue. Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) analysis and sequential extraction experiments will be conducted to identify the specific phases hosting the REE enrichment.

Keywords: Karst bauxite, rare earth elements (REE), green technologies

Identification of bauxite deposits in the Philippines using remotely sensed spectral indices: a case study from Paranas, Samar
Island

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A recent shift in the search for rare earth elements (REE) deposits has put the spotlight on bauxite, an aluminum oxide-rich ore formed from igneous and carbonate-sedimentary rocks in tropical climates. In the Philippines, bauxite mineral reservation sites are identified in Samar Island. Among these, the deposit in Paranas, Samar has extensive exploration and drilling data available. Thus, this study explored the identification of potential areas with bauxite deposits in Paranas using remotely sensed images and remote sensing techniques. The study utilized Quantum GIS (QGIS) software with a semi-automatic classification plugin for image processing, map generation and calculation of spectral indices. Field validation was performed to confirm the presence of bauxite in the study area, and the spectral signatures of minerals identified by XRD analysis were used to further refine the deposit locations. The image processing was based on the RGB, near-infrared, and SWIR reflectance bands of Copernicus Sentinel-2 satellite images of the study area. The Normalized Difference Limestone Index (NDLI) and Normalized Difference Vegetation Index (NDVI) were used to highlight limestone mineral indices, which is distinct from the lower mineral spectral index values of the bauxite minerals identified from X-ray Diffraction analysis of representative samples. The NDLI values for limestone in the area are found to be in the range of 0.45 – 0.55, which coincides with the lower elevation in the area (<200 masl). The results of this study will enable reconnaissance exploration of unexplored portions of the country with similar geological properties that could potentially have bauxite deposition.

Keywords: Remote Sensing, Sentinel-2, Bauxite, Spectral Index

Gold-Copper Prospectivity Mapping in Masara Gold District, Eastern Mindanao: Application of Weights of Evidence and Fuzzy Logic using Field Validation and GIS Approach

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The Masara Gold District located in Eastern Mindanao, Philippines, stands as one of the principal gold-producing districts in the country. Past and recent studies in the area provided enhanced insights into the mineralization characteristics of the gold-copper deposits. Since its discovery in 1937, the Masara Gold District has offered promising exploration potential for both porphyry copper and epithermal gold. This study aims to delineate zones with high prospectivity of containing Au (gold) and Cu (copper) deposits through the utilization of geospatial data, Geographic Information System (GIS) tool, and field validation methods. The study employs analytical methodologies such as Weights of Evidence (WoE) and Fuzzy Logic (FL). Integrating knowledge- and data-driven methods enhances mineral exploration by improving the identification of mineral-rich areas, even in the face of geological data complexity and uncertainty, leading to more successful and sustainable resource exploration. The study utilizes six key parameters (i.e., Au and Cu soil geochemistry, magnetic anomaly, epithermal veins, alteration zones, and lithologic patterns), with soil geochemistry being the prominent and influential parameter. The study reveals a 91.26-hectare with high potential presence of gold deposits mostly in the eastern portion of the tenement coinciding with epithermal veins, alongside a 30.42-hectare region indicating a high potential copper-containing deposits situated at the western portion of the tenement which concurred with the potassic alteration zone. The study contributes to the advancement of mineral exploration techniques, providing a valuable tool for resource industry professionals and decision-makers to optimize exploration efforts and investments while minimizing environmental impact.

Keywords: Weights of evidence (WoE), fuzzy logic (FL), Masara gold district, mineral prospectivity mapping (MPM)

Uranium geochemical map of the Philippines (ver. 3)

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The Philippines has adopted a National Position for a Nuclear Energy Program in 2022 committing the inclusion of nuclear energy in the State's energy mix. Under the International Atomic Energy Agency (IAEA) Milestone Approach are nineteen infrastructure issues that need to be addressed. This includes the Nuclear Fuel Cycle which starts with the exploration of uranium. Therefore, necessitating the identification and evaluation of available Philippine uranium natural resources. With the patronage of the then Philippine Atomic Energy Commission, extensive uranium exploration datasets from various provinces, albeit with data paucity in Mindanao, were generated by the Nuclear Fuels Division (now Nuclear Materials Research Section). The current database comprises 2349 stream sediment and 1185 heavy mineral samples, 111 stream water samples from selected localities, and 1007 ground and carborne radiometric readings. This drainage geochemical database is combined with a uranium rock geochemical database from published datasets and GEOROC. The spatial distribution of uranium exploration geochemical data is visualized in geochemical maps with exploratory data analysis (EDA) classes. With boxplot upper hinge as a threshold, anomalous stream sediment (SS) and heavy minerals (HM) samples are defined with 1.6 ppm and 1.1 ppm U, respectively. A catchment basin approach is also adopted identifying uranium anomalous source regions which brings the uranium targeting efforts from a country-wide (~100km) to a region/province-wide scale (~10km). Spatially-consistent SS and HM geochemical anomalies are recognized in Mindoro Island. In contrast, the Larap Cu-Mo(-U) deposit is associated with only a single HM anomaly. HM anomalies are also recognized in Pangasinan, northern Luzon, and northern Samar. The combination of drainage and rock geochemistry enables the characterization of primary (source rock) and secondary (hydrothermal fluid assisted) uranium enrichments in Philippine geoscapes. Anomalies identified here associated with Fe and/or Cu prospects/mineralization are potential targets for renewed uranium exploration endeavors.

Keywords: uranium, geochemical anomaly, geochemical map

POSTER SESSION:
Tectonics and Petrology

Soil Physico-Chemical Characterization and Mineralogy of Blue Soil Hills in Kaman Utek, Sagada, Mt. Province

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The Blue Soil Hills in Sagada, Mt. Province in the Philippines is a popular tourist destination due to the "blue color" of the soil. Soil color is one of the physical properties that gives clues on the processes that the soil has undergone. Factors that contribute to soil color include oxidation-reduction process and its mineral component. The unique color of Blue Soil Hills was locally believed to be influenced by copper- content. However, published literature regarding its actual composition are still unavailable. Hence, this study characterized the soil physical and chemical properties of the Blue Soil Hills in Sagada, as well as its mineralogical composition.

Particle size and soil color were determined through the hydrometer method and Munsell Soil Color Chart, respectively. For the chemical properties, potentiometric method was used in analyzing the soil pH while Walkey-Black method was used in order to determine the organic carbon, organic matter and nitrogen content in the soils. X-ray diffraction (XRD) and X-ray fluorescence (XRF) were carried out to determine the mineral composition and major oxide elements present in the samples. The results of soil physical analyses showed that the samples have sandy loam texture, in which soil color ranges from light greenish gray to pale green in moist condition. Chemically, the soils are slightly acidic in nature, with low organic carbon, organic matter and nitrogen content. XRD analysis revealed the presence of glauconite, a green-colored mineral, which influenced the unique color of the soil. Trace element analysis showed 0% of copper (Cu) content in the samples, which is verified further through Inductively Coupled Plasma Mass Spectrometry (ICP-MS), which showed an average of 3.04 ppm concentration. Such values imply that the Cu content is low, contrary to the belief that it is the source of the bluish color of the soil. The computed values of Chemical Index of Alteration (CIA) vary from 19.23 – 73.27 which indicate moderate alteration. The unique color of the soil may have been caused by hydrothermal alteration of the parent materials that have been facilitated by hydrothermal fluids near the area.

Keywords: Soil Color, Mineralogy, Hydrothermal alteration

Freshwater Fish Fossils of the Pleistocene Laguna Formation (Antipolo, Rizal)

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The lacustrine facies of the Pleistocene Laguna Formation, exposed in several outcrops in Cogeo in Antipolo, Rizal, yielded several fish fossils in its tuffaceous shale unit. This assemblage consists of 16 moderately-preserved, semi-articulated specimens of bony fish (Teleostei) that were assigned to three distinct groups based on the combination of a set of skeletal characters unique to each group. The first and most abundant group in the assemblage is the small clupeiform species showing clear affinity to the family Dorosomatidae. A single specimen each of a gobioid fish (order Gobiiformes, family (?)Gobiidae) and a synbrachid fish (family Synbrachidae) were also identified in the assemblage. This new data on the paleo-ichthyofauna of the site contributes to the relatively few macrofaunal studies on the formation which mainly focused on the large vertebrate remains from the pyroclastic facies. This present study aims to provide a more comprehensive understanding of the ichthyofaunal assemblage of the Laguna Formation and its paleoenvironmental implications by presenting a detailed description and classification of the fish fossils from the deeper lacustrine facies of the formation. This study represents the first systematic description of freshwater fish fossils in the Philippines.

Keywords: Pleistocene, Laguna Formation, fish fossils

Deep-Seated Volcano-Tectonic Seismic Swarms: Insights from the 2021 Activity of Pinatubo Volcano

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Seismic swarms of volcano-tectonic earthquakes occurred in Pinatubo Volcano, Philippines, in 2012 and 2021, roughly within three decades after its cataclysmic eruption in 1991. These swarms originated at depths way beneath the assumed shallow magma reservoir. Data for the 2012 swarm were available for only one seismic station, thus precluding precise location determination. In contrast, the current Pinatubo Volcano Network recorded seismic swarms in 2021 in high-fidelity. In this study we determine the earthquake locations and focal mechanisms to understand the geological processes responsible for seismic unrest of these periods. As a first step, Pinatubo's 1-dimensional velocity model was refined using VELEST, which is an important step in subsequent analyses. This improved model became the starting model for a double-difference location method, allowing precise determination of earthquake locations. Focal mechanism solutions were then generated using the polarity of first arriving P-waves or through full waveform inversion to analyze the interplay among the stress field distributions during unrest. Using the results of these analyses, we describe and characterize the underlying processes and construct a conceptual model of the volcano's magmatic plumbing system. Finally, we discuss the broader implications of these processes, especially when considered alongside other volcano monitoring parameters.

Keywords: Pinatubo Volcano, seismic swarms, velocity model, focal mechanism solutions

Investigating the Geological Processes Contributing to Pseudokarst Sinkhole in Siargao Island, Surigao Del Norte

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The 2013 Bohol earthquake and other phenomena has caused numerous sinkholes to emerge in several areas in the Philippines, especially in karstic regions, hence paving the way for the proliferation of karstic studies. However, the attention is mainly centered on karst sinkholes, leaving a significant gap in research concerning pseudokarst sinkholes, especially in the Philippines. In an island primarily composed of carbonate materials like Siargao Island, Surigao del Norte, it becomes imperative to understand the potential geological hazards that may arise beyond the karstic regions. The evaluation of these geological hazards necessitates the use of remote sensing techniques, such as the generation of sink depth maps from Interferometric Synthetic Aperture Radar (IfSAR) Digital Elevation Model (DEM), which are processed in a Geographic Information System (GIS). Initial finding shows that approximately 30 (11%) possible pseudokarst sinkholes were identified in non-karst environment by the Mines and Geoscience Bureau - Caraga using IfSAR Generated Sink Depth Map. This will then be subjected to further field investigation which includes in-depth geological and geomorphological assessments. The finding of this investigation will not only contribute to a deeper comprehension of the geological forces influencing the island's topography but also provide valuable insights for better land-use planning and risk mitigation in this region, where such geological phenomena can have significant implications for local communities and infrastructure.

Keywords: Pseudokarst Sinkhole, IfSAR DEM, Siargao Island

Delineation of the tectonic provinces along the Manila Trench Subduction Zone

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The Manila Trench subduction zone has a complex crustal structure affected by subduction, strike-slip faulting, and collision-related processes. The western Luzon forearc region is characterized by two distinct forearc basins, the North Luzon Trough, and the West Luzon Trough, bounded by an accretionary margin and erosive margin, respectively. Other tectonic structures observed in the forearc region are various bathymetric highs. The Stewart Bank is an uplifted region in the subduction zone associated with the subduction of the Scarborough Seamount Chain (South China Sea extinct spreading ridge). Paoay High and Vigan High are bathymetric highs extending from offshore La Union northward to offshore Ilocos Norte. These features are affected by the strip-slip faulting of the offshore extension of the Philippine Fault Zone. Analyses of gravity data (Earth Gravitational Model, EGM 2008) and magnetic data (CCOP-GSJ 2021) indicate the tectonic provinces' distinct morphological and deformational characteristics. Enhancement techniques (e.g., regional-residual separation, edge detection, source location, and depth estimation) were applied to the gravity and magnetic data to extract additional information from the anomalies. The regional and residual anomaly maps provided information on the extent of the sediment cover and the basement of the tectonic provinces. The 1st-order X and Y horizontal derivatives and tilt derivative techniques were used to delineate the boundaries of the provinces along faults and morphological structures. The edges of the features are observed in the total horizontal derivative and vertical derivative maps. This present study attempts to delineate the boundaries of the tectonic provinces and provide insights into their formation.

Keywords: Manila Trench, subduction zone, bathymetric high, tectonic province

Gas hydrate stability zone thickness estimates for the Manila Trench forearc region

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The presence of gas hydrates in the Manila Trench forearc is inferred based on seismic indicators such as bottom simulating reflectors (BSR) and enhanced amplitude reflectors (EARs). These features are distributed mainly in the northern accretionary prism segment and the West Luzon Trough. The BSR depths obtained from seismic reflection data approximate the gas hydrate stability zone (GHSZ) thickness for the region. However, the unequal distribution of high-resolution seismic profiles leads to gaps in the distribution of mapped BSRs. This study utilized bathymetry and bottom-water temperature data to generate revised theoretical GHSZ thickness estimates. Three gas hydrate molecular compositions consisting of 100%, 96%, and 90% methane were considered for the modeling to account for biogenic and thermogenic hydrocarbon input. Geothermal gradient values ranging from 30 to 60°C/km were utilized in the models to simulate higher geothermal gradient values expected in an active plate margin, as determined by in-situ measurements in SW Taiwan. The resulting theoretical GHSZ estimates were compared with observed BSR depths to determine best-fit models. For the northern frontal wedge segment, the model utilizing a 50°C/km gradient assuming a hydrate composition of 96% methane showed the best correlation with the observed BSRs. For the West Luzon Trough, the best-fit model used a 30°C/km gradient and a 90% methane hydrate composition. These revised theoretical GHSZ models provide more accurate thickness estimates in the Manila Trench forearc compared to existing models for the South China Sea region.

Keywords: GHSZ thickness, Manila Trench, gas hydrates, BSR

Delineating structures offshore La Union and Pangasinan using Sub-Bottom Profiles

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The Philippine Fault Zone is an active system of left-lateral strike-slip faults that extends north-northwest across the Philippine archipelago. It accommodates the excess stress induced by the oblique convergence of the Philippine Sea Plate and the Eurasian Plate. Although it is a major geologic feature, its offshore extensions specifically in the regions of the La Union and Pangasinan are not widely studied. New sub-bottom profiles were collected to image the subsurface offshore Western Luzon. The SBP 120 Sub-Bottom Profiler was used during the marine survey. The raw profiles were processed using the SonarWiz and SeiSee software. The delay in seabed travel time was adjusted to obtain the correct bathymetric morphology. Processing techniques include bandpass filter and gain control. Sub-bottom profiles offshore La Union and Pangasinan reveal a series of unmapped structures such as old and new possibly active faults. Features of near vertically dipping faults and mass transport deposits are observed in the sub-bottom profiles. Structures indicative of strike-slip faulting could possibly be offshore extensions of the Philippine Fault Zone. This study attempts to delineate offshore fault systems that may pose seismic hazards to population centers in Western Luzon.

Keywords: sub-bottom profiles, fault, mass transport deposits

Bulged and uplifted west coastal margins of the Southwest Coast Range-Cotabato Arc: A result of impinging forearc terraces?

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Bathymetric highs, resembling forearc terraces, marked by isostatic gravity high anomalies and shallow terraced bathymetry lie west offshore of the Southwest Coast Range in southern Mindanao. East landward of the bathymetric highs are oddly bulged and uplifted west coastal margins of the Southwest Coast Range. This bulge serves as the hinge zone of the arcuate-convex continentward configuration of the Cotabato Arc. This study seeks to determine the possible existence of impinging bathymetric highs that may have resulted to the remote and unusual bulging and uplifting of the west coastal margins of the Southwest Coast Range-Cotabato Arc through comprehensive review of geological and geophysical data from previous works supplemented by recent remote sensing and field mapping data. The bathymetric highs are situated in front of the central segment of the Cotabato Trench and are interpreted—in correlation with the results of the ODP Leg 124 Site 767—as downfaulted basement rocks of probable continental affinity overlain by extensive volcanic apron based on multi-channel seismic profiles from previous surveys off southern Mindanao and across the Cotabato Trench. In between the Cotabato Trench and the bathymetric highs are highly distorted sediments of the inferred post-Middle Miocene to pre-Pleistocene accretionary wedge indicating active compressional deformation along the Cotabato Trench. The parallel linear and arcuate fault zones comprising of N-S and NW-SE folded and faulted turbiditic rocks along the bulged west coastal margins of the Southwest Coast Range apparently mirror the results from the analog models (sandbox experiments) showing the deformation in response to seamount/bathymetric high subduction or accretion. Further studies, such as detailed seismic survey, structural mapping, and deep-sea drilling, are imperative to verify the nature and possible origin of these bathymetric highs.

Keywords: bathymetric high, Southwest Coast Range, Cotabato Arc

Determining the provenance of the clastic sequences in southwestern Mountain Province using sedimentary geochemistry

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Whole-rock and trace element geochemical analyses have found extensive application in examining the provenance and tectonic affinity of sedimentary rocks, providing important information on understanding the geologic evolution of a region. Examples of such applications in the Philippines have demonstrated their efficacy in delineating source terranes and determining their tectonic associations. In the southwestern part of the Mountain Province, siliciclastic rock samples were analyzed from the Late Oligocene to Early Miocene Mabaay Formation, a newly recognized unit from this study, and the overlying Middle Miocene to early Late Miocene Balili Formation. The application of sedimentary geochemistry on samples collected from these formations will provide insights into the history and evolution of the southwestern Mountain Province during the Oligocene to Miocene.

The Mabaay Formation is distinguished by rhythmically alternating sequences of mudstone and siltstone, with minor very fine- to fine-grained sandstone units. A Late Oligocene to Early Miocene age for the formation was determined from identified foraminifera in mudstone samples (e.g. *Dentoglobigerina sellii, Paragloborotalia siakensis, Paragloborotalia mayeri*). In contrast, the Balili Formation is characterized by thick sandstone sequences and volcanic conglomerates. The U/Pb age dating from detrital zircons in sandstone collected from this formation yielded a Middle Miocene to early Late Miocene age.

Using the chemical index of alteration (CIA), the source rocks from both of the formations were determined to have undergone a weak to intense degree of chemical weathering (CIA = 55-94). Discriminant function analysis (F1 vs. F2 of Roser and Korsch, 1988) suggests sources from intermediate to mafic igneous provenance, with minor input from quartzose sedimentary provenance for the Mabaay Formation, and a mafic to intermediate provenance for the Balili Formation. However, the geochemical signatures of trace elements and REEs normalized to Post-Archean Australian Shale (PAAS) for the Mabaay and the Balili Formation show strong similarities with each other, with depleted LREE and flat HREE suggesting a source rock with weak geochemical fractionation. The source region for both of the formations has an oceanic island arc affinity determined using immobile elements (e.g. La, Th, Sc, and Zr). The outcomes derived from geochemical analyses of samples from the clastic units of the Mabaay and Balili Formation offer additional insights into the existing understanding of the evolution of the Central Cordillera.

Keywords: Mountain Province, sedimentary geochemistry, provenance

Petrographic Characteristics of Volcanic and Intrusive Units of the Ancient Negros Arc

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Negros is a boot-shaped island situated at the western portion of central Philippines. The island is divided into three (3) tectonostratigraphic terranes, the Ancient Negros Arc, the Recent Negros Arc, and the sedimentary Visayan Sea Basin. The Ancient Negros Arc, in particular, is located at the southwestern (SW) portion of the island. It is an important terrane where the emplacement of the Cretaceous-Paleocene volcano-sedimentary rocks have been recognized, and where the extensive exposures of Eocene to Miocene batholithic bodies are mostly observed. The oldest unit, Cretaceous to Eocene Basak Formation, consists of amygdaloidal basalt and agglomerate with andesitic and basaltic clasts. A Late Eocene to Middle Oligocene hornblende to quartz diorite intrusion of the Pangatban Diorite intruded the Basak Formation. This intrusion is responsible for the occurrence of the NW-trending chain of porphyry copper (Cu) deposits in the area. Most studies have focused on the mineralization of the porphyry Cu deposits, with fewer studies conducted on the basement unit and the intrusive rocks in Southwest (SW) Negros island.

This paper reports new field and petrographic data of the volcanic and intrusive rocks which occur in SW Negros. Exposures of the Basak Formation are mostly observed as volcaniclastics, and lava flows in Culipapa and Alim in the municipality of Hinobaan. The Pangatban Diorite is typically exposed as massive diorite bodies in Hinobaan and Sipalay. In some other areas, the diorite is cut by an intrusion containing sulfide inclusions. Elsewhere, tonalites occur as floats near the dioritic plutons. The notable occurrence of cognate xenoliths within the intrusion is also reported in this work. Petrographic analysis shows that the xenolith of the Pangatban Diorite is identified as hornblende diorite and is characterized by inequigranular texture. It consists mainly of plagioclase and hornblende with minor amounts of biotite and quartz. Quartz occurs as intercumulus crystals that fill the interstices of the xenolith. Traces of opaque Fe-Ti oxides are also observed. The host rock containing the cognate xenolith is identified as hornblende-bearing quartz diorite. It exhibits granular texture and is characterized by large euhedral grains of plagioclase, hornblende, biotite, and quartz. Quartz grains are sometimes large, anhedral, and interstitial crystals which indicates late-stage crystallization. Large biotite crystals are frequently observed in the host rock which occur in the interstices of plagioclases. Minute Fe-Ti oxides are minor in abundance than in the xenolith. Interestingly, the sizes of primary minerals are larger in the host rock and smaller in the xenolith and there are no reaction selvages found in between their contact. Other intrusive units are described as quartz diorite, tonalite and hornblende tonalite. In particular, the hornblende tonalite contains significant amounts of sulfides which appear as disseminated pyrite within the primary hornblende. The rock samples obtained from the Basak Formation are composed of basalts and volcaniclastics. The basalt is

composed of plagioclase with a very small amount of clinopyroxene microphenocrysts set in a glassy groundmass. The vesicles are infilled with secondary minerals such as zeolites and quartz suggesting low-temperature alteration of the basalts. The volcaniclastic is composed of plagioclase, secondary amphibole, and lithic fragments of volcanic origin. Additional techniques such as mineral chemistry and geothermobarometry of primary minerals (e.g. amphibole, plagioclase, among others) and whole-rock composition of the volcanic rocks will be done in future works to better constrain the magmatic nature of igneous rocks underlying SW Negros.

Keywords: SW Negros, Basak Formation, Pangatban Diorite, cognate xenolith

Decoding pre-eruptive storage conditions beneath the Macolod Corridor, southwestern Luzon arc

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Textural and geochemical information of primitive arc lavas are crucial in deciphering the magma storage conditions and petrogenetic processes that transpire in the plumbing systems. In the Philippines, primitive magmas occur in the Macolod Corridor, a northeast-southwest trending extensive region of Quaternary volcanism located in the southwestern Luzon Arc. This work carried out textural, whole-rock, and mineral chemistry analyses of primitive basalts obtained from monogenetic (e.g. scoria cones, tuff cones) and polygenetic volcanoes to determine the pre-eruptive storage conditions and processes beneath the Macolod Corridor. Primary juvenile clasts were mostly obtained from monogenetic centers while basaltic lava flows comprise the polygenetic volcanoes. Four primitive lava types are identified based on their modal mineralogy: (1) olivine basalt; (2) olivine clinopyroxene basalt; (3) olivine-bearing basalt; and (4) olivine plagioclase basalts. Phenocryst, microphenocryst, and glomerocryst assemblages include olivine, clinopyroxene, plagioclase, and fine-grained spinel inclusions embedded in a glassy matrix. These phases sometimes display dissolution (i.e. sieved and resorption) and disequilibrium textures (i.e. reverse zoning).

The primitive basalts are classified as sub-alkaline, medium-K, and medium-Fe composition from whole-rock geochemistry. These basalts have MgO >6 wt.%, whole-rock Mg# >50, high Ni (ave. 122 ppm), and high Cr (ave. 314 ppm) concentrations. Based on mineral chemistry analysis, olivine forsterite ranges from Fo_{58-89} while clinopyroxene and plagioclase range from $Mg\#_{71-90}$ and An_{42-93}, respectively. Variations in the whole-rock geochemistry and complex zoning patterns in the Macolod basalts are attributed to fractionation and magma mixing. Using the olivine addition method, the primary magma composition yielded $Fo_{\sim91.5-91.8}$. Estimated pressure (P)–temperature (T) of olivines reveal that these primitive magmas last equilibrated at depths ranging from 26-42 km at 1176-1286°C, while clinopyroxene is estimated to form at depths of around 10 km (ave. 1198°C). These petrological and geochemical parameters contribute to the better understanding of the magma plumbing system which is vital for forecasting future potential hazards in the region.

Keywords: primitive basalts, magma storage, Macolod Corridor, southwestern Luzon Arc

Magmatic and metasomatic processes beneath a double-island arc inferred from the xenoliths and andesite host rocks from Dinem Island, Batanes

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A double-island arc forms when an initially single volcanic chain shifts its locus of magmatism either away or towards the trench resulting to an older inactive volcanic chain and a more recent, active volcanic chain. One such chain is the Babuyan Segment of the Luzon Arc which is made up of the west volcanic chain (WVC) and the east volcanic chain (EVC). Geochemical and geochronological differences distinguish the two chains. The EVC volcanics have more enriched La/Yb and LREE values and are younger (0.01 – 2.0 Ma) compared to the WVC volcanic rocks (1.4 – 22 Ma). Some volcanic centers in these two chains also host mantle to crustal xenoliths such as Mt. Iraya of the EVC and Sabtang of the WVC. Dinem Island of the EVC was also previously reported to contain xenolith-bearing volcanic rocks albeit information on them is scarce. This study presents new petrographic and geochemical data on the volcanic rocks and xenoliths from Dinem Island.

The volcanic rocks in Dinem Island are identified as porphyritic andesites with plagioclase and amphibole phenocrysts and minor clinopyroxene and Fe-Ti oxides. These andesites exhibit high values of Cr (56 – 91 ppm) and Ni (22 – 34 ppm) indicating their primitive characteristic. The Dinem volcanics also have high values of $(La/Sm)_N$ (3.52 – 4.51) and Th/Yb (7.43 – 9.51) and low values of Ba/Th (42.31 – 44.26). These high $(La/Sm)_N$ and Th/Yb and low Ba/Th in the volcanic rocks of Dinem indicate the significant influence of slab sediment-derived fluids in the magmatic source of these volcanic rocks.

The xenoliths hosted in these volcanic rocks range from clinopyroxene harzburgite, harzburgite and dunite with minor gabbros and hornblendites. The ultramafic xenoliths are composed of olivine (Fo = 88 – 90), spinel (Cr# = 0.20 – 0.50), and minor cpx (Mg# = 0.80 – 0.93). Based on the high Fo and MnO content of the olivine (MnO = 0.09 – 0.20) and the high Cr# and Mg# of spinel, the xenoliths are interpreted to be residual peridotites. These are cut by melt pockets of either symplectitic hornblende+clinopyroxene or plagioclase-only composition. These melt pockets likely represent melts and/or fluids that infiltrated the peridotites at shallower depths. Finally, the xenoliths are surrounded by an inner orthopyroxene and an outer hornblendite selvage. The selvage concentrically surround the xenoliths suggesting their formation during the interaction of these xenoliths with the host andesites during entrainment.

Keywords: Dinem Island, xenolith, andesite, melt pockets, selvage

Petrological characterization of the intrusive rocks in northern Zambales and Pangasinan: From ophiolite emplacement to arc magmatism

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Intrusive rocks in ophiolites (e.g. isotropic gabbros, plagiogranites, sheeted dikes, and/or late-stage dikes) hold key information on the magmatic processes, origin, and tectonic environments from which an ophiolite is generated. Plagiogranites and mafic dikes could occur as late-stage intrusives which provide evidence for post-ophiolite processes like subduction, obduction, and/or emplacement. In this study, the intrusive rocks associated with the Acoje block of the Zambales Ophiolite Complex (ZOC) exposed in the northern Zambales and Pangasinan are examined. These intrusive rocks possibly record spatial and temporal variations which could provide new constraints on the tectonomagmatic evolution of northern Luzon.

Isotropic gabbros occur in different localities in the study area. In Sual, isotropic gabbros are cut by sub-parallel to parallel diabase dikes. In Bugallan, isotropic gabbros are cut by diabase dikes and their apophyses with observable baked and chilled margins. Isotropic gabbro exposures in Mabini and Infanta are intruded by tonalites while the isotropic gabbro in Sta. Cruz exhibits a fault contact with peridotite A dunite exposed in Sta. Cruz is cut by both gabbroic and plagiogranite dike swarms with prominent baked and chilled margins.

Petrographic analysis of the gabbronorites revealed a crystallization order of olivine → pyroxene → plagioclase → hornblende which is typically observed in island arc-related setting. They exhibit orthocumulate and sub-ophitic textures. Diabase dikes are generally composed of pyroxenes and plagioclase and reveal intergranular and sub-ophitic textures. Tonalites show myrmekitic texture at times and are mainly composed of interlocking crystals of amphiboles, plagioclase, and quartz. Whole rock geochemical analyses of the gabbronorites and diabase dikes indicate island arc tholeiite signature. Positive trends of TiO_2 and FeO* and negative trends of MgO, Cr_2O_3, and Ni were observed with increasing FeO*/MgO. In contrast, tonalites reveal very high FeO*/MgO ratio and Na_2O with very low concentrations of TiO_2, Cr_2O_3, and Ni. Based on trace element concentrations of the gabbronorites, diabases, and tonalites, a slight depletion of LREEs relative to HREEs and negative Nb and positive Pb and Sr anomalies were observed. U-Pb age dating of the zircon grains from an olivine-bearing gabbronorite from Bugallon and a gabbronorite from Sual yielded ages of 45.64 ± 0.97 Ma and 45.28 ± 0.30 Ma, respectively. Moreover, an 8.68 ± 0.80 Ma age was obtained from a diabase from Bugallon. The results suggest that the intrusive rocks from northern Zambales and Pangasinan are island arc tholeiites that formed during the Eocene. Meanwhile, the diabase from Bugallon with a late Miocene age may be a product of the subduction of the South China Sea Basin along the Manila Trench.

Keywords: gabbro, diabase, plagiogranite, northern Luzon

From boninites to alkali basalts:
Records of subduction initiation in the volcanic section of the Southern Palawan Ophiolite?

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The Cretaceous Southern Palawan Ophiolite (SPO) constitutes the basement unit in southern Palawan. The SPO is said to represent a fragment of the Proto-South China Sea (PSCS), a vanished oceanic domain theorized to have existed from the Cretaceous to the Eocene. The SPO is composed of dismembered outcrops of mantle peridotites, gabbros, and volcanic rocks. The volcanic sections in Quezon, Brooke's Point, Bataraza, and Balabac Island reveal records of both effusive and explosive volcanism. Effusive eruptive products are represented by basaltic lava flows exhibiting pillow, lobate, and sheet morphologies. These flows are cut by basaltic dikes. Red chert intercalated with lobate lava flows are observed in Espina Point, Balabac Island. Explosive eruptive units observed in Quezon are composed of pyroclastic breccias which unconformably overlie lava flow units. Glassy, lapilli-sized clasts within the pyroclastic breccias are identified as boninites. This work focuses on the possible records of subduction initiation (SI) preserved in the volcanic section of the SPO through field, petrographic, and geochemical analyses.

Basalts are hypocrystalline and are composed of plagioclase, orthopyroxene, and clinopyroxene phenocrysts and microphenocrysts. Orthopyroxenes and minor clinopyroxenes are set in a groundmass of glass and quenched pyroxenes in the boninites. Initial whole-rock geochemical data supports the co-existence of boninite and subalkaline, moderate Fe tholeiites in Quezon. Lava flows in Bataraza and Balabac Island exhibit subalkaline, moderate Fe tholeiite signatures. Rare earth element (REE) plots of tholeiites show that they are more depleted in light REEs than mid-oceanic ridge basalts. Samples from Brooke's Point are identified as alkali basalts.

The lithologies comprising the volcanic section of the SPO resemble the forearc region of the Izu-Bonin-Mariana forearc and other suprasubduction zone ophiolites (e.g., Zambales Ophiolite, Oman Ophiolite). The volcanic units of the SPO preserve possible evidence of SI processes that can be linked to the evolution of the SPO and the PSCS. Detailed volcanostratigraphic, geochemical, and tomotectonic work will be done to further constrain the magmatic and petrologic evolution of the SPO's volcanic section.

Keywords: Palawan, ophiolite, subduction initiation, submarine volcanism

Petrogenesis and significance of Cretaceous alkaline rocks in southern Palawan

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Palawan comprises ophiolitic slivers which are exposed in the central and southern portions of the islands. Previous works have suggested the possibility of the occurrence of two distinct ophiolites in Palawan namely the Eocene Central Palawan Ophiolite (CPO) and the Cretaceous Southern Palawan Ophiolite (SPO). Recent field mapping activities conducted in the island have led to the identification of distinct characteristics between the two ophiolites. In this work, we highlight the occurrence of biotite-bearing gabbros and syenites in southern Palawan, which have not been recognized in the CPO. Medium to coarse-grained biotite-bearing gabbros and syenites were observed as boulders in Brooke's Point, southern Palawan. The biotite-bearing gabbro boulders are more dominant and usually larger than the syenites. Plagioclase, biotite, clinopyroxene and olivine are the mineral phases in this lithology. Biotite usually occurs in the interstices of the samples indicating its late-stage formation. Alkali feldspars account for almost ~90% modal abundance in the syenites. Perthitic texture showing exsolution lamellae of albite is also common in the alkali feldspars. Minor abundance of biotite, alkali amphibole and sphene were also noted in the samples. Initial whole rock geochemical data on these rocks reveal that the biotite-bearing gabbros have lower SiO_2 and total alkalis ($Na_2O + K_2O$) compared to the syenites. Novel geochemical data on these rocks will be further compared with other intrusive units in the study area and vicinity. The recognition of these intrusive rocks in the study area further raises questions on the evolution of southern Palawan. The relationship of these mafic intrusive units with other SPO lithologies and their implications on the geologic evolution of the area will be further explored.

Keywords: Biotite-bearing gabbros, syenites, alkaline magmatism, Palawan

Mineral assemblage and characteristics of continent-derived metapelites and metapsammites in Sibuyan Island, Romblon

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In Sibuyan Island, metamorphic rocks which are part of the Romblon Metamorphics are observed. These are metamorphosed pelitic and psammitic rocks that occur along with the mafic-ultramafic units of the suprasubduction zone type Sibuyan Ophiolite Complex (SOC). In particular, the metapelitic and metapsammitic rocks are observed in the western and eastern portions of the island, while SOC gabbros and peridotites occur at the center of the island. The occurrence of these metamorphic rocks are attributed to the arc-continent collision of the Palawan Microcontinental Block (PCB) and the Philippine Mobile Belt (PMB). In this work, we present novel field and petrological data from the metapelites and metapsammites exposed in Sibuyan to provide insights into their petrogenesis and the pressure-temperature-deformation (*P-T-D*) conditions that they preserve.

In northern Sibuyan, alternating layers of phyllitic metapelites (biotite-rich) and metapsammites (quartz-rich) are observed. The foliation direction of these interlayers generally dip in the southeast direction. On the other hand, schist exposures are more predominant in the eastern and southwestern portions of the island. They are also comprised of alternating metapelites and metapsammites suggesting similar protolith to the phyllites but possibly with distinct peak metamorphic conditions.

An exposure of the metapelites was documented near the coast in Barangay Mabini. It is composed of dark-colored schists with white prismatic plagioclase porphyroblasts and is cut by leucocratic dikes that are often subparallel to the foliation of the schists. Petrographic analysis and back-scattered electron (BSE) imaging of the metapelite schist and dike samples revealed similar mineral assemblage of quartz (Qz) + plagioclase (Pl) + biotite (Bt) + orthoclase (Or) + apatite (Ap) (± muscovite (Ms) ± chlorite (Chl) ± pyrite (Py) ± oxides) in varying abundances. Qz, Pl and Or are more abundant in the dike, while Bt and Pl are the dominant minerals in the schist. Pl and Bt are the common porphyroblasts, whereas Qz typically occur in the matrix of both the schist and dike. Foliations are marked by the elongation direction of these minerals. Two occurrences of Pl grains are found both in the schist and dike. The first type is characterized by oscillatory zoning, indicating a difference in the composition of its core and rim, while the second type exhibits myrmekitic texture. These Pl grains are also altered by clay minerals. Most of the Qz grains in the matrix of both the schist and dike exhibit a sigmoidal structure. Subparallel foliations present in the dike and schist imply that the intrusion happened earlier than the deformation event that possibly caused the metamorphism in the area. The presence of mica, Or and Qz suggests a protolith related to the PCB. Further petrological and geochemical analyses will be done to interpret the *P-T-D* history and petrogenesis of these metamorphic rocks in Sibuyan Island.

Keywords: schists, phyllites, Sibuyan, Romblon island group