Shahid Beheshti University

Sustainable Earth Trends

Journal homepage: http://sustainearth.sbu.ac.ir

The pacific island volcanology and its relation to the groundwater features through magmatic signatures

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ABSTRACT

The Pacific Plate is one of the heaviest tectonic plates, hosting multiple Pacific Island countries. Geological research has long provided evidence of volcanic magmatic events, which have frequently caused subsurface activities. The formation of an active ring of fires across the Pacific Ocean is a geological signature of the intense volcanic events occurring over time. The study aims to verify the close correlation between groundwater features and volcanic magmatic events, which is evident in near-surface ground signatures and geothermal systems. Hot water springs and geysers emerge as manifestations of the active molten volcanic processes, releasing intense heat flux, gases, and pressure. Pacific Island countries exhibit common geological features, particularly in terms of parent rock materials, resulting in a unique combination of aquifer characteristics essential for long-term hydrological sustainability. The sustainability of groundwater resources is intricately linked with volcanic events and their associated signatures, which emerge abruptly over time. Furthermore, the study is to access the correlation of the pacific geological features within Fiji and various regions and its usages in terms of implementing water resources upon the identification of the active aquifers in the terrestrial and coastal plains. Fieldwork using various tomography methods from various regional countries executed by the Secretariat of the Pacific Community through the implementation of various programs has provided various supporting evidence that the magmatic activities featured by dikes, basins, and aquifers have water holding capacity which is hydrogeological connected to the main water aquifer.

ARTICLE INFO

Keywords:
Aquifer
Geology
Magmatic events
Pacific ring of fires
Volcanic

Article history:
Received: 27 Jul 2024
Accepted: 19 Nov 2024

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Citation:
Maharaj, R. et al., (2025). The pacific island volcanology and its relation to the groundwater features through magmatic signatures, *Sustainable Earth Trends:* 5(2), (37-50).

DOI: 10.48308/set.2024.236417.1061

1. Introduction

The Pacific Islands are situated along the horseshoe-shaped structure known as "the ring of fire," which contains numerous outlets of molten magma visible as islands. Geological studies aim to comprehend the physical processes involved in the Earth's formation, with volcanic signatures serving as crucial indicators of magmatic activities, atmospheric phenomena, and oceanic processes (Nunn and Pastorizo, 2007). Magma, originating from the Earth's innermost core, emerges onto the surface through seafloor spreading and volcanic eruptions driven by mantle plumes, subsidiary pathways, and subduction plate movements (Walker, 1993). These geological activities contribute to the formation of various structures on Earth's surface, including hydrological features related to volcanism and water presence. Chemical signatures play a vital role in understanding volcanic processes, including the release of gases and water. When conducting investigations or field observations, it is essential to select methods that identify groundwater features associated with volcanic activities while distinguishing them from geological features determining hydrological factors. This unique geological setting leaves the Pacific Islands with distinctive characteristics. The viscosity of molten magma increases with higher silica content. During eruptions, the amount of gas and water present indicates the presence of lighter minerals within the rising magma, with less dense materials rising to the top and denser elements sinking to the bottom of the chamber. Groundwater can become trapped by rising magma, serving as a medium for transporting water to the Earth's surface either as gas or springs. This process contributes to the plumbing of volcanoes, where rising magma travels through conduits, forming interconnected channels and chambers (Hamilton et al., 2010). Over time, these magma channels become filled with water traveling through the conduits, eventually emerging as surface water sources (Johnson et al., 2012).

The permeability of the ground allows water to move from one location to another, with groundwater in the Pacific region manifesting through rivers, streams, springs, and lakes. The geography of the Pacific Islands exhibits significant abrupt topographical features, indicating past violent volcanic activities (Neall and Trewick, 2008).

Many of these features, such as atolls and islands, are associated with stratovolcano activities, which were characterized by a lesser degree of aggression. These features also give rise to other underlying formations such as batholiths and laccoliths, which push near-ground surface features upward into uplifted forms. The volcanic events responsible for these features primarily involve Vatukoro greywacke geological materials, combined with significant proportions of basaltic elements (Setterfield et al., 1991). This indicates the basic nature of the magmatic activities with a lesser degree of silicon elements present. Geological compartmentalization becomes significant when assessing hydrogeological parameters due to similarities in water-holding capabilities. In many tropical islands in the Pacific, groundwater is the primary source of water contained in aquifers. Pacific Islands' aquifers are abundant in groundwater storativity and offer optimum quality. Natural mechanisms of water recharge are common in the Pacific due to factors such as rainfall, land topography, and natural aquifer alignment, which facilitate seepages. Many tropical islands rely on groundwater due to limited salinity and the potential for lower intrusions. Groundwater can also occur at elevations above sea level on some tropical Pacific Islands, where groundwater bodies can form at low-permeability geological features or structures, producing springs. Rainfall is the main source of freshwater for groundwater recharge, leading to aquifer replenishment and balancing (Adachi et al., 1986).

In high mountainous islands, rainfall is typically heavier on the windward side and over the mountainous areas, where moisture in clouds condenses, producing fog and drips. This phenomenon is observed in the Solomon Islands on the windward side, leading to the formation of clouds and heavy downpours of rain in areas such as Malaita, Isabel, and Makira. Prominent features of groundwater linking to aquifers are evident in Fiji, with scattered springs found across the geology, particularly in locations such as Savusavu, Tavua (Rabulu), Nadi (Sabeto), and Kadavu. The hydrothermal heat generated by the hot springs is primarily due to the heat flux provided by the molten states of the magmas. The high heat generated by the fluidized rocks releases a significant amount of latent heat of vaporization (Lv) and latent heat of fusion (Lf), which affects the adjacent geological materials. This allows for high absorption of heat and generates gaseous states of the hydrological materials, shifting from fluid to gaseous states. Excessive pressure encountered by the volume of water passing through the intense bed of molten fluidized heat can affect the elasticity in the conduit walls, leading to other features such as rupturing, which can result in magma outflow to near surface points. This desktop-based study is of first in its kind which is trying to relate the pacific geological features within Fiji and various regions and its usages in terms of implementing water resources. The objective of this study is to access the correlation of the pacific geological features within Fiji and various regions and its usages in terms of implementing water resources upon the identification of the active aquifers in the terrestrial and coastal plains This focus on the identification of the local or regional fractures, indicating groundwater preferential flow and storage. Lineaments were identified using google earth satellite imagery, these lineaments normally join parallel direction with the each other. Field observations around these surficial features supported the identification of exact locations based on-site accessibility. This forms the basis for the remote sensing data which is integrated with surveying tasks of analyzing topography, structural geology, hydrogeology and elongated feature of the common groundwater aquifers (Rahiman and Pettinga, 2008; Ghosh et al., 2022).

2. Material and Methods

Fiji and the pacific region share a similar geologic attribute due to the abrupt explosions. Methodologies required to classify the geologic materials based on the types of eruptions which occurred. Desktop based study was taken to study various scenarios of geological signatures through certain synopsis which depicted points of interests. Various cases were looked at ranging from various hot water springs, volcanic aquifer outflow and methods of groundwater investigation using topographies of the geological water bearing zones formed from the volcanic events. The desktop analysis required specific technical knowledges to match features of the identical nature through the usages of the lineament analysis tasks. This desktop and review based studies showed a correlation of the near surface features of topography showing significant abrupt features which aligned to the geological and hydrogeological points. The studies were looked at based on the pacific geology and climatology. Fig. 1 shows the position of the Pacific plate in alignment with the other adjacent boundaries.

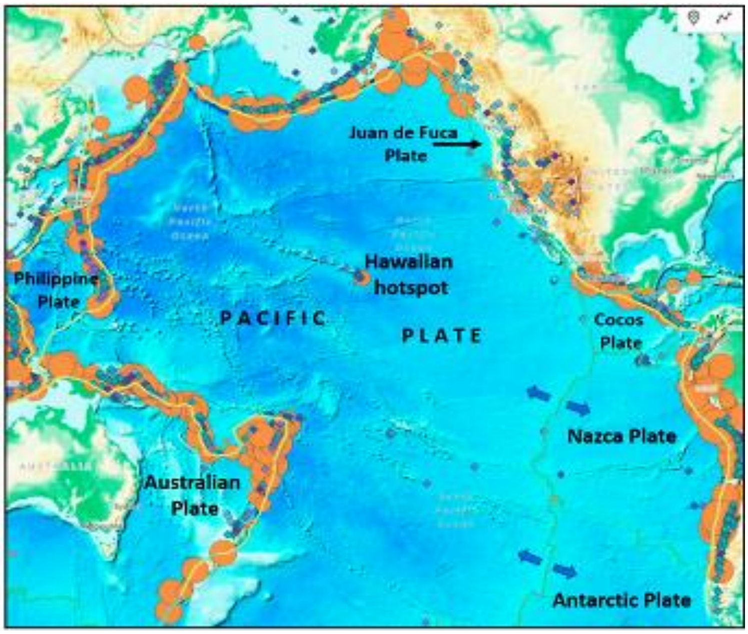

Fig. 1. Shows the position of the pacific plate in alignment to the other adjacent boundaries.

2.1. Pacific geology and Climatology

Atolls are on surface geologic signatures which are a result of basaltic volcanoes which has subsided into the oceans. Various other signatures become prominent from this the interactions of the erupted volcano and sea water giving rise to the reef growth resulting in a cap of calcium carbonate minerals extending from the sea surface to the top of the submerged volcano. Various volcanoes formed in the pacific such as the Marshall Islands were active for over 150 million years ago (Schlanger et al., 1984). Chemical alterations due to the weathering effects has caused of the carbonate minerals from the geological materials. The weathering has had effects from rigorous and rampant precipitations with extreme heat conditions in and around the ground level at the near surface points, further climatic conditions such as the and sea-level changes, have governed the shallow subsurface geology, which is generally described by the following three-layer model: 1. Upper sediment unit is composed of unconsolidated and well-sorted coral sand and gravel; 2. Lower sediment unit is composed of unconsolidated lagoonal sands and gravel of Late Pleistocene/Early Holocene age; and 3. Dense and well-consolidated limestone unit of Pleistocene age, which was formed during subaerial exposure and recrystallization to calcite. The unconformity between the younger sediments and the underlying Pleistocene limestone is called the Thurber Discontinuity, and is typically encountered at depths ranging between 16 ft

(5m) and 82 ft (25m). Fresh groundwater occurs in atolls as a thin lens buoyantly supported by dense underlying saline water. The occurrence of these freshwater lenes is expressed through existing shallow hand-dug wells that atoll communities rely on, either as a primary source for drinking and cooking, or a secondary source for washing, toilets and irrigation, depending on the water quality and salinity. A freshwater lens is formed within the unconsolidated sediments according to suitable hydraulic conditions. On wider islands – those greater than 3280 ft (> 1000 m) – that receive an appreciable amount of rainfall, the base of the freshwater lens can reach the Thurber Discontinuity. The higher permeability of the underlying limestone cannot support the formation of a lens, which is truncated at that point due to immediate mixing with the underlying saltwater (Hamlin and Anthony 1987; Hunt 1997). The thickness of the freshwater lens across the width of the island depends on the recharge rate, the island's width, the thickness and hydraulic conductivity (K) of the upper sediment units, and the depth to the Thurber Discontinuity and the presence or absence of a reef flat (Rowland and Sibson, 2004; Bailey et al., 2013). A zone of transitional salinity, or transition zone, typically exists between the infiltrated rainwater and underlying saltwater. This zone is formed by the mixing of the two water types promoted by tidal forces and its thickness largely depends on the aquifer's hydraulic properties. Islands comprising the Republic of the Marshall Islands are shown in Fig. 2.

Fig. 2. Islands comprising of the Republic of the Marshall Islands.

The hydraulic properties of freshwater lens aquifers strongly depend on the orientation and position of the island with respect to the prevailing winds, in addition to the thickness and compositions of the aquifer materials. Islands in the direct path of the prevailing winds and associated high-energy waves tend to have a coarse sediment structure, and therefore higher K, which is less conducive to the formation of thick freshwater lenses. In contrast, aquifers on islands located on the partially protected leeward side of atolls tend to acquire a finer sediment structure and have lower K, which is more conducive to thick freshwater lenses. According to figure 2. the freshwater lens at Laura on Majuro Atoll was used in this work to calibrate the geophysical results with measured groundwater electrical conductivity (EC) in monitoring wellsLaura islet is on the western end of Majuro Atoll and has a maximum width of 3940 ft (1.2 km). It holds a known freshwater lens of national significance for meeting both the local community water demands, and the greater Majuro Atoll water demand during drought periods. The Laura lens has been the subject of numerous investigations as documented by United States Geological Survey (Hamlin and Anthony 1987) and SPC (Sinclair et al. 2017). It has been equipped with 10 monitoring sites that allow for multiple depth investigation points. Seven infiltration galleries have been constructed across the islet. The galleries skim the freshest part of the lens through the placement of horizontal pipes below the water table, and allow groundwater production via pumping and distribution towards a dedicated treatment plant managed by MWSC. After treatment, the water is distributed to households in Laura (on Monday and Friday), and to nearby communities eastward to Ajeltake (from Tuesday to Thursday), during normal conditions. During prolonged drought periods, more demand is placed on the Laura lens, and water is piped to the MWCS airport reservoir to support the main Majuro urban areas of Delap, Uliga and Darrit, as experienced during the 1998 and 2016 drought events.

3. Results and discussion

Studies encompassing the groundwater in alignment with the magmatic signatures can be categorized in terms of volcanic and natural stress applied by the earth due to the prevailing weather conditions. The classification of the geothermal springs and fresh water lenses development are the obvious features which has a hydrogeological physics associated due to its physical existence.

3.1. Volcano and geological signatures

Groundwater interaction with the surface topological features is interactive based on the internal flow movement and the directions. Parameters such as transmissivities conductivies and permittivity's govern the near surface point seepages which leads the near surface topological features in the form of the sharp vegetations and creeks. The movement of the water may be dictated by the slopes, soil porosity, soil drainage and the membrane of the rocks that lie within the aquifer and the adjacent zones. The inner water movement draws vegetation features which may be visible and significant on the satellite imagery in the form of the sharp boundaries, geological areas and the dikes. Ground water exploration works has been carried out in the Village of Nubutautau within Fiji through the detection of underground aquifers with the usage of the Geophysical techniques. An interesting feature of the water zones with the near surface topological feature has been observed.

Groundwater seepage alignment with the surface indicates a significant topological vegetation interaction with water movement within the geological and sub geological layers. The water bearing units on the geological profile tends to be the region of higher saturation for the fluid to be contained and this moves to a lower region through the mechanics of flow. Features such as the perennial, intermittent creeks with dikes present near surface point, are interconnected to allow the surface movement to be visible through the near surface features visible on the satellite imagery. In the intermittent springs the invisibility of the surface water table indicates a water table far below the surface point and may tend to fluctuate during severe meteorological conditions. The drier basement of the creeks with the intense topological features channels to water bearing zones or containment units which are saturated with groundwater (Malin and Edgett, 2000; Crain et al., 2009). Depending on the near surface features the ground water seepage aligns from the higher saturation into the lower sub channel containment zones which linearly moves to other surface interactions areas accounting for rich vegetation's.

3.2. Classification of Geothermal Systems

Geothermal systems formed due to the hydrogeological events pertaining to the groundwater and the volcanic features are categorized based on various physical parameters such as reservoir temperature, enthalpy, physical state, nature of fluid and utilization and geological setting (Saemundsson et al., 2009; Masum, 2015). The most common classification of geothermal systems is based on enthalpy of geothermal fluids which transports heat from deep inside the earth to the surface (Dickson, 2002). According to this criterion, geothermal systems are classified as low, medium and high enthalpy resources. Dickson (2002) adds that high enthalpy systems are suited for electricity generation and low enthalpy systems are utilized for direct heat use applications. Table 1 below presents a summary on geothermal system classification based on reservoir temperature, enthalpy and physical state (Lal, 2019). Three hot springs from the Fiji Islands were examined: Sabeto, Rabulu, and Savusavu. The physical and chemical parameters were compared to the volcanic properties of the Pacific Island countries. Figs 3, 4, and 5 show the Savusavu hot springs and Tavua Rabulu and Sabeto springs, respectively.

Table 1. Represents the categorization of the geothermal system based on the reservoir temperature, enthalpy and physical state.

Reservoir temperature	Enthalpy	Physical state
Low temperature systems with reservoir temperature at 1 km depth are below 150 °C. Mainly characterised by hot or boiling springs	Low enthalpy geothermal systems with fluid enthalpies less than 800 kJ/kg. Low temperature and high temperature geothermal system falls in this category.	Liquid dominated geothermal system.
Medium temperature systems with reservoir temperature at 1 km depth are between 150 to 200 °C.		
High temperature systems with reservoir temperature at 1 km depth are greater than 200 °C. Characterised by fumaroles, steam vents and mud pools.	High enthalpy geothermal systems with fluid enthalpies greater than 800 kJ/kg.	Two-phase geothermal reservoir where water and steam co-exist.
		Vapour dominated reservoirs

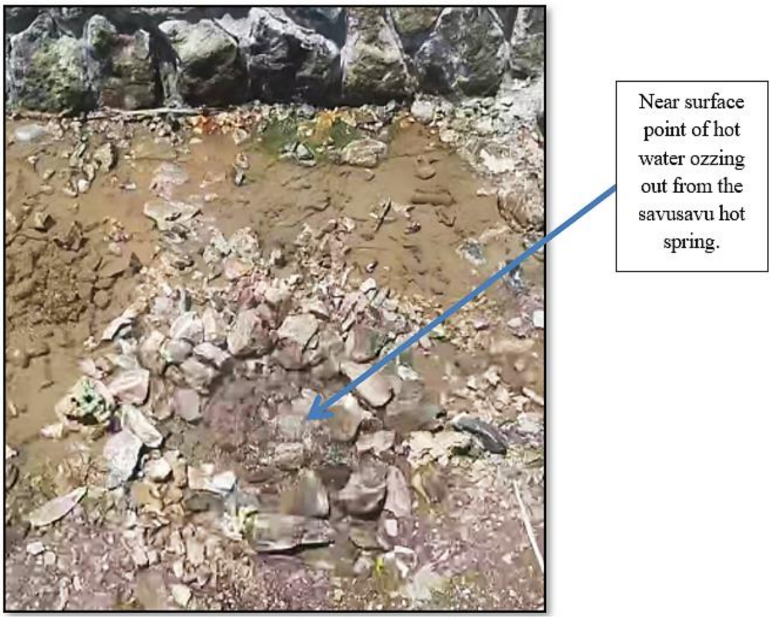

Fig. 3. Savusavu hot spring in the form of the geyser in Fiji with the higher degree of heat given out.

Fig. 4. Hot spring located in Rabulu Tavua on the western of Viti Levu.

Fig. 5. Hot spring located in Sabeto Nadi, Viti Levu, Fiji.

Hydrogeological features are prominent from the volcanic activities and this leads to the significance of the water chambers such as aquifer, aquifuge, aquicludes being formed (Hassan Baioumy, 2015). These chambers vary according to the distribution of the rock materials and the geological elements present, within the hydrogeological systems (Mathon, 2015). The porosity and permeability of an aquifer determines the shape of freshwater lens and its flow through aquifer. The porosity is the percentage of a geological formation consist of small spaces that can hold water and the permeability is the property of ground that determines the rate at which water can flow through a geologic formation. Other factors being equal is of high zone result in high-rate groundwater than zone of low porosity (Ogden, 2011; Burgmann, 2018). This is a diagram showing major components of groundwater of the "hydrological" cycle on most tropical Pacific Islands, the arrow indicates rainfall movement and other recharging precipitation and its flow towards the ocean, and the cycle where water vapor returns through evaporation then precipitates and fall back to the earth's surface continued (Pasquale, 2015).

3.4. Fresh water lenses development and Intrusions

Fresh water lenses development has been significant in land surface areas, surrounded by the sea salt water containing ionic charges. Due to the volcanic eruption types, such as strombolian or vulcanian events, the underwater volcano eruptions have not significantly reached high altitudes. This has created a lesser amount of land mass submerged and surrounded by sea. In most cases the upper parts of the volcano mostly get reshaped into craters. Due to the significant interactions with the hydrogeological environment, fresh water lenses feature emerges, which are significantly classified as water bearing zones (Singh et al., 2021). These fresh water lenses aquifer becomes a potential water bearing zone feature, which are identified using topographies in mapping electrical parameters with the hydrogeological parameters.

In the Solomon Islands with its diverse and multicultural islands located on the archipelago consist of approximately nine hundred and ninety-two scattered islands, and atolls. There is a significant geological and hydrological feature interrelated by the volcanic-tectonic structures of the volcanic deposits and man-made features. The physical features of geology can be evidently shown as volcanic activities that have volcanic vent, lava, rock fragments, and volcanic gases. These features are so significant for scientific approach of identifying groundwater features as it gives alignment to volcanic activities producing various magma chemistry. A rising magma went through temperature differential as it came out of volcanic vent exposing molten material and adjusting its temperature outward-in, during this period of change chemical signatures transformed and also changing the magma chemical composition (Huang et al., 2011). The molten lava chemical composition also changes its signatures as it rises through to reach the earth's surface from various types of mineral present with different cooling temperate zones. It provides an avenue for rocks to combine forming fragmentation inside the lava and producing gas and water.

Hawai'i is another classic example of the uniqueness of the Pacific territory water availability, according to (Wilson et al., 2019) their studies have confirmed the unique geology feature related to groundwater and that is they recharge, "the large-scale entry of lava during the 2018 eruption of Kilauea volcano created a large and biological productive surface plume that was observed hundreds of kilometers offshore and persisted for the duration of the eruption. This strong biological response depended not only on the lava itself but also on an exogenous source of nitrate, which is believed to have derived from lava entering the deep ocean creating buoyant plumes of nitrate-rich deep water into the nitrogen-starved surface ocean." Thus, can be shown by the chemical signatures indicated and differentiated with samples specifying major and minor compositions of water origin. Hydrothermal emanations provide evident characteristic on a possible contribution of some elements related to the volcanic activity related to minerals found in hot spring water and saline water. *"The related can be ascribed to an intimate connection between the hydrothermal exhibition including metals and volcanic processes indicating the stationary chemical condition in the Pacific since the middle Cretaceous"* (Adachi et al., 1986).

Pacific Island Countries, geological features designed by nature of its location "along the ring the fire" gives its uniqueness to groundwater features. The volcanic activities have prepared territories or zones allowing water to travel and store in various groundwater store reflecting landform sizes, volcanic-dike complexes, basin-filling, atoll islands, layered volcanic rocks, and uplifted marine limestone known to be the aquifer materials with various conductivities. The lesser turbidity of volcano producing porous and permeable geologic formation throughout the archipelago of the Pacific making it a better groundwater source to the people, this would be an area that nationally should be address. Although some countries in the Pacific have tend to utilize this resource most are still in demand to access it in greater volume. There are accounts of volcanoes in the Pacific that known to originally sourced through the ring of fire. Molten magmas expose to the earth's surface by channeling through volcanic activity caused by movement of tectonic plates known as subduction process. Subduction is the movement of plate when oceanic plate moves beneath the continental plate, which in every situation causes earthquake "plate movement" resulting in molten magma exposes on earth's surface either in the ocean or inland. Exposed molten magma in the ocean can be as submarine volcano, terrestrial volcano or ocean floor spreading that occurs consistently on oceanic plate balancing the renewal cycle of plate boundaries producing different rock types and minerals. Thus, this essay will be focusing on subduction zone, ring of fires, Pacific plates and its link to the volcano including its relationship to magma effects and types of eruptions governing the Pacific Island Geology. Pacific Oceanic Plate have the largest marine territory on the ocean floor that has a complex geological event recorded. Geologically, oceanic – to – oceanic plate movement occurs in the Pacific result in transformational fault colliding past, towards, or both ways and develop landform in other part of the plate while deform at the center point location of where it occurs. It is also quite intriguing about the geologic behavior of Pacific Plate that leads to Pacific Island Volcanic events as it dictated the geological concept of other parts of the world that has been studied in time. Geologist & scholars have written accounts that oceanic plate subducted due to its density, however, in the Pacific an event after a lengthy period changes Pacific history showing a situation occurs differently, where the continental plate subducted beneath the oceanic plate. The volcanoes have terrorized the world for centuries and scientists have recognized the belt of activities that causes volcanoes from the series of tectonic plates that slowly move into and apart from each other that make up the Pacific. The complexity of plate boundaries in the Pacific connects well with the Pacific Islands' myths as in oral histories most events entail some record that linked geologically in relation to the formation and deformation of the Pacific landmasses (Nemeth and Cronin, 2009). More than 500 years ago Pacific Islanders have witnessed the evolving land formation and deformation events since then it has become tales and myth passed down through generations. Myths created varies amongst Island groups in the Pacific that perhaps have adjusted in response to witness the geological phenomena depicting creatures or biota species in a different form from the original (Nunn and Pastorizo, 2007).

Therefore, Pacific history can be revealing when it comes to unveiling the past geological map of ancient landmasses, these events somewhat foretold parts and parcel of the Pacific basin that relatively form quasi-linear chains of Islands and seamounts. The series of In the Pacific a lot of volcanic activities occur under water forming numerous trends of chains of islands. One of the classic examples there due to the change in chain trend between the Emperor, Gambier-Tuamotu, Austral-Cook, Gilbert-Marshal, and the Hawaiian reflects the direction of Pacific plate movement relative to the underlying convectional current (Jarrard and Clague, 1977). In one occasion in the Pacific where the Pacific plate subducted beneath the Australian plate that formed the first arc of Islands in the Solomon Islands, due to this rotational convectional change the motion traversed causing Australian plate subducted and formed another set of island arc including volcanic events which are recently part of the subduction shift.

The molten magma composition highly varies from basaltic, andesitic, altering olivine, plagioclase, sedimentary limestone, apatite, and mixture of primary to secondary rock and minerals range to 500 to some 200 million years ago present in these chains of islands in the Pacific (Jarrard and Clague, 1977). There are around two hundred volcanic activities in the Pacific Ocean, eight Holocene volcanos are recorded in Solomon Islands' geological history. The kavachi and tinakula are the andesitic volcano, savo is the pyroclastic volcano, and Nando-Vella in western province is the andesitic-stratovolcano. Most types of volcanic eruptions in the Pacific are caused by subduction while a few from hotspots along weak points of the plate boundaries. Many volcanoes from the subduction zones erupt lavas of dacitic to rhyolitic composition and these magmas often erupt explosively due to high volatile contents and their relatively high viscosity (Haase et al., 2006). The volatile contents of the magmas cause the explosive eruptions of dacitic volcanoes and volatiles elements like Chloride that often assimilated by magmas as it rises through the crust collecting different portion of rocks to the surface. In the model a parent composition for fractional crystallization and crust partial melting is composed of these sources from the basaltic recovery lava of the outer volcano flank. It is interesting to discover the consolidation Pacific tectonic plates is evidently seen by Island chains, volcanic activities, seamounts, and land formation and deformation. Volcanic activities represent mantle exposure on earth's surface through volcanic eruption (Haase et al., 2006).

activities of Pacific plate with clear indication showing relatively consistent magma composition that originated from the same parental magma, this is known to explain the content of land forms or deformed landmasses from the Pacific collection.

3.5. Geophysical Monitoring and Identification of water points

Geophysics approach using the Terrameter LS2 tool is mostly used to understand heterogeneity and homogeneity at the groundwater aquifers because it provides continuous rather than point measurements (Coscia et al., 2011). A range of geophysical function could be applied with different nature of measurements scales from airborne techniques. The field work executed on the volcanology are using the electrical resistivity method, which measures consecutive continuous measurement with the nature of physical principles between wo current electrodes. An electrical resistivity survey can map three potential targets which includes the porosity, pore fluid conductivity and clay contents, all of which are relevant in characterizing streambeds or lake beds. Surveys on stream or lake bottoms help reveal heterogeneity of fluvial and lacustrine sediments and the impact on groundwater–surface water interaction Distinguished (Mitchell et al., 2008). Areas that showed presence of the fault features such as fracture zones and splits in addition to the presence of the aquifer correlated with the locations of known seeps.

3.6. Hydrogeology of groundwater and perennial Surface water Interactions

A surface water body is described as perennial when it is present throughout the year, regardless of seasonal rain or runoff water. The water present in low water periods is known as the baseflow. Baseflow is the quantity of stream flow released to be sustained by groundwater discharge (Sprenger et al., 2011). A water flow that emerges directly from water containment units to the surface is known as a spring and is possible where there is sufficient hydraulic conductivity within the rock materials, the groundwater top level commonly known as the water table, topo form (Dahm et al., 1998). No matter how small the spring is, perennial water bodies occur when the water flow is protected from evaporation and absorption by nearby plants. In discharge zones, processes of recharge and/or throughflow may also take place as superimposed flow systems, with their discharge occurring in other zones. The principal feature indicating a discharge zone is the permanent presence of water, waterlogging, mud, and/or flooding, and a shallow static water level. Low hydraulic conductivity materials that impede downslope ground-water flow can create unstable areas with locally elevated pore-water pressures. The destabilizing effects of small hydraulic heterogeneities can be as great as those induced by typical variations in the frictional strength (Haneberg, 1995; Reid, 1997).

3.7. Interpretations of the seepage with the vegetation's

The internal seepage through of groundwater will cease off in discharge zones, of the perennial creek which shows the existence of the water on the surface. The interconnecting vegetational features from the aquifer and the topographical undulating features primarily connects to the discharge zones boundaries. The discharge zone are characterized by primary attributes (Toth, 1971). Positive potential slope, relatively low-lying position, allochthonous physicochemical composition of water, and allochthonous water temperature. One or more of these attributes may be present (Kachadourian-Marras et al., 2020). The intensity of the primary attributes of the seepage discharge is heavily governed by the combination of the physical and the hydrogeological conditions air temperature, slope of the relief, physicochemical composition of the rocks, permeability of the rocks, vegetation, land uses, etc. Natural mechanisms of the groundwater discharge area can be gauged by the presence of the surface pattern when seen from the GIS image of diffused pattern, which consists of the perennial creeks, base flow, springs represented at higher elevations, marshland, lands with quicksand, landslips or landslides, river valleys, swamp, eutrophicated water bodies, topographic

Depressions, hydrophilic vegetation, and/or halophyte vegetation. The first indication of the discharge zone within the area presence are showed by the limited amount of water in the creeks, waterlogging's and the shallow static water level depths. Upon the inspection of the area evidence of the permanent water on the surface in relation to the local or regional scale condition does not exist. The approach of the zones was assessed on the related geological features and the existing conditions which includes the underlying rock basement captured in the Electrical Tomography Resistivity (ERT), Rainfall conditions and the soil vegetative associations (Toth, 2000).

Pacific geophysical survey has brought about a common finding about the high probability of existence which has the capability of holding in great volumes. Most of the pumping test done has revealed a moderate to greater yield based on the thickness of the water holding chambers it is seen from the geological studies most of the parent rock materials are classified with four seven categories which has a combination of clay, gravels, basaltic materials, fresh water and corals. Based on this hydrogeological parameter there is a corresponding geo-electrical parameter from which interpretations can be derived on the yield quantity of water holdings. Table 2 shows the corresponding tabulation values of hydrogeological and geo electric correlation.

Table 2. Resistivity magnitude variations for various rocks and sediment types.

Rocks and Sediments type	Resistivity Range (Ohm.m)
Clay Containing brackish to saline water	<3
Clay Containing brackish to fresh water	5-8
Clay, Silty sand and some gravel saturated with fresh water	11-25
Weathered basalt containing fresh water	30-60
Fresh basalt saturated with saline water	30-40
Fresh basalt saturated with fresh water	300-700
Dry coral sediments	500-1000

Geophysical instrument requires a conversion of the instrumentational data to the analogical parameters in the context of the hydrogeology. According to the tomography survey carried out in Vanuatu, Kiribati by the Secretariat of the Pacific community there are similar geological signatures which are existing due to the historical pacific volcanic events. Pacific reports for water security in Vanuatu, highlight volcanic aquifers with various rocks corresponding to the hydrogeological logs and interpretations. It has been revealed that resistivity values in the lower range from 3-8 Ohm.m indicate the presence of the clay with saline and freshwater. A slightly higher resistivity of 11-25 Ohm.m reveals silty with some gravels saturated with fresh water. Resistivity higher than 30 Ohm.m may indicate the presence of the basaltic rocks with fresh or saline water and this ranges are significant in the entire pacific. Limitations placed on the field work was mainly due to the mapping of the abrupt features which was obtained during the desktop map generation. Not all features provided a clear indication about the geological and near surface topological profile as there was a possibility of profile misalignment. Near surface features has a close correlation with the below ground surface in terms of perennial and intermittent springs.

The research carries implications, that the volcanic signatures from the different types of eruptions such as the Strombolian, Pilcanan has significant effects of the physical geography, but there exists higher probability of correlations with the hydrogeological factors. This feature formed by the volcanic eruptions has layed a permeant signatures under which the mechanics of the groundwater interactions with the surface studied. Aquifer's size and hydrogeological attributes are the features of underground soil physics and aqueous reactions within the chambers. It can be quantified from the hot springs within certain pacific island countries, the pacific plate has a common feature of the volcanic signatures, these signatures are still varied much live a and active today as water from the springs continue to flow to the surface through the vents and natural pathways which has been created due to gaseous and pressures from the high thermal larva materials. It can also be inferred that the seepages from the water holding chambers and the natural springs are the connecting supply to the vertical water movement which travels through various distances till it connects with near ground features of the similar nature. Most of the interior of Viti levu and vanua levu has been identified with the hot water spring zones, which ultimately reveals there is a common secondary aquifer which connects to a larger area (Maharaj et al., 2023). Spring water has been a common source of economy to the pacific, which has been in existence since the volcanic activities.

3.9. Volcanic water quality and Quantification

Fiji water connected to the natural volcanic spring and aquifer, bottled at the source in Viti Levu (Fiji Islands), is the second largest imported bottled water brand with number 1 premium bottled water brand in the United States. The source is a natural artesian aquifer located in the Yaqara river valley and is receives some external replenishment from the natural rainfall due to the purified by trade winds as it travels across the Pacific Ocean to the islands of Fiji. A product of one of the last virgin ecosystems on the planet, natural pressure forces FIJI Water out of its aquifer deep below the earth's surface and into its iconic square bottles through a sealed delivery system free of human contact (Company, 2017).

The water analysis is a major sample and indication of the pacific mineral elements in the global market and has been proven that chemical elements found within the water has a good proportionate as fluids tends to associates within the large water holding chambers and as they pass through the narrow rock vents.

Table 3. Mineral contents and its qualtification.

General Mineral Analysis	FIJI Water
Bicarbonate	160 mg/L
Calcium	19 mg/L
Chloride	10 mg/L
Fluoride	0.24 mg/L
Magnesium	14 mg/L
Sodium	18 mg/L
Silica	96 mg/L
Sulfate	0.97 mg/L
Total Dissolved Solids	230 mg/L
Total Alkalinity	130 mg/L
Conductivity	290 mg/L
pH	7.8

Similar spring water analysis was at the Nubutautau village in Fiji which had the mineral contents in the similar nature and quantity as revealed in table 4 (Maharaj et al., 2023). This concludes that the two tables revealing the chemical nature contents of different synopsis share the same range of mineral values which are the derivatives from the volcanic aquifers within Fiji and the Pacific as a whole.

Table 4. Mineral contents from the three springs within the Nibutatutau Village.

Customer ID Lab No	Spring 1 Nubutautau Spring 2020/3851	Spring 2 Tauboto Spring 2020/3852	Spring 3 Yavulagi Spring 2020/2853	Date Analyzed	Method Ref. No
Alkalinity (mg/L)	108	97.7	71.2	14/01/20	AP 2320B
Chloride (mg/L)	90	120	95	20/10/20	AP 4500-Cl^- B
Calcium (ug/L)	13.5	12.2	16.4	14/10/20	AP3111B
Electrical conductivity (uS/cm)	213	147	185	20/10/20	AP2510B
Iron (mg/L)	3.72	1.08	1.90	15/10/20	AP3113B
Magnesium (mg/L)	5.41	7.61	6.75	14/10/20	AP3111B
Manganese (mg/L)	<1	<1	1.17	15/10/20	AP 3113B
Silica (mg/L)	28.8	43.9	46.9	04/10/20	AP 4500-SiO_2D
Sodium (mg/L)	13.9	2.30	9.85	14/10/20	AP 3500-Na B
Sulphate (mg/L)	2.45	4.29	10.4	12/11/20	AP 4500-SO_4^{2-} E

4. Conclusion

Pacific Island countries located within the pacific plates have demonstrated unique features in term of their unique geology to hold and sustain water for a longer period of time. This groundwater holding capacity within the aquifers are conserved and continue to get replenished from the external rainwater through the natural climatological process. Pacific geology has been well studied over the period of time, for the potential work which can be carried out. According to the groundwater strengthening programme it can be concluded that there has been multiple investigations or field work in the pacific in expanding water security for the pacific islanders use and generate revenue. Fiji is well known to export its natural water which is directly seeping through various geological layers and is connected to the enlarge aquifer. These products are the natural Fiji Water, Aqua safe, Vai Wai etc. To conclude, in the Pacific as we note the complexity of plate movement varies between series of plate boundaries that determines its volcanology. The record of Pacific Island volcanology history interestingly some of which are entailed as myth passing down through generations that these Pacific voyagers actually witnessed the events. The processes continued happening where Islands and volcanoes will continue to form, understanding these facts requires going back to the past which would trace the gap and to allow us understand the future.

Acknowledgment

The authors of this manuscript would like to acknowledge everyone who have contributed to this paper through their scientific and technical knowledge about the pacific island geology and its links to the magmatic mechanics of groundwater. This article was not under any financial support by any agencies.

References

Adachi, M., Yamamoto, K. & Sugisaki, R., 1986. Hydrothermal chert and associated siliceous rocks from the northern Pacific their geological significance as indication of ocean ridge activity. *Sedimentary Geology*, 47(1–2), 125–148.

Bailey, I., G. M. Hole, G.L. Foster, P.A. Wilson, C.D. Storey, C.N. Trueman, & M.E. Raymo., 2013. An alternative suggestion for the Pliocene onset of major northern hemisphere glaciation based on the geochemical provenance of North Atlantic Ocean ice-rafted debris, *Quaternary Science Reviews*, 75, 181-194.

Burgmann, R., 2018. The geophysics, geology and mechanics of slow fault slip. *Earth and Planetary Science Letters*, *495*, 112-134.

Company, F.W., 2017. Bottled water quality report.

Coscia, I., S.A. Greenhalgh, N. Linde, J. Doetsch, L. Marescot, T. Gunther, T. & Vogt, A.G. Green., 2011. 3D crosshole ERT for aquifer characterization and monitoring of infiltrating river water, *Geophysics*, *76*(2), G49-G59.

Crain, C.M., Halpern, B.S., Beck, M.W. & Kappel, C.V., 2009. Understanding and managing human threats to the coastal marine environment. *Annals of the New York Academy of Sciences*, 1162(1), 39-62.

Dahm, C.N., Grimm, N.B., Marmonier, P., Valett, H.M. & Vervier, P., 1998. Nutrient dynamics at the interface between surface waters and groundwaters. *Freshwater Biology*, 40(3), 427-451.

Dickson, J.A.D., 2002. Fossil echinoderms as monitor of the Mg/Ca ratio of Phanerozoic oceans. *Science*, 298(5596), 1222-1224.

Ghosh, S., D'Souza, J., Goud, B.R. & Prabhakar, N., 2022. A review of the Precambrian tectonic evolution of the Aravalli Craton, northwestern India: Structural, metamorphic and geochronological perspectives from the basement complexes and supracrustal sequences. *Earth-Science Reviews*, 232, 104098.

Hamilton, C.W., Fagents, S.A. & Thordarson, T., 2010. Explosive lava–water interactions II: self-organization processes among volcanic rootless eruption sites in the 1783–1784 Laki lava flow, Iceland. *Bulletin of Volcanology*, 72, 469–485.

Hamlin, S.N. & Anthony, S.S., 1987. Ground-water resources of the Laura area, Majuro Atoll, Marshall Islands (Vol. 87, No. 4047). US Department of the Interior, Geological Survey.

Haase, K.M., Stroncik, N., Garbe-Schonberg, D. & Stoffers, P. 2006. Formation of island arc dacite magmas by extreme crystal fractionation: An example from Brothers Seamount, Kermadec island arc (SW Pacific). *Journal of Volcanology and Geothermal Research*, 152, 316–330.

Hunt, S.D., 1997. Competing through relationships: Grounding relationship marketing in resource-advantage theory. *Journal of Marketing Management*, 13(5), 431-445.

Huang, S., Hall, P.S. and Jackson, M.G., 2011. Geochemical zoning of volcanic chains associated with Pacific hotspots. *Nature Geoscience*, 4(12), 874–878.

Haneberg, W.C., 1995. Steady state groundwater flow across idealized faults, *Water Resources Research*, *31*(7), 1815-1820.

Hassan Baioumy, M.N., Karl Wegner, Mohd Hariri., 2015. Geochemistry and Geothermometry of non-volcanic hot springs in west Malaysia, *Journal of Volcanology and Geothermal Research 290*, 12-22.

Johnson, T.C., Slater, L.D., Ntarlagiannis, D., Day-Lewis, F.D. & Elwaseif, M., 2012. Monitoring groundwater-surface water interaction using time-series and time-frequency analysis of transient three-dimensional electrical resistivity changes. *Water Resources Research*, 48(7).

Jarrard, R.D. & Clague, D.A., 1977. Implications of Pacific island and seamount ages for the origin of volcanic chains. *Reviews of Geophysics*, 15, 57–76.

Kachadourian-Marras, A., Alconada-Magliano, M.M., Carrillo-Rivera, J.J., Mendoza, E., Herrerias-Azcue, F. & Silva, R., 2020. Characterization of surface evidence of groundwater flow systems in continental Mexico. *Water*, 12(9), 2459.

Lal, A.A., 2019. Development of sustainable groundwater management methodologies to control saltwater intrusion into coastal aquifers with application to a tropical Pacific island country, James Cook University.

Masum, M., 2015. Low-temperature geothermal systems in sedimentary basin and their prospect in Bangladesh, paper presented at Proceedings World Geothermal Congress.

Mathon, B.R., Schoonen, M.A., Riccardi, A.L. & Borda, M.J., 2015. Measuring flow rates and characterizing flow regimes in hot springs. *Applied Geochemistry*, 62, 234-246.

Maharaj, R., Kumar, S., Rollings, N. & Antoniou, A., 2023. Groundwater detection using resistivity at Nubutautau village in Viti Levu in Fiji. *Water*, 15(23), 4156.

Malin, M.C. & Edgett K.S., 2000. Evidence for recent groundwater seepage and surface runoff on Mars, *Science*, 288(5475), 2330-2335.

Mitchell, N., Nyquist, J.E., Toran, L., Rosenberry, D.O. & Mikochik, J.S., 2008. April). Electrical resistivity as a tool for identifying geologic heterogeneities which control seepage at Mirror Lake, NH. In 21st EEGS Symposium on the Application of Geophysics to Engineering and Environmental Problems (pp. cp-177). European Association of Geoscientists & Engineers.

Neall, V.E. & Trewick, S.A., 2008. The age and origin of the Pacific islands: a geological overview. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1508), 3293-3308.

Nunn, P.D. & Pastorizo, R., 2007. Geological histories and geohazard potential of Pacific Islands illuminated by myths. *Geological Society, London, Special Publications*, 273(1), 143–163.

Nemeth, K., Cronin, S.J., 2009. Volcanic structures and oral traditions of volcanism of Western Samoa (SW Pacific) and their implications for hazard education. *Journal of Volcanology and Geothermal Research*, 186, 223–237.

Nunn, P.D. & Pastorizo, R., 2007. Geological histories and geohazard potential of Pacific Islands illuminated by myths. Geological Society, London, Special Publications 273, 143–163.

Ogden, D., 2011. Fluid Dynamics in ExplosiveVolcanic Vents and Craters, *E arthand the Planetary science letters*, 312, 401-410.

Pasquale, V., Verdoya, M. & Chiozzi, P., 2015. Measurements of rock thermal conductivity with a Transient Divided Bar. Geothermics, 53, 183-189.

Reid, M.E., 1997. Slope instability caused by small variations in hydraulic conductivity, *Journal of Geotechnical and Geoenvironmental Engineering*, 123(8), 717-725.

Rowland, J.V. & Sibson, R.H., 2004. Structural controls on hydrothermal flow in a segmented rift system, Taupo Volcanic Zone, New Zealand. *Geofluids*, 4(4), 259-283.

Rahiman, T.I. & Pettinga, J.R., 2008. Analysis of lineaments and their relationship to Neogene fracturing, SE Viti Levu, Fiji. *Geological Society of America Bulletin*, 120(11-12), 1544-1555.

Schlanger, S.O., Garcia, M.O., Keating, B.H., Naughton, J.J., Sager, W.W., Haggerty, J.A. ... & Duncan, R.A., 1984. Geology and geochronology of the Line Islands. *Journal of Geophysical Research: Solid Earth*, 89(B13), 11261-11272.

Setterfield, T.N., Eaton, P.C., Rose, W.J. & Sparks, R.S.J., 1991. The Tavua caldera, Fiji: a complex shoshonitic caldera formed by concurrent faulting and downsagging. *Journal of the Geological Society*, 148(1), 115-127.

Sinclair, P., Loco, A., Chand, A., Boseerelle, A. & Pattersen, M., 2017. Groundwater Assessment of the Nubutautau Village, Rep., 1-11 pp, Secretariat of the Pacific Community.

Saemundsson, K., Axelsson, G. & Steingrímsson, B., 2009. Geothermal systems in global perspective. Short course on exploration for geothermal resources, UNU GTP, 11.

Singh, U., Sharma, P.K. & Ojha, C.S.P., 2021. Groundwater investigation using ground magnetic resonance and resistivity meter. *ISH Journal of Hydraulic Engineering*, 27(sup1), 401-410.

Sprenger, C., Lorenzen, G., Hulshoff, I., Grutzmacher, G., Ronghang, M. & Pekdeger, A., 2011. Vulnerability of bank filtration systems to climate change. *Science of the Total Environment*, 409(4), 655-663.

Toth, J., 1971. Groundwater discharge: a common generator of diverse geologic and morphologic phenomena, *Hydrological Sciences Journal*, 16(1), 7-24.

Toth, J., 2000. Las aguas subterráneas como agente geológico: causas, procesos y manifestaciones, *Boletín Geológico y Minero*, 111(4), 9-26.

Walker, G.P., 1993. Basaltic-volcano systems. *Geological Society, London, Special Publications*, 76(1), 3–38.

Wilson, S.T., Hawco, N.J., Armbrust, E. V., Barone, B., Bjorkman, K.M., Boysen, A. K. ... & Karl, D.M., 2019. Kīlauea lava fuels phytoplankton bloom in the North Pacific Ocean. *Science*, 365(6457), 1040-1044.