Drought, freshwater availability and cultural resilience on Easter Island (SE Pacific) during the Little Ice Age

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Abstract

After decades of human-deterministic explanations for the collapse of the ancient Rapanui civilization that inhabited Easter Island (Rapa Nui) before European contact (1722 CE), paleoecological studies developed during the last decade have provided sound evidence for climate changes and their potential socio-ecological impact. Especially significant is the occurrence of a century-scale (1570-1720 CE) drought occurred during the Little Ice Age. Freshwater is a critical resource at Easter Island that heavily depends on rain, which maintains the three only permanent surficial freshwater sources of the island: two lakes (Kao and Raraku) and a marsh (Aroi). In these conditions, the LIA drought could have significantly affected human life; however, the Rapanui civilization remained healthy showing a remarkable resilience. There are two main hypotheses on how the ancient Rapanui civilization could have obtained freshwater to guarantee its continuity. The intra-island migration hypothesis proposes that Lake Raraku, the cultural center of this civilization, dried out and the Rapanui were forced to migrate to Lake Kao, which was likely the only surficial freshwater source during the LIA drought. This shift was accompanied a profound cultural reorganization. The coastal groundwater hypothesis dismisses the use of lakes and other surficial freshwater sources to maintain the water-stressed Rapanui population and contends that the only routine freshwater sources during the LIA drought were the abundant and widespread coastal seeps fed by fresh/brackish groundwater. The pros and cons of these two hypotheses are discussed on the basis of the available archaeological and paleoecological evidence and it is concluded that, in the present state of knowledge, none of them can be rejected. Therefore, these two proposals could be complementary, rather than excluding.

Keywords: Easter Island, Rapa Nui, Little Ice Age, drought, freshwater, brackish water, groundwater, lakes, coastal seeps, cultural change, archaeology, paleoecology

Introduction

Easter Island (Rapa Nui) is a small (~164 km^2) and isolated island of the SE Pacific formed by the coalescence of three volcanic cones: Kao, Poike and Terevaka (Fig. 1A). The island is famous for its ritual megalithic statues (*moai*) (Fig. 1B) built by an ancient and enigmatic Polynesian civilization that settled the island between 800 CE and 1200 CE -depending on the authors (Rull, 2019)- and assumedly caused its own destruction by overexploitation of natural resources, prior European contact (1722 CE) (Flenley & Bahn, 2003; Diamond, 2005). This ecocidal hypothesis largely relies on the apparently abrupt and island-wide deforestation inferred from pollen analyses of lake sediments (Flenley & King, 1984; Flenley et al., 1999). Others contend that the collapse of the ancient Rapanui civilization was actually a genocide mainly due to post-contact events, such as slave trading and the introduction of alien infectious diseases, which is historically well documented (Peiser, 2005; Hunt, 2007). Both ecocidal and genocidal views are considered human-deterministic, as they attribute the collapse of the ancient Rapanui culture exclusively to

anthropogenic causes (Rull, 2018). A potential role for climate change in the deforestation and the general deterioration of island's resources has traditionally been ignored or explicitly dismissed.

During the last decade, increasing paleoecological evidence of climatic shifts has suggested that climate and climate-human feedbacks and synergies could have played a significant role on pre-contact ecological and cultural developments (Rull et al., 2018). Especially significant is the occurrence of an extended Little Ice Age (LIA) drought, between 1570 CE and 1720 CE, just before the European arrival. This drought was inferred from paleoecological evidence of the drying out of Lake Raraku (Fig. 1A) (Cañellas-Boltà et al., 2013), the quarry where the *moai* were carved and the center of the ancient Rapanui civilization during the so called *moai* cult. The absence of surficial water currents and springs due to the high permeability of Easter Island's volcanic rocks (Herrera & Custodio, 2008) makes freshwater a critical resource, which heavily depends on rainfall to recharge the groundwater system and the only three permanent waterbodies of the island: two lakes (Kao and Raraku) and a marsh (Aroi), all of them within volcanic craters (Fig. 1A). In these conditions, the LIA drought, lasting about a century and a half, would have been critical for the ecology and the culture of the island. However, recent archaeological evidence suggests that the Rapanui civilization not only survived but also remained healthy until European contact (Mulrooney, 2013; Stevenson et al., 2015).

The potential impacts of the LIA drought are still to be ascertained but several ideas have already been proposed for the ancient Rapanui society to successfully circumventing this climatic bottleneck. The combination of recent paleoecological and archaeological findings is consistent with intra-island population reorganizations in the search for new freshwater sources (Rull, 2016; Rull et al., 2018). This is called here the intra-island migration hypothesis. On the contrary, the coastal groundwater hypothesis proposes that freshwater was obtained from coastal groundwater seeps and explicitly dismisses other possibilities (Brosnan et al., 2018; DiNapoli et al., 2019). This paper briefly summarizes these two proposals and aims to show that they may be complementary, rather than mutually exclusive.

Intra-island migration hypothesis

A first approach to the problem was based on internal population reorganizations around the surficial freshwater bodies, mainly the Raraku and Kao lakes (Rull, 2016). Recent paleoecological evidence shows that, when the relatively small and shallow Lake Raraku (~300 m diameter and ~2 m deep) dried out during the LIA (1570-1720 CE), its basin and the surroundings were already deforested. Multiproxy paleoecological records show that forest clearing at Raraku was almost complete by 1450 CE and the lake disappeared roughly a century later (Cañellas-Boltà et al., 2013). The last signs of cultivation date from 1300-1450 CE (Horrocks et al., 2012a). The combination of anthropogenic deforestation and extended aridity would have turned the site into a wasteland, unable to support human life and, hence, the activities related with the *moai* cult. During this cult, the *moai* were carved on the soft volcanic tuff that forms the Raraku crater using stone tools (*toki*) made of harder basalt rocks obtained in other craters, the Kao among them (Gioncada et al., 2010). After carving, the *moai* were transported by means that are still debated to every part of the island and placed into groups on rectangular stone platforms (*ahu*) (Fig. 1A and B). The entire Rapanui civilization was organized around the *moai* cult, during which more than 950 moai and 300 *ahu* were built (Van Tilburg, 1994). The *moai* cult ceased at some point and was replaced by the birdman cult, involving a totally different religious, political and social organization (Robisnon & Stevenson, 2017). The birdman cult was centered on the ceremonial village of Orongo, situated on top of the Kao crater (Figs. 1A and 2).

The date of this replacement is also debated but recent archaeological findings indicate that Orongo was founded by 1600 CE (Robinson & Stevenson, 2017). Therefore, the birdman cult must have been active at or after this date, that is, few decades after the onset of the LIA drought and the desiccation of Lake Raraku

(1570 CE). Paleoecological records indicate that Lake Kao did not desiccate during this drought, likely due to its larger size (>1 km diameter) and depth (>10 m) (Rull et al., 2018); hence, its catchment was more suitable for human life than the Raraku quarry. The Kao catchment would had been already settled before 1600 CE, as suggested by its earlier deforestation (1350 CE) coeval with a conspicuous fire increase. However, the absence of fire during the next two centuries suggests that the catchment was not settled permanently until 1600 CE, when sudden and maintained fire incidence was recorded, together with the permanent presence of domestic herbivores (Rull et al., 2018; Seco, 2018). Therefore, paleoecological evidence supports the previous archaeological date of 1600 CE as the onset of permanent settlement of the Kao crater and likely the earliest date for the shift from the *moai* cult to the birdman cult. The Kao crater was not suitable to maintain the *moai* industry because it is made of hard basalt -more appropriate for obtaining carving tools (Gioncada et al., 2010)- and, therefore, impossible to carve with the technology available to the Neotithic Rapanui society.

The whole picture suggests that the shift from the *moai* cult to the birdman cult and the corresponding change of the cultural center from Raraku to Kao ocurred by 1600 CE could have been fostered by the degradation –i.e., deforestation followed by desiccation of the lake- of the Raraku quarry and its surrondings and a population migration to the Kao crater in the search for permanent freshwater supply (Rull, 2016). Another potential destiny for the Rapanui in their escaping from the inhospitable Raraku catchment could have been the Aroi marsh, situated on the inland Terevaka uplands (Figs. 1A and 3). It is possible that, owing to the elevational precipitation gradient (Stevenson et al., 2015; Puleston et al., 2017), drought was less intense at these uplands and this marsh contained freshwater. Human presence is supported by the occurrence of total deforestation by fire between about 1550 CE and 1650 CE (Rull et al., 2015). However, human presence on Aroi was ephemeral. Indeed, the site was likely abandoned by 1700 CE, as indicated by the abrupt fire decrease (Rull et al., 2015) and the last evidence of cultivation dated to 1670 CE (Horrrocks et al., 2015).

Coastal groundwater hypothesis

A different view has been proposed more recently, according to which fresh/brackish coastal seeps could have been the major source of water for the ancient Rapanui civilization to survive during the LIA climatic drought (Brosnan et al., 2018). Such conclusion is based on the consideration that other potential freshwater sources (permanent lakes, springs, ephemeral streams and pools) would not have been sufficient to support a population of thousands of individuals. According to these authors, Lake Kao is too difficult to access to have been a routine source of freshwater and, moreover, there is no archaeological evidence of human habitation on its shores. Lake Raraku is considered to be a reliable source of freshwater but only for populations of the surroundings. The same would be true for Rano Aroi, which spring is unlikely to have been useful to satisfy the needs of the whole island due to its remoteness. Temporary water currents and ponds were also considered too ephemeral (hours to a few days after a rain event) for such purpose and some recipients found on archaeological sites to collect rainwater (*taheta*) were too small and too susceptible to water evaporation for large-scale human usage (Brosnan et al., 2018). This, together with the absence, in the arcaheological record, of large water containers and intense habitation near lakes and marshes, led these authors to conclude that coastal seeps would have been crucial for prehistoric Rapanui subsistence.

In the groundwater system, freshwater accumulates on top and salinity increases with depth due to the penetration of seawater from below, which creates a vertical density gradient. This groundwater system is shallower on the coasts, where fresh/brackish waters are more accessible and artificial wells are common today (Herrera & Custodio, 2008) (Fig. 3). These coastal wells contain small amounts of freshwater, less than

a meter deep, above brackish and marine groundwater (Brosnan et al., 2018). The Rapanui did not have the technology to drill deep wells on volcanic rocks, to capture fresh and brackish waters from coastal seeps, they used pits excavated parallel to the shoreline. Remains of these structures, called *puna*, have been found on several sites along the island's coasts, which where the preferred sites for the Rapanui to live. Therefore, fresh/brackish-water sources would have been frequent, widespread and close to the populated sites (Brosnan et al., 2018). According to DiNapoli et al. (2019), the *ahu*, in addition to their ritual meaning, would have a signaling function to indicate situation of such coastal seeps. All waters found today on coastal seeps are brackish (ca. 4 to 28 g/L, as compared to 1g/L or less for freshwater and 35 g/L of seawater), which led Brosnan et al. (2018) to suggest that the Rapanui drank brackish water, a fact that, according to these authors, has been well documented historically.

Discussion

The assumed uniqueness of coastal seeps as a routine freshwater source for the Rapanui is based on the dismissal of other potential sources (Brosnan et al., 2018; DiNapoli et al., 2019). In the case of Lake Kao, the main arguments for its eventual dismissal as a routine freshwater source are the difficulty of access and the lack of archaeological evidence of habitation at lake margins. But these arguments are only mentioned without further explanations and a more in-depth analysis is needed for a sound assessment. Regarding accessibility, it is true that the inner Kao walls are high and steep (Fig. 2) but not impracticable at all, as it is possible to easily descend to the lake and come back by foot in about one hour or less. Modern paleoecologists know this well and we use to do that in sediment-coring campaigns with all the equipment and the necessary provisions. The ancient Rapanui demonstrated an outstanding transport capacity by translating the *moai* (up to 20 m high and over 250 tons of weight) from the Raraku quarry to any part of the island, including elevations above 200 m (Fig. 1A). Transporting water across the Kao walls is a much easier task that could be developed on a daily basis.

On the other hand, human presence around the lake is well documented by the relict village of Orongo, which was the center of the Ranapuni culture during the LIA drought since, at least, 1600 CE. Archaeological evidence of this fact is abundant and well preserved, including almost intact stone dwellings and many petroglyphs featuring the birdman cult and other representations (Robinson & Stevenson, 2017). The inhabitants of Orongo could have easily obtained freshwater from Lake Kao as explained above. Indeed, the birdman cult required to descend to the sea and come back to Orongo by the outer Kao cliffs, which were remarkably higher and difficult to climb than the inner walls of this crater. This, together a 2-km swimming to the Motu Nui islet (Fig. 1A) to obtain the eggs of the migratory sooty tern and come back was performed the same day by the Rapanui athletes. Obtaining freshwater from the lake is a much easier task that could be performed by common people, as in the case of paleoecologists, as a routine. It seems totally out of reason that Orongo people refused to obtain water from Lake Kao as a routine, to avoid a barely one-hour trip to the lake shores.

In addition, there is sound paleoecological evidence of intense pre-contact agriculture along the Kao shores, where large-scale deforestation by fire and mixed-crop production (paper mulberry, taro, banana, greater yam) on gardened terraces has been documented (Horrocks et al., 2012b, 2013). Most of this evidence of usual cultivation has been found on the lake shores immediately below Orongo (Fig. 2), which suggests a connection with this relict village. There is no evidence of human dwellings on lake shores and it is reasonable to assume that the agricultural products were transported to Orongo for human consumption and, eventually, distribution to other places. The same would be true for lake freshwater, whose transport could have been performed in the same way and at the same time. Transporting agriculture products but no freshwater from Lake Kao shores to Orongo seems absurd. Given the already mentioned outstanding

transport capacity of Rapanui people, distributing agricultural products and water from Orongo to other places would have been very easy.

The main advantage of the coastal groundwater hypothesis is that water sources are numerous, widespread and closer to the habitation sites but there are two main drawbacks to be considered the only possibility of obtaining freshwater during the LIA drought. First, this hypothesis has been erected after the detailed study of only the eastern half of the island (Fig. 1A), where access is easier. In the present state of knowledge, this situation cannot be extrapolated to the western sector, which included the center of the Rapanui culture during the LIA drought, where physiography is very different and coastal seeps have not been reported. Second, all present-day coastal seeps identified in the eastern sector produce brackish water, rather than freshwater (Brosnan et al., 2018). If this was the main water source for the ancient Rapanui during the LIA drought, they must have survived for about six generations (150 years; 1570-1720 CE) with only brackish water for drinking and for agriculture, which is challenging and does not seem the most efficient solution. Finally, as rain is the only freshwater source for the groundwater system, such supply should have been drastically reduced during a drought like the discussed here, suggesting that the salinity of coastal seeps could have been higher than today. Therefore, coastal seeps could have been used by the ancient Rapanui but other truly freshwater sources should have been needed to maintain this civilization in good shape.

Conclusions

In summary, both intra-island migration and coastal groundwater hypotheses have advantages and drawbacks but, with the available evidence, none of them can be rejected. Therefore, there is no reason to exclude any of these hypotheses to explain freshwater availability during the LIA drought. From a human perspective, it seems reasonable to take advantage of any freshwater sources available during a secular-scale drought like that. No matter the strategy adopted, the continuity of the Rapanui culture in spite of landscape degradation by anthropogenic deforestation and climatic drought is a good example of cultural resilience that challenges former deterministic explanations and emphasizes human adaptability to changing environments. It is hoped that further research will provide new empirical data not only to test the existing hypotheses but also to erect new ones, thus providing a clearer picture on how ancient Easter Islanders circumvented the scarcity of freshwater to keep living on the island and developing their civilization.

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Figure captions

1. Location map and example of a moai cluster (*ahu*). A) Topographic sketch map of Easter Island and the sites mentioned in the text. The position of the island in the world map is indicated by a red star. Permanent lakes and marshes are in blue. The location of Orongo (Og) and the Motu Nui islet (MN) are highlighted by red dots. Green dots represent the distribution of present-day *moai* and *ahu*, according to Van Tilburg (1994). Red lines indicate the westernmost boundary of studies by Brosnan et al. (2018) and DiNapoli et al. (2019) regarding coastal groundwater seeps. B) The moai complex of Ahu Tongariki, which statues are up to 9 m high and 90 tons of weigth (see upper panel for location). Foto N. Cañellas.
2. Lake Kao, within the crater of the same name. The surface of the lake is a mosaic of open water (ca. 10 m depth) and floating-mat patches of about 3 m depth, which can be walked across. The position of the ceremonial village of Orongo on top of th Kao crest is indicated. The yellow line shows the location of former cultivation terraces documented by paleoecological records (Horrocks et al., 2012b, 2013). The photo was taken from the upper part of the pathway used today to descend from the crest of the Kao crater to the lake shore. Photo: V. Rull.
3. Schematic cross-section of a N-S transect showing the hydrological model of Easter Island. Note the progressive thining of the freshwater table toward the coast. The approximate elevation of lakes Kao and Raraku and the position of the Aroi marsh is indicated. Redrawn from Herrera & Custodio (2008).

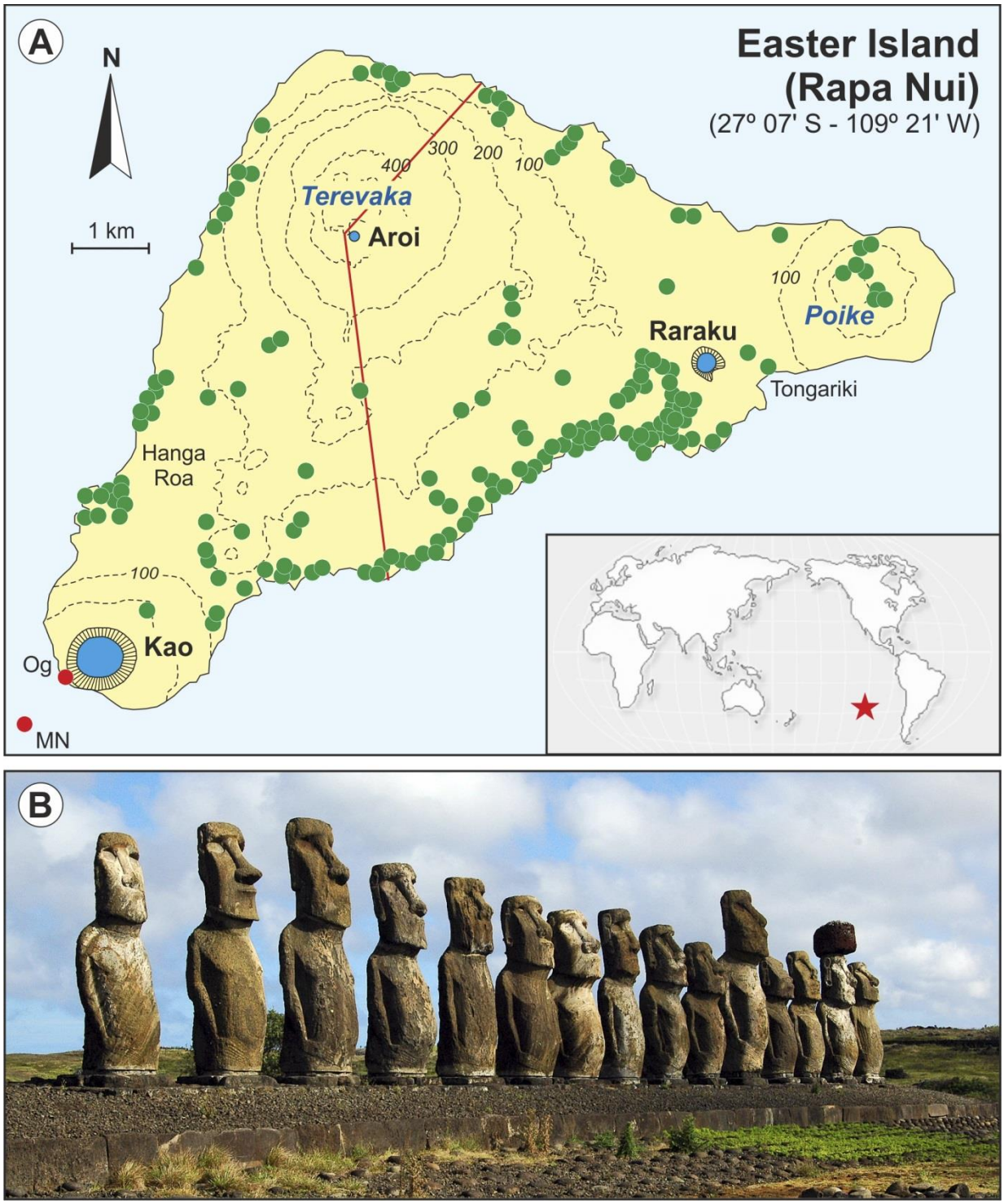

Figure 1

Figure 2

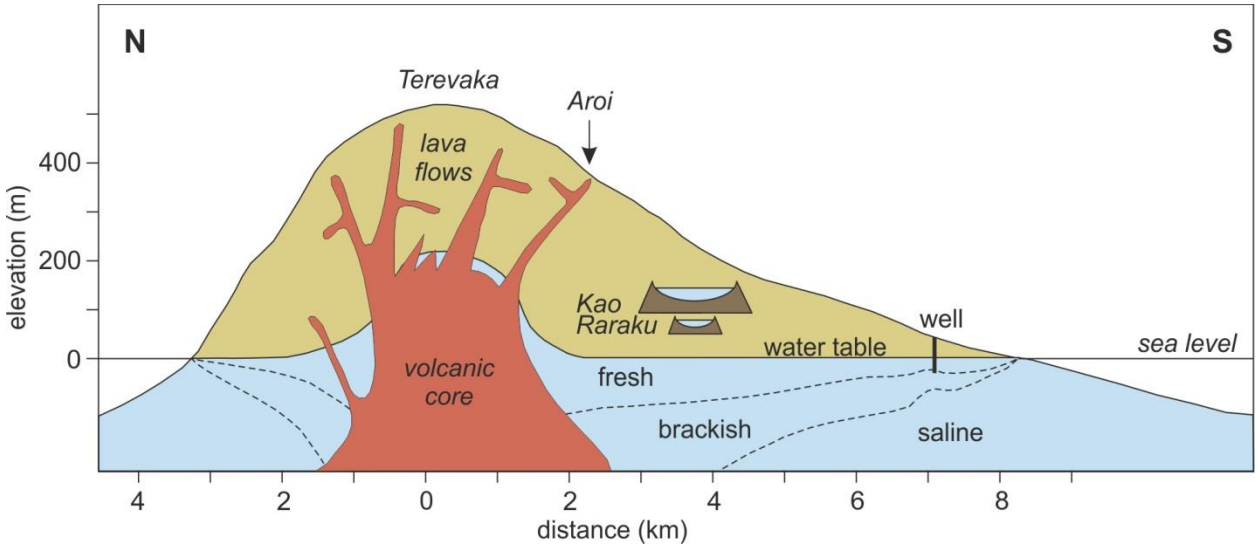

Figure 3