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 culture that inhabited Easter Island (Rapa Nui) before European contact (1722 CE), paleoecological studies developed over the last decade have provided sound evidence of climate changes and their potential socioecological impacts. Especially significant is the occurrence of a century-scale (1570-1720 CE) drought occurred during the Little Ice Age. Freshwater is a critical resource on Easter Island that heavily depends on rain, which maintains the only three permanent surficial freshwater sources on the island: two lakes (Rano Kao and Rano Raraku) and a marsh (Rano Aroi). Under these conditions, the LIA drought could have significantly affected human life; however, the Rapanui society remained healthy, showing remarkable resilience. There are two main hypotheses on how the ancient Rapanui could have obtained freshwater to guarantee its continuity. The intra-island migration hypothesis proposes that Rano Raraku, the cultural center of this culture, dried out and the Rapanui were forced to migrate to Rano Kao, which was likely the only surficial freshwater source during the LIA drought. This shift was accompanied by 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 archeological and paleoecological evidence, and it is concluded that in the present state of knowledge, neither can be rejected. Therefore, these two proposals could be complementary, rather than mutually exclusive.

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

Introduction

Easter Island (Rapa Nui) is a small (~164 km^2) and isolated island in the SE Pacific that was 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 Polynesian culture that settled the island between 800 CE and 1200 CE, and this settlement time depends on the authors (Hunt and Lipo, 2006; Wilmshurst et al., 2011; Rull, 2019). This culture is assumed to have caused its own destruction by overexploitation of natural resources prior to European contact (1722 CE) (Flenley and 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 and King, 1984; Flenley et al., 1999). It has also been suggested that rats introduced by Polynesian colonizers contributed to deforestation by extensive eating of palm fruits, thus restraining forest regeneration (Hunt, 2007). Others contend that the collapse of the ancient Rapanui culture was actually a genocide mainly due to postcontact events, such as slave trading and the introduction of alien infectious diseases, which are historically well documented (Métraux, 1957; Peiser, 2005; Hunt,

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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 of climate change in the deforestation and general deterioration of island 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 in precontact 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, which occurred immediately before European contact. This drought was inferred from paleoecological evidence of the drying out of Rano Raraku (Fig. 1A) (Cañellas-Boltà et al., 2013), which is the quarry where the *moai* were carved and the center of the ancient Rapanui society during the so-called *moai* cult, when these statues representing the more prominent Rapanui ancestors were considered the protectors of island's fertility (Edwards and Edwards, 2013). The absence of surficial streams and springs due to the high permeability of Easter Island's volcanic rocks (Herrera and Custodio, 2008) makes freshwater a critical resource, and this island heavily depends on rainfall to recharge the groundwater system and the only three permanent waterbodies on the island: two lakes (Rano Kao and Rano Raraku) and a marsh (Rano Aroi), all of them within volcanic craters (Fig. 1A). Under these conditions, the LIA drought, lasting approximately a century and a half, would have had critical impacts on the ecology and the culture of the island. However, recent archeological evidence suggests that the Rapanui society not only survived but also remained in good condition until European contact (Mulrooney, 2013; Stevenson et al., 2015; Jarman et al., 2017).

The potential impacts of the LIA drought are still to be ascertained, but several ideas have already been proposed to determine how the ancient Rapanui society successfully circumvented this climatic bottleneck. The recent paleoecological and archeological findings are consistent with intra-island population reorganizations resulting from the search for new freshwater sources (Rull, 2016; Rull et al., 2018). In this paper, this phenomenon is called the intra-island migration hypothesis. In contrast, 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

The first approach to the problem was based on internal population reorganizations around the surficial freshwater bodies, mainly Rano Raraku and Rano Kao (Rull, 2016). Recent paleoecological evidence shows that when the relatively small and shallow lake of Rano 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 Rano Raraku was almost complete by 1450 CE, and the lake disappeared roughly a century later (Cañellas-Boltà et al., 2013) (Fig. 2). 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 that was unable to support human life and, hence, the activities related to the *moai* industry. The *moai* were carved on the soft volcanic tuff that forms the Rano Raraku crater using stone tools (*toki*) made of hard basalt rocks obtained from other quarries, including Rano Kao (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 society was organized around the *moai* industry, and more than 950 moai and 300 *ahu* were built (Van Tilburg, 1994). The cult to the *moai* ceased at some point and was replaced by the birdman cult, involving a completely different religious, political and social organization (Robinson and

Stevenson, 2017). The birdman cult was centered on the ceremonial village of Orongo, which was situated on top of the Rano Kao crater (Figs. 1A and 3).

The date of this replacement is also debated, but recent archeological findings indicate that Orongo was founded not early than 1600 CE (Robinson and Stevenson, 2017). Therefore, the birdman cult must have been active at or after this date, which was a few decades after the onset of the LIA drought and the desiccation of Rano Raraku (1570 CE). Paleoecological records indicate that Rano Kao did not desiccate during this drought, likely due to its large size (>1 km diameter) and depth (>10 m) (Rull et al., 2018); hence, its catchment was more suitable for human life than the Rano Raraku quarry. The Rano Kao catchment would have been already settled before 1600 CE, as suggested by its early deforestation (1350 CE) coeval with a conspicuous increase in fire (Fig. 2). However, the absence of fire during the next two centuries suggests that the catchment was not permanently settled until 1600 CE, when sudden and maintained fire incidence was recorded, together with the permanent presence of domestic herbivores (Rull et al., 2018; Seco et al., 2019). Permanent settlement of Rano Kao area is supported by paleoecological evidence of intensive cultivation at the lake shores below Orongo (Horrocks et al., 2012b, 2013). Therefore, paleoecological evidence supports the previous archeological date of 1600 CE as the onset of permanent settlement of the Rano Kao crater and likely the earliest date for the shift from the *moai* culture to the birdman cult. The Rano Kao crater was not suitable for the maintenance of the *moai* industry because it is made of hard basalt, which is more appropriate for obtaining carving tools (Gioncada et al., 2010). Therefore, it was impossible to carve with the technology available to Neolithic Rapanui society.

The whole picture suggests that the shift from the *moai* culture to the birdman cult and the corresponding change in the cultural center from Rano Raraku to Rano Kao occurred by 1600 CE or later could have been fostered by the degradation –i.e., deforestation followed by desiccation of the lake - of the Rano Raraku quarry and its surroundings, as well as a population migration to the Rano Kao crater in the search for a permanent freshwater supply (Rull, 2016). Another potential destination for the Rapanui during their escape from the inhospitable Rano Raraku catchment could have been the Rano Aroi marsh, which is situated at 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 in these upland areas, and this marsh contained freshwater. Human presence is supported by the occurrence of total deforestation by fire between approximately 1550 CE and 1650 CE (Rull et al., 2015) (Fig. 2). However, human presence on Aroi was ephemeral. Indeed, the site was likely abandoned by 1700 CE, as indicated by the abrupt decrease in fire (Rull et al., 2015) and the last evidence of cultivation dated at 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 survival of the ancient Rapanui society during the LIA climatic drought (Brosnan et al., 2018). Such a 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, the lake of Rano Kao is too difficult to access to have been a routine source of freshwater, and moreover, there is no archeological evidence of human habitation on its shores. Rano Raraku is considered to be a reliable source of freshwater but only for the populations in the immediate surroundings. The same would be true for Rano Aroi, whose spring is unlikely to have been useful to satisfy the needs of the whole island due to its remoteness. Temporary streams and ponds were also considered too ephemeral (hours to a few days after a rain event) for such purpose, and some receptacles found on archeological 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 archeological record of large water containers and intense habitation near lakes and marshes, led the conclusion by these authors 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 diffusion 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 and Custodio, 2008) (Fig. 4). 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 in volcanic rocks; to capture fresh and brackish waters from coastal seeps, they used pits excavated parallel to the shoreline. The remains of these structures, called *puna*, have been found at several sites along the island's coasts, which were 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 the situation of such coastal seeps. All waters found today on coastal seeps are brackish (ca. 4 to 28 g of marine salt/L, compared to 1 g/L or less for freshwater and 35 g/L for 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 Rano Kao, the main arguments for its eventual dismissal as a routine freshwater source are the difficulty of access and the lack of archeological evidence of habitation at lake margins. However, 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 Rano Kao walls are high and steep (Fig. 3) but not impracticable, 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 this method during sediment-coring campaigns with all the equipment and necessary provisions. The ancient Rapanui demonstrated an outstanding transport capacity by transporting the *moai* (up to 20 m high and over 250 tons of weight) from the Rano Raraku quarry to any part of the island, including elevations above 200 m (Fig. 1A). Transporting water across the Rano Kao walls is a much easier task that could be conducted on a daily basis.

On the other hand, human presence around the lake is well documented by the relic village of Orongo, which was the center of the Rapanui culture during the LIA drought since at least 1600 CE. Archeological 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 and Stevenson, 2017). The inhabitants of Orongo could have easily obtained freshwater from Rano Kao as explained above. Indeed, members of the birdman cult were required to descend to the sea and return to Orongo via the outer Rano Kao cliffs, which were remarkably higher and difficult to climb than the inner walls of this crater. Together, a 2-km swim to the Motu Nui islet (Fig. 1A) to obtain the eggs of the migratory sooty tern was performed in a single day by the Rapanui athletes. Obtaining freshwater from the lake is a much easier task that could be performed by common people, such as paleoecologists, as a routine. It seems totally out of reason that Orongo people refused to obtain water from Rano Kao as a routine to avoid a barely one-hour trip to the lake shores.

In addition, there is sound paleoecological evidence of intense precontact agriculture along the Rano Kao shores, where large-scale deforestation by fire and mixed-crop production (paper mulberry, taro, banana, greater yam) on gardened terraces have 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. 3), 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 Rano Kao shores to Orongo seems absurd. Given the already mentioned outstanding transport capabilities of Rapanui people, distributing agricultural products and water from Orongo to other places would have been very easy.

The main strength of the coastal groundwater hypothesis is that water sources are numerous, widespread and close to the habitation sites. However, there are two main drawbacks in considering this possibility as the only way of obtaining freshwater during the LIA drought. First, this hypothesis was erected after a 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 the 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 approximately six generations (150 years; 1570-1720 CE) with only brackish water for drinking and agriculture, which is challenging and does not seem to be 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, as 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 society in good shape.

Conclusions

In summary, both intra-island migration and coastal groundwater hypotheses have advantages and drawbacks, but with the available evidence, neither can be rejected. Therefore, there is no reason to exclude either 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 such as that during the LIA. Regardless of the strategy adopted, the continuity of the Rapanui culture despite 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 of how ancient Easter Islanders circumvented the scarcity of freshwater to continue living on the island and developing their culture.

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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 on 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. The green dots represent the distribution of present-day *moai* and *ahu*, according to Van Tilburg (1994). The red lines indicate the westernmost boundary of the studies regarding coastal groundwater seeps by Brosnan et al. (2018) and DiNapoli et al. (2019). B) The moai complex of Ahu Tongariki, which has statues that are up to 9 m high and 90 tons (see upper panel for location). Photo: N. Cañellas.
2. Summary of climatic and vegetation shifts recorded in continuous and chronologically coherent sediment cores from Rano Aroi (Rull et al., 2015), Rano Kao (Seco e al., 2019) and Rano Raraku (Cañellas-Boltà et al., 2013) sediments using multiproxy paleoecological analyses. Climatic phases according to Nunn (2007). The gray bands represent the droughts recorded at Rano Raraku, during which the lake dried out. Abbreviations: ch – charcoal, as a proxy for fires, cf – spores of coprophilous fungi, as a proxy for domestic herbivores, cu – last cultivation records, pd – partial deforestation, td – total deforestation. The red arrows indicate migration events from Rano Raraku to the other catchments.
3. 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 approximately 3 m depth, which can be walked across. The position of the ceremonial village of Orongo on top of the Rano 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 Rano Kao crater to the lake shore. Photo: V. Rull.
4. Schematic cross-section of a N-S transect showing the hydrological model of Easter Island. Note the progressive thinning of the freshwater table toward the coast. The approximate elevation of Rano Kao and Rano Raraku and the position of Rano Aroi are indicated. Redrawn from Herrera and Custodio (2008).

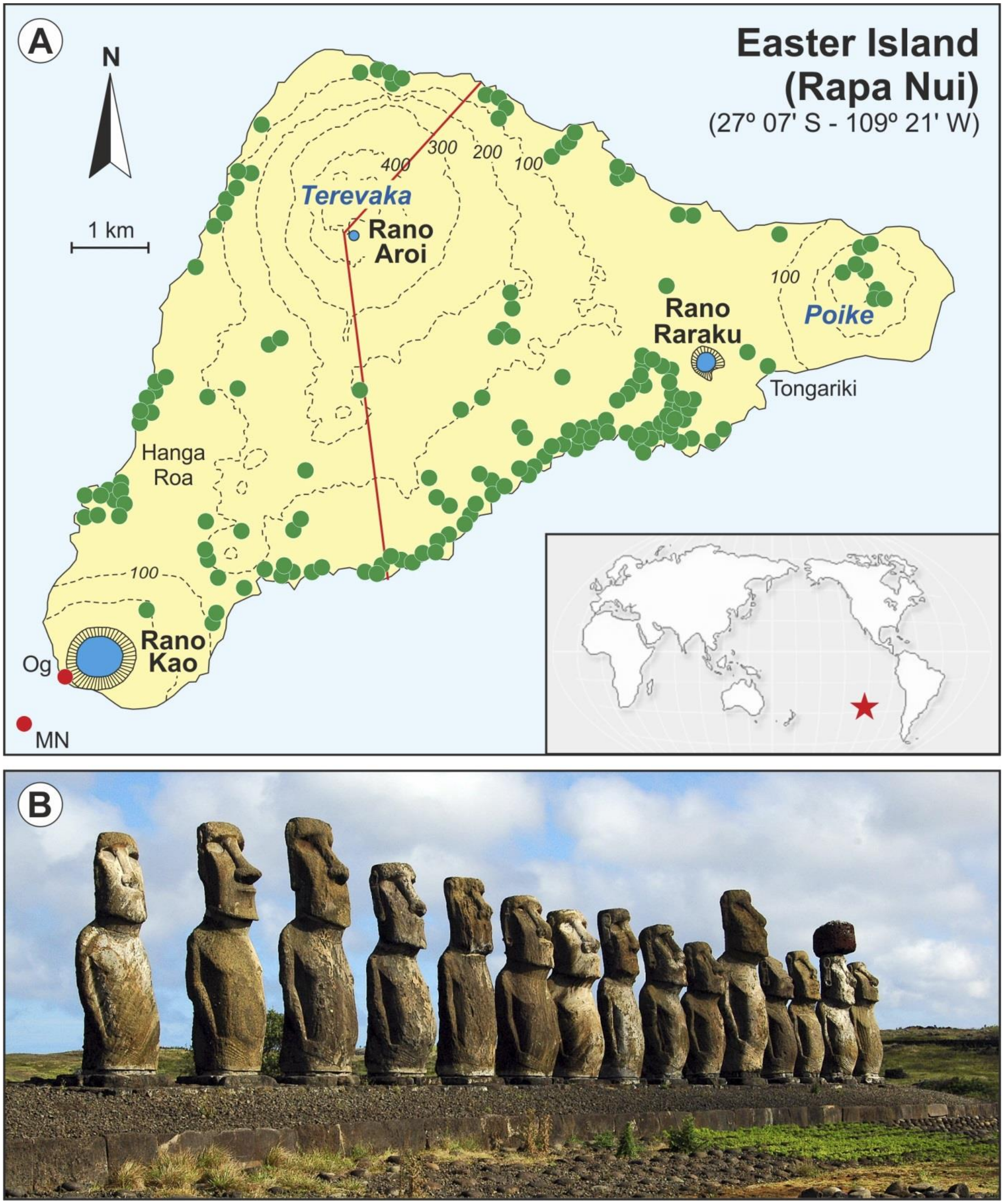
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Figure 1

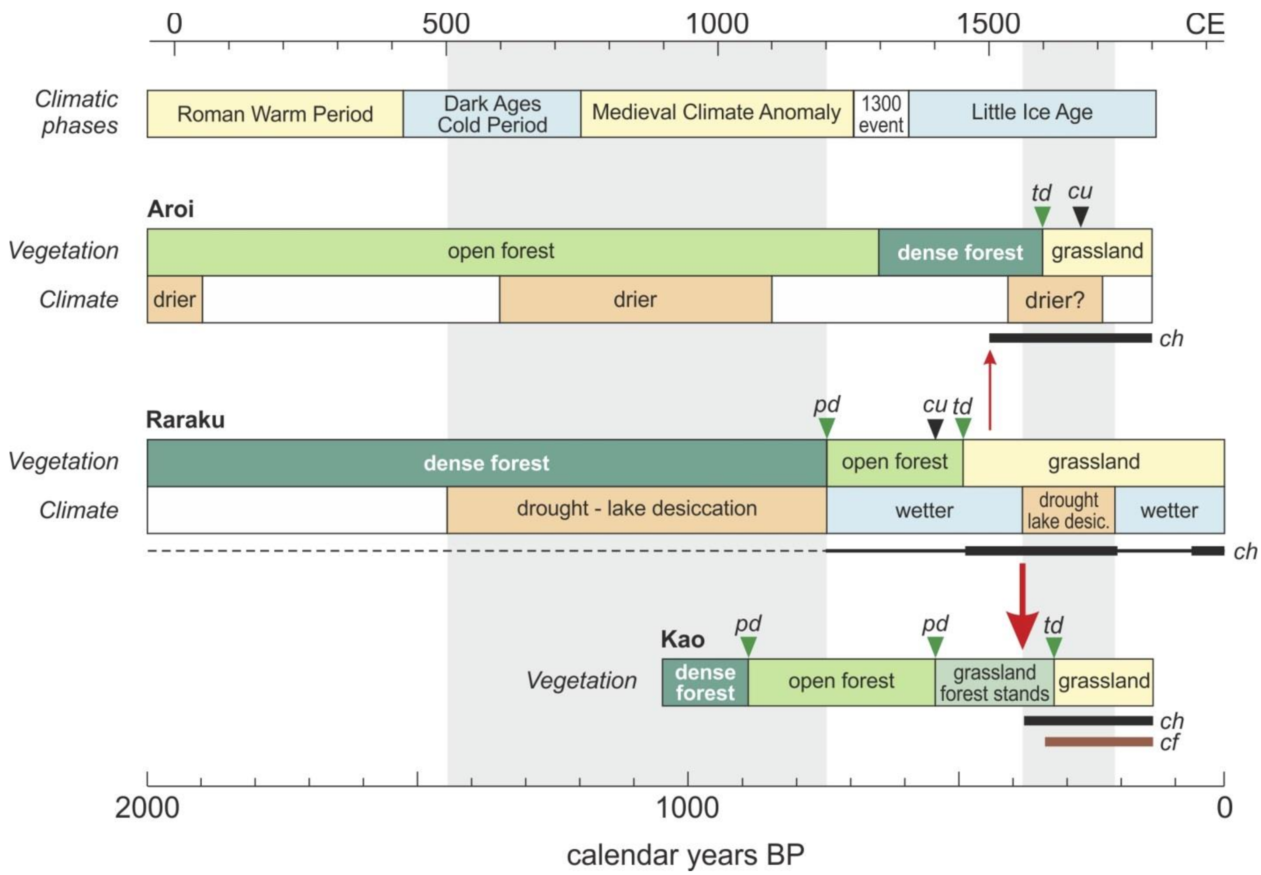
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Figure 2

Figure 3

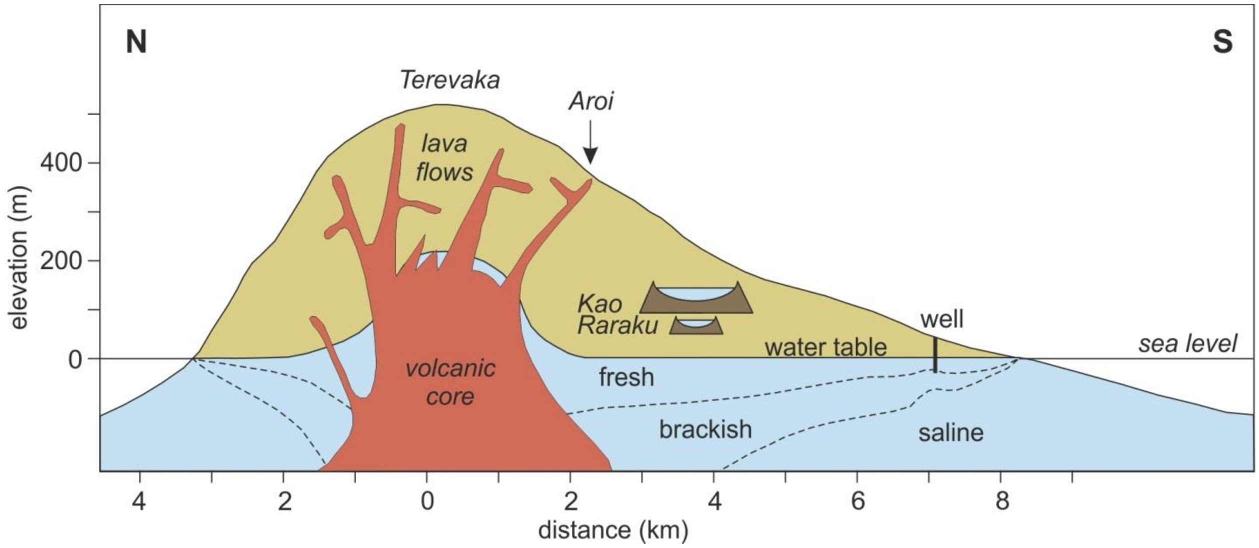

Figure 4