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Exploring Synergies Between Māori Knowledge and Western Science on the Formation of Natural Colors

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Ko te Whai Hua ki te Rangahau, ki te Pūtaiao, o Ngā tae I te Nuku o te Whenua

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ABSTRACT

Whakarewarewa is an iconic centre of Māori culture and of geothermal features in the New Zealand that offers a unique opportunity to develop research with mutual benefits, providing insights into Māori understanding of frontier materials science and corroboration of historical knowledge. The unique and spectacular geothermal activity at Whakarewarewa is a fantastic playground to integrate related scientific data and Mātauranga-a-iwi to better understand the formation of natural colors of water and rocks at geothermal vents and deposits from geothermal waters.

A Māori worldview traditionally saw life conducted within 'tenets of sacred narratives', which informed society on the natural environment. The blood from the arms of Ranginui dripped down on to Papa [the Earth, rocks], and hence is the horu [red oxide of iron], and the pukepoto [blue phosphate of iron], used today in painting. Legends have been handed down from generation to generation and the Māori cultural stories about where the water and rocks colors come from. Within this context, western science, and in particular material sciences and physical chemistry, are an opportunity to incorporate valuable resources and case studies that recognized aspects of science particularly relevant to not only the Whakarewarewa geothermal system but also to the Whakarewarewa Village. It is about bringing Whakarewarewa Village's stories, legends, songs and the science together. An approach where Mātauranga Māori - the knowledge, comprehension, or understanding of everything visible and invisible existing in the universe - passed through generations of guides and in stories and songs, can be woven together with western science to bring understanding of the material environment of the village.

The paper explores how modern technologies and sciences can be used to align the Mātauranga observations with the scientific data and recorded changes in Whakarewarewa geothermal area. This approach aims at developing a framework where traditional knowledge systems and scientific approaches and reasoning are mutually supportive to consider realities of living with natural hazards and adapting to this environment. Thus, this will ensure that a gateway of co-discovery and unite minds is develop across Māori Knowledge and Western Science without compromising the integrity and tradition of each knowledge system.

1. INTRODUCTION

1.1 Whakarewarewa the Living Village

Whakarewarewa is a living village significant for its rich history, culture and geothermal features. Located in the central North Island of Aotearoa-New Zealand in Rotorua, the name Whakarewarewa is short for Te Whakarewarewa O Te Ope Taua A Wahiao (Neilson et al., 2010) meaning the uprising of the warriors of Wahiao. The people of Whakarewarewa are from the tribe Tūhourangi-Ngāti Wāhiao that hail from the ancestral canoe called Te Arawa (Pohuhu et al., 1997). Whakarewarewa is a living village (The Living Māori Village, 2019) where many local tribal members reside. It is open to tourists to come, enjoy and visit the many geothermal pools and geysers that are located in the village. Local Māori have lived with the geothermal activity for hundreds of years, utilising the pools for rituals, heating of homes as well as general activities such as cooking, washing clothes and bathing. For hundreds of years the local tribe has developed an in-depth knowledge of their home and the fascinating geothermal phenomena that occur there.

1.2 Formation of Whakarewarewa

Māori arrived to Aotearoa-New Zealand around 1350AD on a fleet of canoes from Eastern Polynesia (cite). The formation of Whakarewarewa is understood to have occurred just after the arrival of one of these great canoes called Te Arawa to the shores of Aotearoa-New Zealand. On board the canoe was the Tohunga (high priest) Ngātoroirangi. Upon arriving him and his group went to explore the land and travelled to the central Volcanic plateau. Ngātoroirangi knew the great mana (power) of the mountain and if he climbed it as he believed it would see the survival of his people. Ngātoroirangi instructed his group to stay whilst he and Ngaruhoe climbed the mountain. He instructed the others to not eat until he had reached the peak of the first mountain. This was to ensure that the Gods would be with him and would give him strength. Whilst ascending however the others grew restless and began to eat. Ngātoroirangi collapsed as the sharpness of the cold grasped his heart. He called out to his siblings' way off in their original homeland

Hawaiki to send fire to warm his heart. The sisters hearing his call, ran to beach and called upon the gods Te Pupu and Te Hoata the goddesses of fire to help their brother. The goddesses plunged into the Ocean and swam to Aotearoa-New Zealand in search of Ngātoroirangi. In their search they emerged firstly at White Island, their flames there creating the volcano, Te Ahi Tupua. Then plunging again, they came up at Whale Island (Moutohora), where they left hot water. They then searched different regions at each place leaving a volcano, geyser, hot pools, or hot water. To rest they went to Whakarewarewa where they created the many geothermal features that are there today. Their breath created the geysers that inhale and exhale as they did. The goddesses continued until they found Ngātoroirangi and burst through the mountain heating the ground beneath them. Ngātoroirangi was saved (Marsh et al., 2003, Nielson et al., 2010). We shall see later in our discussion that this formation narrative is not just a historic record but also a theory of how these geologically active regions were formed and the link between them and to the Pacific.



Figure 1: Whakarewarewa Thermal Village including the Marae (center left), the WWII Memorial Archway (bottom) and Pohutu geyser (top right).

3. MĀTAURANGA MĀORI

Mātauranga Māori refers to a body of knowledge developed by Māori and their ancestors in Aotearoa-New Zealand. It is defined as "the body of knowledge originating from Māori ancestors, including Māori world view and perspectives, Māori creativity and cultural practices" (Māori Dictionary", 2019). Mātauranga Māori is not static and continues to grow, however with the arrival of the Europeans to Aotearoa, the growth and development of Mātauranga Māori has been significantly stunted. Thus, the recovery of Mātauranga Māori has been a priority for many Māori for the last 100 years. Mātauranga Māori includes a plethora of knowledge from religion to carving to gardening practices and astronomy. Within Mātauranga Māori as a whole there are many parts that we would call scientific knowledge (Broughton & McBreen, 2015). This knowledge however in the past has been undervalued by the mainstream education system and scientific research sector, which has contributed to the decline of Māori knowledge as well as distrust by Māori with the western education and science system.

Māori knowledge including scientific knowledge is embedded in various forms with some recorded in writing after the arrival of Europeans to that which was orally passed on. Knowledge can be passed on in various forms through, narrative, stories, proverbs, idioms, songs and chants.

3.1 Vision Mātauranga

There is an increasing want and desire for institutions to engage with Māori and Māori knowledge. This is largely driven by policy implementation such as that developed by Ministry of Science, Research, Science and Technology, now the Ministry Business, Innovation and Employment (MBIE) called Vision Mātauranga (2007). Vision Mātauranga has four distinctive themes, these being based on Māori philosophy, cultural practice and aspirations. The themes are:

1.Indigenous Innovation: Contributing to Economic Growth through distinctive Research & Development.
2.Taiao: Achieving Environmental Sustainability through Iwi & Hapü Relationships with land & sea.
3.Hauora/Oranga: Improving Health and Social Wellbeing.
4. Mātauranga: Exploring indigenous knowledge and Research Science & Technology Māori knowledge over the last 200 years has been significantly decimated. Language and knowledge are in a time of recovery, revitalization, preservation and re-growth. Mātauranga Māori encompasses not only traditional knowledge but also contemporary and future knowledge.

Although the implementation of Vision Mātauranga has been varied in the past, the current regime is wanting a more genuine implementation of Vision Mātauranga across the research sector. For Māori historically there has been varied trust when it has come to collaborating with scientists, however of late there has been a growing interest by Māori communities, tribes and subtribes to collaborate as well.

3.2 Interface between Mātauranga Māori and Western Sciences

The MacDiarmid Institute for Advanced Materials and Nanotechnology (The MacDiarmid Institute, 2019), one of New Zealand's oldest Centres of Research Excellence, creates and explores innovative, sustainable materials that will improve the lives of people in

Aotearoa and around the world with a focus on addressing global challenges such as clean water, renewable energy and climate change. The MacDiarmid Institute has in the past endeavoured to engage with Māori organisations and tribal entities to develop meaningful relationships. In the last two years the Institute has increased its capacity by bringing in Māori researchers as Principal Investigators and developing meaning relationships with Māori organisations such as the Whakarewarewa Village. The collaboration aims at developing an interest in exploring synergies between the two knowledge systems. The research will have mutual benefits, providing insights into Māori understanding of frontier materials science, corroboration of historical knowledge and identifying new research opportunities. This targeted knowledge base will deliver direct impacts for Tūhourangi-Ngāti Wahiao in capability enhancement, added-value to commercial tourism operations, and a stronger knowledge base for hazard mitigation and future planning. In particular synergies already have been found in the Sustainability space whereby the indigenous Māori philosophies around environmental sustainability align with The MacDiarmid Institute.

Māori interest in sustainability stems from the close relationship with the environment. This relationship can be understood through the creation narratives. Māori creation narrative describes a Universe that is formed from a great potential called Te Kore and from Te Kore there is a complex description of how the Universe was created through eons of time. One of the later phases is the creation of the sky father Ranginui and the Earth mother Papatuanuku. These two gods were lovers whom created offspring that are now rulers over such realms as the forests, winds, storm, and sea. There are said to some that there are more than 70 children in total that are gods over these various realms. Humans are also the descendants of Rangi and Papa through their child Tane Mahuta the God of the Forest whom created humans through him fashioning dirt from the earth and placing his breath of life to create the first human (Pohuhu et al., 1997). Within this creation narrative we see that humans are intrinsically a part of the Universe from its very beginning. Tane Mahuta the creator of humans had children who were trees and animals; he had siblings who were the gods of the winds and storms, the sea etc. This thus places humans in a genealogical relationship with the universe around them and all humans being related to all animals, fish, insects, the earth, the sky, stars, sun and moon and more. This relationship means that we are fundamentally related and responsible to everything, hence sustainability is a fundamental concept that forms a synergistic relationship with Māori philosophies.

Māori have a rich history of knowledge that has many times been placed in the realms of myth and legend. However, Māori understandings of phenomena are based on centuries of observations. Indigenous knowledge on many occasions has been misappropriated especially in areas such as medicines. Māori have become cautious with sharing their knowledge with outsiders and have been largely suspicious of scientists and researchers. However, if genuine relationships and collaborations are established then both parties have the opportunity to discuss, and share what they feel is appropriate to. Through this sharing of knowledge, we hope to find commonalities, and also new understandings of old knowledge and new scientific discoveries.

At Whakarewarewa this research explores knowledge around the Parekohuru and Roto Kanapanapa pools (Figure 2) that are not only visually fascinating but also offer rich historical, cultural and spiritual significance, and depictions of specific Maori legends that can be compared and understood with data recorded in conventional western science and methods. Local iwi have been observing the environment for hundreds of years. These observations have led to theories of how, why and what the pools can be used for. In order to explore the interface both Mātauranga Māori and western science understandings must be explored. For science deep beneath the ground lies a system of streams and water which are constantly heated by the volcanic remnants of eruptions long ago and are discharge at the surface. This has resulted in geothermal features ranging from geysers, steam vents, boiling mud pools, effervescent and boiling springs and turbid pools. In this paper we are particularly interested in discharging waters in Parekohuru and Roto Kanapanapa investigating and measuring characteristics of the pools such as salinity, acidity, trace elements, rock composition etc. Whilst for Mātauranga Māori one needs to explore the various form which knowledge on the pools is possibly embedded. These could be in narrative, stories (purakau), proverbs (whakatauki), idioms (kiwaha), songs (waiata) and chant (moteatea). In order to investigate what lay at the interface one must first explore each knowledge system and then discuss with each other the understandings.

In order to do this in a respectful manner one must take a methodological approach called Kaupapa Māori methodology (Smith, 1999: Smith, 1992). Kaupapa Māori based research as Irwin (1994) describes is culturally safe, involves mentoring of elders and is culturally relevant and is conducted by a Māori researcher, not a researcher whom is Māori (Smith, 1999: 184). Graham Smith describes Kaupapa Māori research as, "being related to 'being Māori'; is connected to Māori philosophy and principles; takes for granted the validity and legitimacy of Māori, the importance of Māori language and culture; and is concerned with the struggle for autonomy over our own cultural wellbeing" (Smith, 1992). He further developed these principles into six key elements of Kaupapa Māori theory (Smith, 1997), which have been further developed by others. A summary of these key principles can be found in Smith (1997), Pihama et al., (2002) and an expanded version publicly available at online ("Rangahau", 2019). The methodology is still under current development and will be expanded upon in a future paper (Harris et al., 2019).

For example, the current conversations are centred around the traditional narrative describing how certain soils and waters in the earth were formed, and subsequently used for colouring, dyeing, cooking and important sacred rituals. Roto Kanapanapa lake is a light green / jade pool lying in the bed of the valley surrounded by hills of red and white calcareous stone. It is supplied by the adjacent spring situated to the south east of Pūhunga. It was formerly used before pre-colonisation era by the village Tohunga (priest) in ceremonial funeral rituals to cleanse tupāpaku (bodies) before burial as described by Rangingangana Wade about the history of Wāhiao living in the thermal village (Mare et al., 2017). More recently Muauriora Kingi composed a beautiful chant that recognises the ancestors and their relationship with these springs, pools and geysers, where Roto Kanapananapa lake is mentioned as part of traditional practice for mourning the death "*I now rest at RotoKanapanapa so that my face can be cooled by the wind. I return to the Te Puia Pā and hear Rotowhio whistling, an old cemetery*" (Mare et al., 2017). It is believed that one of the reasons behind using Roto Kanapananapa lake as part of customs, beliefs and practices (tikanga) for dead Māori was related to the acidity of the lake; the water being used as embalming fluid and to preserve bodies. The Village's residents have also developed a strong spiritual and cultural connection with Parekohuru which translates to "murderous rippling waters" (Neilson et al., 2010). This is the largest hot spring in the village and every 45 minutes to an hour the pool pulsates and the water begins to rise. After each pulsation when the water level drops, bubbles rise to the surface. This has earned the pool the nickname "The Champagne Pool". The water is 95° Celsius

on the top of the pool and it gets hotter as it goes down. This pool is used for cooking of leaf and root vegetables and seafood. Corn on the cob, which is cooked in Parekohuru, can even be purchased by tourists.



Figure 2: Images of Parekohuru (left) and Roto Kanapanapa (right) pools.

3. WHAKAREWAREWA – GEOTHERMAL AREA

3.1 Geology and Geothermal Features

The natural geothermal features of Whakarewarewa Village are the result of the large area of geothermal activity known as the Rotorua Thermal Field. The Rotorua Thermal Field covers a surface area of ~12km^2 (Wood, 1992), but extends much further underground to 20-28 km^2 (Bibby et al., 1992). The Whakarewarewa thermal area occurs in the southern part of the Rotorua Geothermal Field, inside the margin of the Rotorua Caldera and beneath Pohaturoa rhyolite dome (Lloyd, 1975). One of the most noticeable features of the region is the Rotorua caldera, a large depression caused by extensive hydrothermal eruption Breccias (42 ka, Lloyd, 1975; and 26.5 ka, Cody, 2003), cropping out to the south and southwest of the Whakarewarewa Village. Several faults within the area provide pathways for geothermal fluids to travel from deep underground and reach the surface resulting spectacular features at Whakarewarewa Village including acidic liquids flowing into warm muddy pools, near-boiling alkaline waters, steam and gas flows, and areas of steaming ground associated with collapsed geothermal holes. Some of these features will be discussed in more details below. In total the Whakarewarewa thermal area contains more than 500 hot springs, 65 geyser vents, colorful sinter terraces and vegetation unique to geothermal areas (Lloyd (1975)). It worth pointing out Pōhutu - "big splash" or "explosion" - Geyser, the largest geyser in the Southern Hemisphere, with up to 15 eruptions per day that travel roughly 30 meters into the air. Since the early 1800s Whakarewarewa Village have hosted and welcomed guests into their homes and backyards, demonstrating the utilisation of the natural geothermal wonders for cooking, bathing and heating. Today the geothermal existence continues to fascinate tourists as the geothermal activity is responsible for all of the billowing steam, odors, and colorful pools.

3.2 Water and Rock Chemistry

The Whakarewarewa Village is characterized by surface features and faults that provide permeable pathways for geothermal fluids to ascend and discharge at the surface. The clear, hot pools of the village can reach near boiling temperature (70 - 100° Celsius) and are generally neutral or alkaline in pH. The water derived from the deep primary geothermal reservoir, which has ascended directly to the surface with minimal mixing and dilution with local groundwater, steam and gases. As a result, the water is saturated with natural silica resulting in layered / scaled aprons of pale grey silica sinter along the edge of pools.

Acidic features such mud and water pools are also present in the Village and are thought to occur away from fault areas at raised elevation. Ponds of cloudy acidic water are formed from hydrogen sulphide gas emitted from boiling liquids underground and mixes with oxidised meteoric ground water to produce acid sulphate waters. While these acidic waters result in a spectacular and varying palette of colors, they are also known to dissolve the surrounding rock, altering and degrading structures, and producing pools of mud. This process, observed and known in the Village over the generations, is responsible for collapse holes, which are common not only at Whakarewarewa but also at Rotorua Thermal Field and has caused many changes of the geothermal landscapes.

Table 1 reports on the water chemistry of Parekohuru and Roto Kanapanapa pools, sampled at Whakarewarewa Village in July and December 2019. The pools have significant chemical property differences, with maybe the most spectacular being the pH, showing a crossover from very acidic (Roto Kanapanapa) to a more alkaline water (Parekohuru). The water from Parekohoru has the end-member alkali-chloride composition (pH 9) characteristic of an up flowing fluid, sourced from the deep geothermal reservoir, with temperature estimate of 220-240°C (Neilson et al., 2010). Water from Roto-Kanapanapa pool (~ pH 2.5-2.6) has a close to end-member acid sulphate composition. It is worth pointing out that we have observed a change of pH as a function of the location of the water samples for Roto-Kanapanapa. The closer the water to the inlet of the pool, the lower the pH (Location 1). The change of pH is ranging from 2 to 2.7 over the pool location. A change in the salinity and electric conductivity as a function of the location of the water samples is also observed as displayed in Table 1 (see aerial photograph below Table 1 for each location). The salinity values are typical of brackish water and are useful for most livestock (ANZECC, 2018) and further studies will take place to understand the conduction mechanisms and the nature of charged ions.

Table 1: Representative water chemistry data, pH, salinity (ppt) and electrical conductivity (mSiemens.cm) for Parekohuru and Roto Kanapanapa pools. The Location 1, 2, 3 and 4 of water samples from Roto Kanapanapa pool are displayed on the aerial photograph.

	Parekohuru	Roto Kanapanapa (Location 1)	Roto Kanapanapa (Location 2)	Roto Kanapanapa (Location 3)	Roto Kanapanapa (Location 4)
pH	9	2.02	2.5	2.6	2.7
Salinity (ppt)	2.9	7.9	3.2	2.6	2.3
Electrical conductivity (mS.cm)	2.5	6.5	2.85	2.3	2.0



Water analysis collected from locations are performed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), a leading technique that uses a plasma as a source and relies on optical emission to determine the elemental concentrations (Gosh et al., 2014). The elemental concentration (in mg/L) of the main constituents is displayed in Figure 3 and have been confirmed by ion beam analysis. The alkali-chloride composition of Parekohoru water is supported by the measurement, that show that one of the main elements is chlorine which could suggest why the pool is so clear. Chlorine is indeed known to reduce microorganisms, bacteria and germs levels in water. Interestingly enough, for Roto Kanapanapa, the level of chlorine is reduced while in the meantime the level of sulphur-based compounds has increased significantly. Sulphur is known to reduce the pH of solution, and colloidal sulphur and precipitated sulfur have the propensity to color water in green. It is worth pointing out that the concentration of heavy elements in water is under the limit of detection, and that chemical elements such as Na, K, and Fe are common in mineral water.

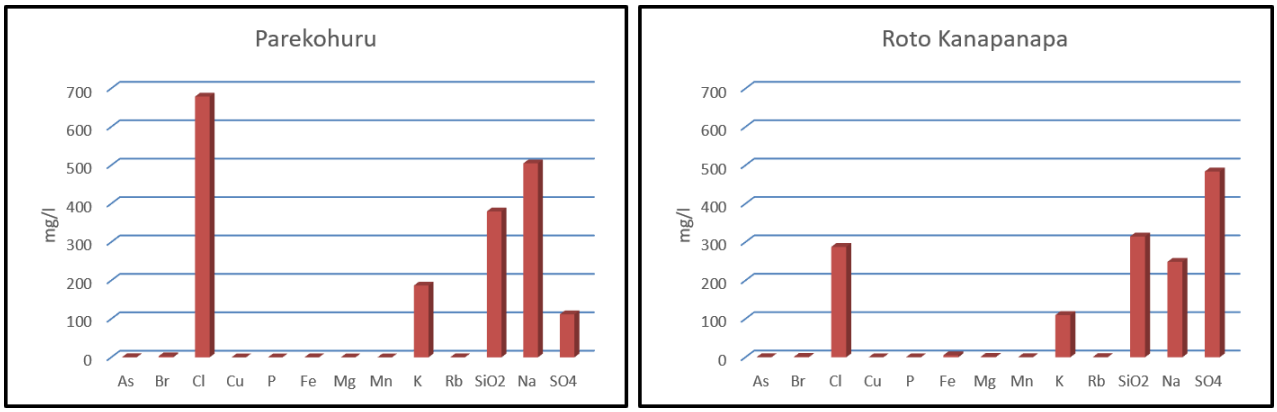

Figure 3: Representative elemental concentrations in mg/l for Parekohuru and Roto Kanapanapa pools.

The elemental composition of rock samples was also analyzed with particle-induced X-ray emission (PIXE). PIXE is based on the emission of characteristic X-rays from a sample when bombarded by protons from a small accelerator (Kennedy et al., 1998). With this technique it is possible to quantify the amount and distribution of elements in rock samples. Rocks from Whakarewarewa Village are composed of over 30 different chemical elements with the 5 more abundant elements being typically Si, Mg Al, K, Ca and Fe, respectively. The weight percentages of the elements of rocks from Parekohuru pool are 76, 17, 5,2.6 and 0,5 for Si, Mg Al, K, Ca and Fe, respectively. It is worth pointing out that rocks at Whakarewarewa village seem to show a higher concentration in magnesium than in “traditional rocks” (i.e. Earth's upper continental crust). This could be explained by the presence of basalt particles formed from the rapid cooling of magnesium-rich and iron-rich lava exposed at or very near the surface, while further crystallographic analysis of the rocks would be needed to further understand their structure.

4. CONCLUSION

There is a growing commitment in Aotearoa-New Zealand to acknowledge and develop a framework of effective strategies that will merge Māori cultural knowledge of land and natural resources and Western Science methods and thinking. The collaboration between the Whakarewarewa Village and the MacDiarmid Institute aims at advocating a cross-cultural engagement that focuses on the aspirations and goals of both parties. The research findings and experience will be shared openly and we expect the project to leverage a range of communication/knowledge transfer mechanisms. The transfer science knowledge and discovery to the Village will in turn be passed on to visitors through the on-going guiding legacy. The long-term vision is also to ensure that Village developments are sustainable and that the integrity of the geothermal taonga (treasures) lives on for future generations. It would also strengthen New

Zealand's skill base and connectivity in Mātauranga Māori, and ensure sustainable natural resource management in Aotearoa-New Zealand.

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