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ORIGINAL RESEARCH ARTICLE

The Eighth Wonder of the World in New Zealand: Seismic studies confirm the new Hochstetter paradigm

Alfred Rex Bunn

Independent Researcher, Caves Beach, NSW 2281, Australia; rexbunn2015@gmail.com

ABSTRACT

The most famous tourist attractions in the southern hemisphere, in the nineteenth century were the Pink and White Terraces—New Zealand's lost Eighth Wonder of the World. They were assumed lost in an1886 eruption. The unpublished 2018 data from passive seismic stations across the Lake Rotomahana overflow in the Taupō Volcanic Zone are examined for evidence of acoustic interfaces that may be traced to Te Tarata, the White Terraces, the stations were coincidentally placed over the reported course of the Kaiwaka Channel buried in the 1886 Tarawera eruption. There was no seismic evidence of the Channel at the reported altitude under either the Smith-Keam or Hochstetter paradigms. This absence is strong empirical negative evidence that the Kaiwaka Channel did not flow beneath today's Lake Rotomahana overflow, as has been assumed since 1886 under the Smith-Keam paradigm. Unlike the seismic and GPR Black Terrace Crater and Te Tuhi's Stream (aka Black Terrace Stream) bed evidence obtained by the same 2018 survey—there is no evidence of a pre-1886 eruption paleochannel beneath today's overflow saddle at the lake and at the Kaiwaka altitude under the 1886 Smith-Keam paradigm or the contemporary Hochstetter paradigm, the latter based upon Hochstetter's unique terrestrial survey of the Rotomahana Basin. The study reports strong empirical evidence contradicting the assumed Kaiwaka location and with it, the assumed locations of old Lake Rotomahana and the Pink and White Terraces. The Smith-Keam paradigm is thereby confounded. The seismic data provide concomitant empirical evidence for the Rotomahana altimetry and topography reported by Bunn and Nolden, who locate the Kaiwaka Channel 440 m west of the seismic stations. The Pink and White Terraces can no longer be assumed destroyed. They may yet be explored and recovered.

Keywords: Eighth Wonder of the World; Pink and White Terraces; Hochstetter paradigm; Rotomahana Basin; Tarawera eruption; Kaiwaka Channel; Smith-Keam paradigm

1. Introduction

In the nineteenth century, the most famous tourism and geoscience attractions in the southern hemisphere were the Pink and White Terraces, the lost Eighth Wonder of the World in New Zealand. The 1886 Mt Tarawera eruption buried the terraces. As they were unsurveyed, uncertainty and controversy followed over their possible survival. The historical paradigm created by a government surveyor (herein termed the Smith-Keam paradigm) held they were destroyed without evidence. What can now be coined the Hochstetter paradigm from Bunn's research[1] began by accident in 2014 when Bunn began researching a lost Eighth Wonder of the World—the Pink and White Terraces of old Lake Rotomahana in New Zealand's Taupō Volcanic Zone. The research led to his wife's painting of Te Otukapuarangi (the Pink Terraces). It developed

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into successive projects to locate the lost terrace coordinates. Up to that time, the unchallenged paradigm was one herein termed the Smith-Keam paradigm after the surveyor who wrote the 1887 Mt Tarawera eruption report S. P. Smith (1840–1922) and the geophysicist Ron Keam (1932−2019), who specialised in the Rotomahana Basin. Keam and Bunn corresponded for years as the old paradigm came under challenge and Keam persisted with it, despite his evidence often supporting Bunn and Nolden's research.

In 2014, Bunn noted the 2011–2012 lay media promotion by IGNS (Institute of Geological and Nuclear Sciences Limited) for a joint New Zealand—American project, publicising their claims of finding both the lost Pink and White Terraces on the bottom of Lake Rotomahana in **Figure 1**. Their claims rested on two photographs and a sonar image. To Bunn, a diagnostic radiographer, neither photo nor sonar interpretation appeared to resemble submerged terraces. Geologists varied in their responses. Nevertheless, that February, Bunn floated the idea of draining the lake to expose the terraces and reinstate them in the tourism industry with the Māori landowners. He undertook the PAWTL Project (Pink and White Terraces Limited), a social enterprise company to undertake the drainage with control passing to Māori operation by the Tūhourangi Tribal authority with the Ngāti Rangitihi Hapu—the Arawa sub-tribes associated with the Pink and White Terraces and the windfall income they generated in the nineteenth century[1].

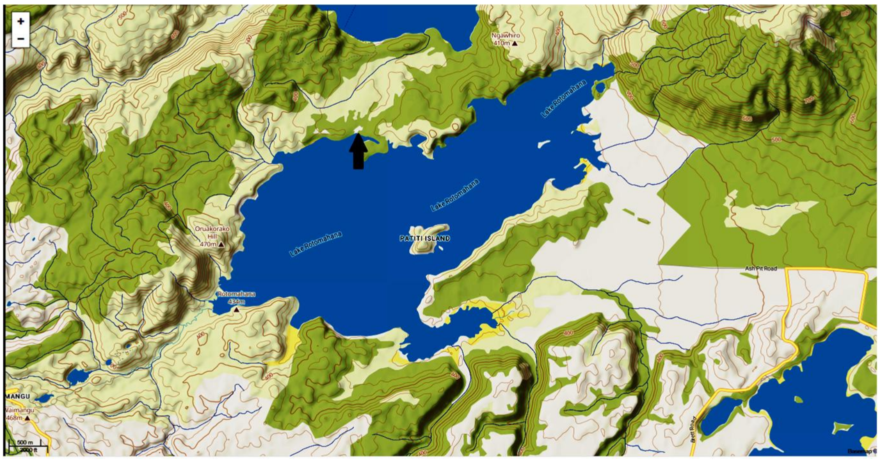

Figure 1. Lake Rotomahana digital elevation map, with the overflow arrowed (New Zealand River Pilot).

Bunn suspended the project near the PAWTL Project launch day after IGNS warned of the risk of another eruption—the lake lowering would allegedly affect the hydrostatic boiling point equilibrium under the lake. IGNS cited (unpublished) new alarming evidence of magma moving under the lake, leaving Bunn with the impression his project could cause a dramatic magmatic eruption, one that might devastate Rotorua—as described in his 2016 book "Quest for the Pink and White Terraces"[2]. This IGNS evidence was later published in 2016 and proved to be a well-documented finding. The phenomenon had been noted on several occasions and was not a cause for alarm. Bunn concluded that IGNS did not want their claimed Pink Terrace site exposed lest there was no Terrace at the location. Their 2011 location was the first of three later claimed by de Ronde[3], for the same Pink Terrace. Surprisingly, no terrace coordinates were published by the joint New Zealand-American project. The IGNS warning overlooked Bunn's hydraulic design, using geologist Phil White's data and discussions with Ron Keam and Ian Nairn. These led Bunn to develop the mega-siphons and Heron's Fountain engineering for a slow lowering over two years, toward the original lake level. This allowed the equilibration of sub-lake, hydrostatic boiling point pressure and thus acceptable risk. However, the IGNS threat precluded PAWTL from obtaining project insurance and this forced the project into recess. Given the later events described herein, this was fortunate for all parties.

After the initial 2011–2012 institutional, lay and social media promotion by IGNS and WHOI (Woods Hole Oceanographic Institute) et al., from the joint New Zealand-American project, there was a hiatus from 2012–2016 until the evidence was published in peer review. The lay media claims from 2011–2012 for in situ terraces were retracted and it was claimed the terraces were destroyed. Unfortunately for IGNS et al., in 2016 and 2017, Bunn and Nolden published their first iterations of Ferdinand von Hochstetter's (1829–1884) 1859 survey (survey iterations III and IV) showing both Pink and White Terraces' springs were on land and hence the joint New Zealand-American project evidence was faulty[4,5]. This prompted a 2018 paper by de Ronde et al.[6], defending their claims and the old paradigm. Their Crown Research Institute colleagues at NIWA (National Institute of Water and Atmospheric Research Ltd) joined with two papers to support IGNS and the old paradigm. The first NIWA paper was withdrawn after Bunn et al., pointed out errors. A revised paper was published and this also contained numerous errors. In 2018–2019, Bunn and Nolden[5], Bunn et al.[7], Bunn[8,9] published more evidence under the new paradigm and in 2020 a reconciliation rebutting the IGNS claims and a refereed commentary refuting the NIWA papers[10,11]. Over 2021–2023, Bunn[12–15] published further refutations of the old paradigm on which the New Zealand-American project claims were based.

In 2015, Sascha Nolden and Bunn first met via Nolden's co-author, geologist Mike Johnston. They began a collaboration that led to the new paradigm, based upon the 1859 survey notebooks of Ferdinand von Hochstetter and later his 1860 cartography Folio. In 2023, the new paradigm was triangulated with Mātauranga Māori knowledge and topographic navigation[14,16]. The new paradigm supersedes the 1886 Smith-Keam paradigm. It provides a better explanation of the topography in the Rotomahana Basin and better connects this with the pre-eruption topography and history, by focusing on a four-dimensional model, i.e., latitude, longitude, altitude and time. It better explains the locations of the three terraces, Te Rangipakaru, the Steaming Ranges and herein the Kaiwaka Channel (**Figure 2**). It also explains key unknowns under the old paradigm, e.g., the old Lake Rotomahana location and dimensions, its depth and altimetry and the locations of other proximal pre-eruption landmarks.

Figure 2. The Lake Rotomahana overflow in 2021 (Bay of Plenty Regional Council)[17].

The 2018 seismic stations were positioned downstream from the camera position (**Figure 2**).

2. Methods

In 2018, follow-up research to the 2017 PAWTL2 Project was conducted over the predicted site of the Black Terrace Crater in the Rotomahana Basin. The location was selected from Bunn's seminal research[18] into the Black Terrace (Te Ngāwhā a Te Tuhi), first identified by Hochstetter in 1859 as Te Ngawha Atetuhi. The correct Māori name and spelling is Te Ngāwhā a Te Tuhi, i.e., Te Tuhi's geothermal crater or pool (Rangitihi Pene, personal communication, 28 June 2016). The stream formed by the Ngāwhā is herein referenced by its possible Māori name, i.e., Te Tuhi's Stream (or generically as Black Terrace Stream). The river pilot lists Te Tuhi's Stream here as Drain 1019568[19]. The drain requires a name.

The Black Terrace Crater is a separate feature and this colonial term was used by Bunn[11,13] and de Ronde[6] from the 2017–2018 PAWTL2 Project. The 2018 follow-up research was led by White et al.[20], the honorary geologist from the PAWTL2 Project. Sub-surface imaging was performed by GPR (ground-penetrating radar) using a Mala© unit and by passive seismic survey using a Tromino® unit from Resource Potentials PTY Ltd in Perth, Australia. The rediscovery of Black Terrace Crater was suggested by the GPR and confirmed by the Tromino passive seismic data[20]. Passive seismic research with the Tromino machine has a simple, easy theory, and non-geoscientists can operate and process data[21]. This protects the author from charges of an ad verecundiam fallacy, sometimes applied to interdisciplinary researchers. As well, this paper benefits with assistance from the geophysicist who tendered the published line 1 and 2 reports on Black Terrace Crater in 2020[20].

2.1. Passive seismic method—HVSR (horizontal to vertical spectral ratio), a lay description

The earth is never still. There is always background seismic (mechanical) noise moving through the subsoil in waves, rather like very small earthquakes or vibrations. These are caused by natural wind, waves and human activity. They stimulate the resonance of both subsoil and buildings. This resonance is akin to that of a microwave oven where the radiation frequency matches that of foods. The food vibrates or oscillates, i.e., its particles vibrate and heat up. Similarly underground, the layers vibrate or resonate in tune with these earth waves. Different layers, e.g., rock and mud respond differently in a way similar to medical ultrasound examinations. There, bones reflect the sound waves more strongly than soft tissues and the impedance contrast forms the ultrasound image. A subsoil layer of say rock and sand yields a similar acoustic contrast, which can be recorded on a passive seismic machine that takes three-dimensional recordings, i.e., horizontal and vertical. By some simple statistics, i.e., normalising the data by dividing the horizontal by the vertical data, we can obtain a clearer picture of the underground responses and these can be depicted as illustrations showing the different acoustic layers in colours.

2.2. 2018 passive seismic surveying of the claimed Kaiwaka Channel paleochannel

In 2018, a second location received passive seismic testing and this was unreported in the 2020 conference paper by White et al.[20]. This second site lay on the new Lake Rotomahana overflow in **Figure 2**, with twelve (in fact thirteen) stations stretching from 85–150 m inland, oriented to the northwest and traversing a natural low point in the 1886, Tarawera eruption ejecta which formed the new lake overflow. As shown in **Figures 1−3**, this saddle was claimed by Smith in 1886 to mark the pre-eruption location of the Kaiwaka Channel, which drained the pre-eruption Lake Rotomahana[22]:

> *The outlet was from the northern end, where a strong stream of hot water formed the Kaiwaka River, which after a course of a mile, and a descent of 40 ft, fell into Tarawera Lake.*
>
> *It was at a point due north of the centre of the lake that the Kaiwaka River flowed out of* [the old] *Rotomahana. The valley has been completely filled up with sand and mud to a depth of 80 ft* [24.4 m]*, forming as it were a great dam.*

Its relevant Smith once visited and mapped the old lake in 1857, as a teenager and marked the Kaiwaka entry north of the lake centre, although his sketch has no north arrow[23]. The Kaiwaka entry on Petermann's 1864 map is north of the lake cent

re, though that map also has no north arrow[24]. In 1886, Smith would draw on these memories in the now-foreign landscape. His resulting claim forms the basis of the Smith-Keam paradigm. Ironically, Smith's memory of this aspect is now proven correct—under the Hochstetter paradigm, once the old lake coordinates and orientation are corrected the true, Kaiwaka entry does lie due north of the lake centre in **Figure 3**. The old paradigm has the Kaiwaka entry 440 m to the east under the overflow. In 1887, this mistake causes delineator Alpha Harding (1856–1945) to graphically depict the old lake nested in the new crater. He draws (by guesswork) the old Lake Rotomahana inside the 1886 crater, centred over ponding in the crater floor. The crater slowly fills to form the new Lake Rotomahana which a century later, enables the joint New Zealand-American project to fortuitously rediscover the lost terraces on the new lake floor.

Strangely, this overflow assumption has never been tested. In 2016, Bunn and Nolden[4] first suggested the Kaiwaka lay west of the overflow. In 2018, by coincidence, passive seismic stations were laid across the assumed Kaiwaka Channel course in **Figure 2**. Under the 1886, Smith-Keam paradigm, the stations' locations were a third of the way down the 1.6 km Kaiwaka Channel and above the rapids lying below the Awaporohe Stream junction. Under the new Hochstetter paradigm, the stations were 440 m east of the true Kaiwaka Channel course in **Figure 3**.

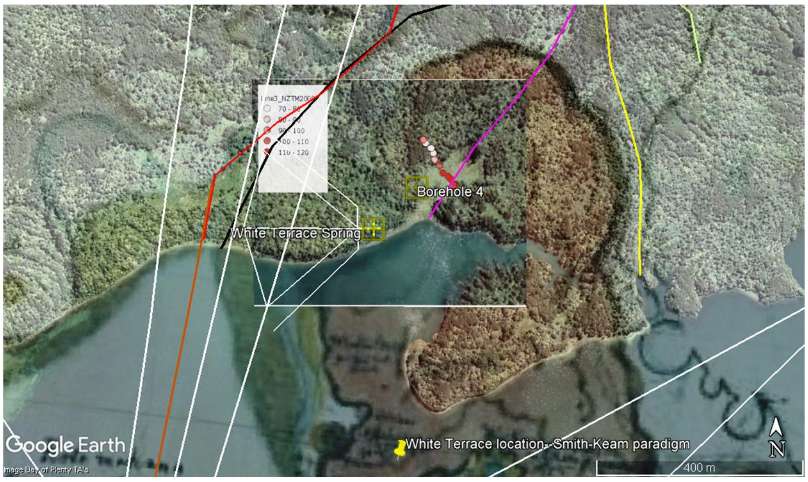

Figure 3. The Lake Rotomahana overflow with twelve Line 3 seismic stations. The Mauve ray is Smith's Kaiwaka Channel. The assumed White Terrace location is marked. The red ray is the Kaiwaka Chanel under the Hochstetter paradigm. The White Terrace is marked by Hochstetter's survey. The umber ray is Hochstetter's bearing to the Kaiwaka Channel. The Black ray marks the Haroharo caldera. Hochstetter's lake map is georeferenced over Google Earth™. (Google Earth/Bunn/Resource Potentials).

3. The new Hochstetter paradigm claims

It is helpful to list the major tenets from the Hochstetter paradigm before the passive seismic results are discussed, under both the old and new paradigms.

1) The Pink, Black and White Terrace springs today lay buried in their original locations. These lie beneath the 1886 Tarawera and Rotomakariri-Rotomahana ejecta around the shores of Lake Rotomahana for the Pink and White. The Black Terrace (Te Ngāwhā a Te Tuhi) lies buried between the Pink Terrace and Te Kumete Ridge.
2) The 1886 paradigm was based on faulty western science, published by a colonial surveyor S. P. Smith and a geologist qualified by an MD, James Hector (1834–1907). In the early days of geology, it was considered a branch of medicine.
3) Available Mātauranga Māori topographic knowledge was ignored until today, due to hubris and racial prejudice.
4) The seismic, cartographic, photographic, topographic, hydrographic, geolocation, georeferencing, historical, archaeological and Mātauranga Māori evidence is more consistent with the new paradigm than the old. Keam's empirical evidence is often consistent with the new paradigm.

This leaves the Smith-Keam paradigm in 1886 resting on the IGNS-NIWA axis on behalf of the joint New Zealand-American project—with a series of contradictory claims based on challenged evidence. Despite a series of IGNS field visits to Lake Rotomahana and $NZ400,000 of taxpayer funding from 2011, they never produced a sinter Terrace sample. Instead, their claims were based on an unfinished map and several photographic and sonar interpretations—which have been challenged, rebutted or refuted. Their altimetry was an admitted guess by Keam and was refuted by the first published evidence-based altimetry in 2022[12]. The joint New Zealand-American project relied on Keam for the history of the Rotomahana Basin and he is deceased.

4. Results

4.1. Nairn's stratigraphy of the isthmus

Pending the availability of core samples from borehole BH4 in **Figure 3**, seismic interpretation from the overflow relies on Ian Nairn's seminal stratigraphy of the Rotomahana Basin and the scientific record[25]. His topography supersedes that of Smith.

Nairn's paper in 1979 contains stratigraphy for the 2018 overflow seismic data. He was possibly on-site when the overflow piping was laid near the seismic stations[26]. He did not join the PAWTL and PAWTL2 Project field activities but offered generous advice. One key datum is his altimetry of the adjacent Lake Tarawera[27]. In 1886, Lake Tarawera was at C. 290 m above sea level (m a.s.l.). It follows that the Kaiwaka Channel cannot have been at an altitude ≤290 m a.s.l., lest it flows in reverse. Together with the old Lake Rotomahana altimetry, this implies the minimum ejecta depth at the overflow. Also, given the old Lake Rotomahana altitude was 303 m a.s.l. ± 1–2 m (for rise and fall) and the new lake is at 338 m a.s.l. ± 1–2 m; the notional ejecta depth could be ≤35 m at the Kaiwaka Channel entry.

> From Nairn 1979[26]: *the deposits near Rotomahana were hot and dry, composed of a mixture of coarse and fine sand mixed with fragments of "trachytic stone" and finely broken sinter. Ash at 0.6 m depth was warm, and at 1.2 m was "quite hot", six days after the eruption. It appeared to have been deposited in a dry state… None of the early investigators described any bedding structures in the Rotomahana ejecta… sinusoidal undulations are exposed in ejecta sections up to 20 m thick on the eastern and southern shores.*
>
> *On the north shore of Lake Rotomahana, 1 km north of Great Crater… excavation of a lake level control outlet channel exposed the upper 5 m of Rotomahana ejecta as finely bedded, near symmetrically undulating, sinusoidal wave-like bed forms… Thickness of Rotomahana ejecta at this site is unknown, but probably exceeds 20 m.* ***The undulating bed forms exposed in the uppermost 5 m are most unlikely to reflect underlying topography, and thus result from depositional processes occurring during the eruption*[26]**. [my bold ARB].

Nairn here refers to the area where the passive seismic stations were positioned in 2018 over redeposited ejecta and explosion breccia at a higher elevation. This helps explain the superficial layers in the shallow 0–40 m HVSR image in **Figure 4**.

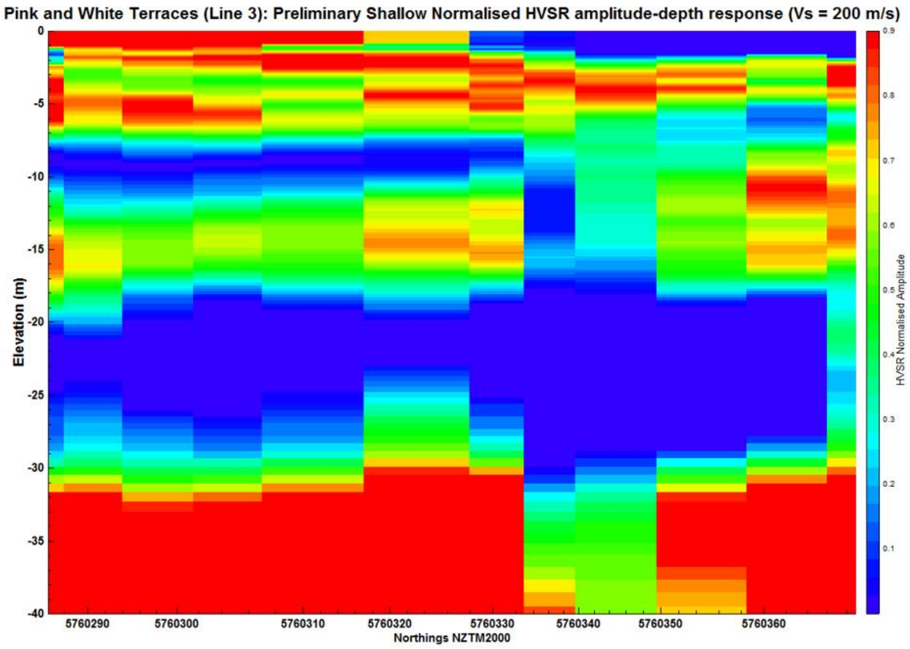

Figure 4. Superficial and shallow HVSR layers at the overflow (Vs = 200 m/s), (Resource Potentials).

4.2. Keam's stratigraphy of the isthmus

In 2003, Keam contributed to, (but was unacknowledged in) an engineering report on the geotechnical hazard posed by the accidental formation of the isthmus between Lakes Rotomahana and Tarawera[28]. He reported on the overflow stratigraphy:

> *The stratigraphy was initially described from a cross-section near the site of Te Ariki village* [his invention at the Kaiwaka exit ARB] *as basal deposits consisting of blocks of rock, evidently derived from the rhyolite mass that occupied much of the eastern shoreline of the pre-eruption lake Rotomahana. Above this was a dry stratum that was a climactic base surge deposit (secondary pyroclastic flow), resulting from the initial hydrothermal eruption at Rotomahana. On top of that was a thick sequence of later pyroclastic flows, largely composed of sandy rhyolitic material derived from the country rock but with a substantial admixture of basalt lapilli… The uppermost deposit, covers a much more limited area and thins more quickly with distance from the crater*[28].

Keam in 2003 claimed the ejecta was 40–45 m thick but in 2016 revised this to ~60 m[29]. His ex-post adjustment was Bunn deduced to correct a contradiction stemming from his earlier faulty altimetry.

4.3. Shallow line 3 HVSR vs. 200 imagery and the Kaiwaka Channel

In **Figure 4**, the 0–5 m layers and most likely the 6–20 m layers portray Nairn's depositional processes, and these are also consistent with Smith. In his 1979 paper, Nairn's Table 1[26] gives grain size data and discusses the ejecta composition. In the 2017, PAWTL2 Project GPR surveys, two Mala GPR units each failed to penetrate > 4–5 m into the Rotomahana ejecta. At the time, Bunn wondered if this reflected the dielectric properties of the bentonite clays forming a significant fraction of the 1886 ejecta[30]. This is corroborated for the 2017 and 2018 GPR and seismic data in the **Figure 4** shallow acoustic interfaces (Tom Dronfield, personal communication, 11 June 2023). Similar clay layers are reported in the Chilalo Tromino paleochannel survey by Resource Potentials[31].

The **Figure 4** layer between 30–40 m would be classed by Keam as post-eruption but could be pre-eruption for Smith and Nairn. It lies at an altitude of ~310–315 m a.s.l. Under the old paradigm, to be the

Kaiwaka paleochannel it must lie at 290–291 m a.s.l. The ~21 m variance is just within an arbitrary error margin for passive seismic when no corroborating evidence is available. However, the layer bears little resemblance to a streambed. The interruption at station 5,760,340 is possibly a fault. The more likely interpretation for the 310–315 m a.s.l. acoustic layer is that we are descending into the noise envelope (Tom Dronfield, personal communication, 11 June 2023).

The Kaiwaka was often included in White Terrace's photographs as in **Figures 5–7** below.

Figure 5. White Terrace with Kaiwaka entry at the apron base, photographed along azimuth 75°. The Kaiwaka curves around the Terrace to its northeast exit in Lake Tarawera. The Ngāhutu and Ngahapu springs are active at three o'clock (Te Papa).

Figure 6. Kaiwaka Channel at the base of White Terrace, photographed along azimuth 95° (Te Papa).

The Kaiwaka course is best shown in **Figures 6** and **7** as it begins its lively descent. **Figure 7** also provides a rare view of the plumes over the Aka Mānuka springs. The five-spring series lies north of the White Terrace embankment. Under the Hochstetter paradigm, the line 3 stations lie over Orangiaho, between the Tarata embankment and Te Aka Mānuka. This was a shallow slope, extending behind the Tarata embankment and connecting south with the valley herein termed the Ngāhutu Valley, after the first geothermal feature on the tourist path. Georeferencing in **Figure 3** shows the Ngāhutu Valley today underlies the bay at the base of the Tarata Peninsula[14].

The shallow imagery in **Figure 4** for the northern stations is close to the Aka Mānuka spring which lay at an elevation at or slightly above Tarata (333 m a.s.l.). While the shallow imagery might be consistent with a spring and underground plumbing, the seismic elevation lies amidst redeposits which argues against any connection with Aka Mānuka.

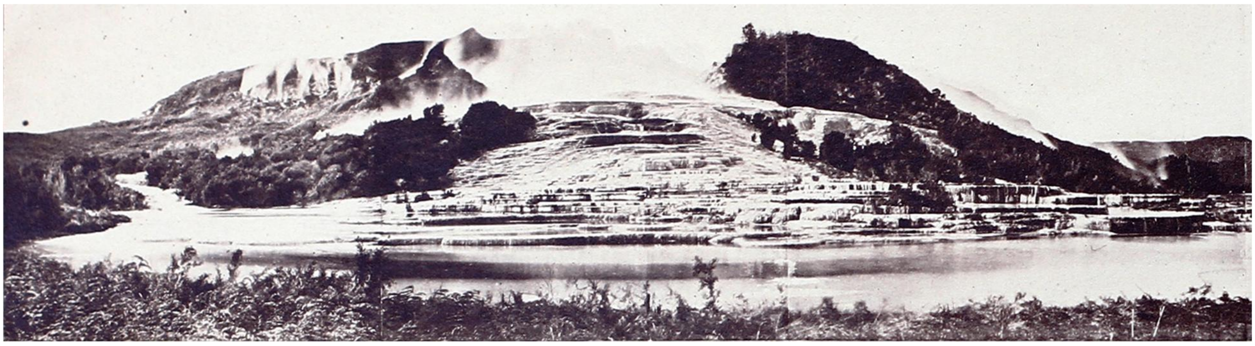

Figure 7. An early panorama (George Pulman 1826−1881) along azimuth 90° showing from left to right: the Kaiwaka Channel and Orangiaho (misnamed Flat Top Hill by Keam)[32].

Orangiaho contains the five plumes of the Aka Mānuka springs. They lay north of the White Terrace embankment, on the northern tip of the Steaming Ranges. South of the White Terrace embankment are the plumes marking Ngāhutu and Ngahapu springs. The Ngāhutu Valley continued north behind the White Terrace embankment and opened out onto Orangiaho. Under the Hochstetter paradigm, the line 3 stations lie here (Hochstetter Collection Basel, HCB 2.14.1). The three adjacent features, i.e., Aka Mānuka, Tarata and Ngāhutu may share botanical nomenclature (Rangitihi Pene, personal communication, 2023)[13,16].

4.4. Deep imagery—Line 3 400 m/s velocity interfaces and the Kaiwaka Channel

The elevations in **Figure 8** peak at 340 m a.s.l. Given the 2018 stations were placed ~90 m inland from the lake shore, they were below the overflow which in 2003 lay at ~344 m a.s.l.[28]. The overflow pipe and culvert are shoreward of the eastern seismic stations 9–12 and lay at 340 m a.s.l. The lake level varies between ~336–340 m a.s.l. It overflowed in 2018. **Figure 8** shows the layer at ~310–315 m a.s.l. is not as well defined as in **Figure 4** and is well above what may be considered bedrock. Also, the best acoustic interface contrast lies under the northern stations beneath explosion breccia versus the redeposited ash and scoria under the southern stations.

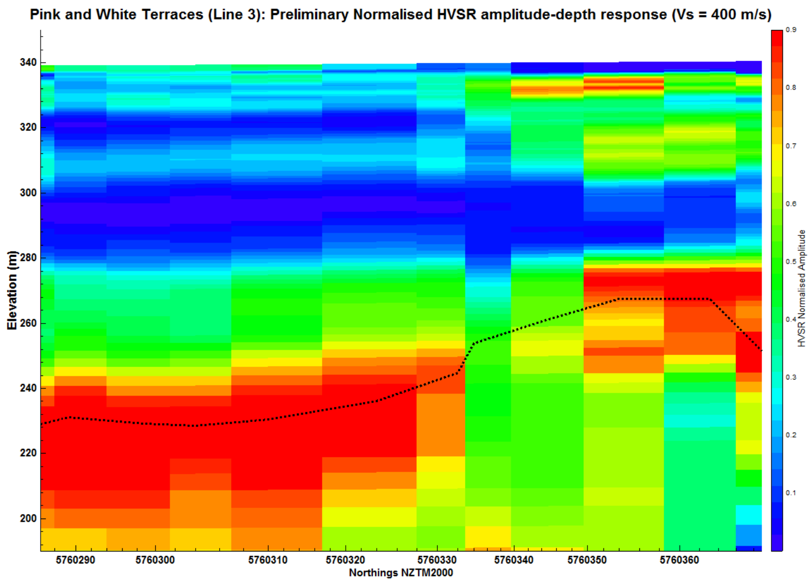

Figure 8. Overflow HVSR response (Vs = 400m/s) (Resource Potentials).

Below the ~310–315 m a.s.l. layer there is a hiatus of 70–85 m under the scoria redeposits until we reach bedrock lying at 230–240 m a.s.l. in the overflow and at ~45–50 m beneath the breccia. For the black line in **Figure 8** to be the Kaiwaka under the old paradigm, it must lie at ~290–291 m a.s.l. beneath the southern stations. The variance here is ~80 m (35%) under the scoria and 45–55 m (16%–24%) under the breccia. This is outside the accepted error margin for unsupported passive seismic results. The variance precludes the overflow being the site of the Kaiwaka paleochannel. This is a striking repudiation of the 1886 Smith-Keam paradigm, which depends on the Kaiwaka Channel being in this precise location.

4.5. Deep imagery and the White Terrace and Aka Mānuka springs

As the shallow imagery in **Figure 4** largely occupies areas of scoria redeposits and precludes the Kaiwaka from being in the location claimed by the old paradigm, we next investigate whether the line 3 stations may provide information on the location of the White Terrace or Te Aka Mānuka, both lying a short distance from Line 3 stations on Hochstetter's survey georeferencing in **Figure 3**.

For this, we require accurate altimetry that is recently published[12]. The White Terrace platform lies at 333 m a.s.l. with Aka Mānuka at a slightly higher altitude. These place the features within the levels covered by the shallow imagery of the line 3 northern stations. The northern station 19 is closest to Aka Mānuka and station 7 is a little further to Tarata spring. In **Figure 8**, it is possible to conjecture that stations 16–18 depict the Aka Mānuka spring at ~333–335 m a.s.l. The shallow interface superimposed over the deep hiatus would be how one imagines a Terrace geothermal spring and chamber appearing on Tromino imagery i.e., with the platform on either side of a void and a conduit connecting with a deep chamber, as shown in **Figures 9−18**. The White Terrace spring basin in **Figures 14** and **15** is ~10 m deep with a conduit below that. Bridget Lynne's Yellowstone work at Old Faithful Geyser with GPR reported the upper cavity beneath it occupies a cross-section area of ~225 m^2 with the roof 15 m below ground[33]. Given the Tarata eruption volume is from Hochstetter's measurements ≥3 million litres compared with Old Faithful Geyser erupting 0.014–0.032 million litres, the Tarata cavity plumbing ought to be larger than Old Faithful. However, the shallow imagery reflected redeposited ejecta clays and breccia and there is no clear evidence of either feature at the appropriate altitudes.

4.6. Post-eruption stratigraphy photography

Included are ten post-eruption photographs to aid stratigraphic interpretation in **Figures 9−18**. These prints are cropped and the lighting is corrected from the original fine-grain plate negatives.

Figure 9. The second 1886 govt team on location. Surveyor S. P. Smith is the fourth seated figure from the left, his later record in ethnography is also in question (Te Papa).

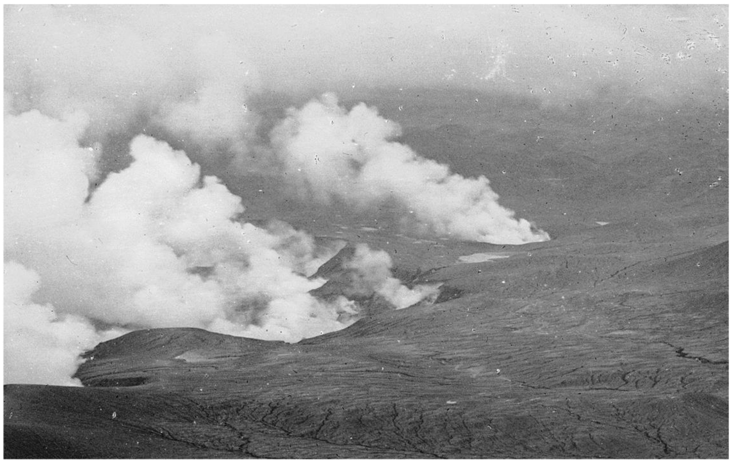

Figure 10. Looking southwest (from right to left at three o'clock) to Te Ngāwhā a Te Tuhi (Black Terrace), Black Terrace Crater (erupting) and Te Tuhi's Stream from Mt Tarawera (Te Papa).

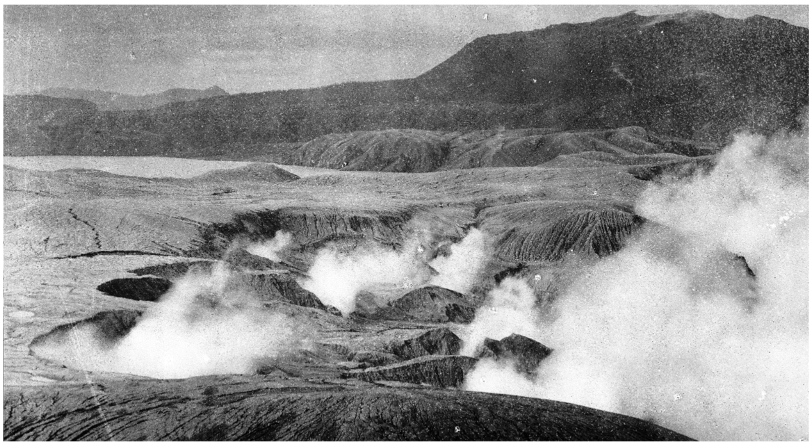

Figure 11. Looking toward the **Figure 10** camera position, the Tromino stations were centrally located (Te Papa).

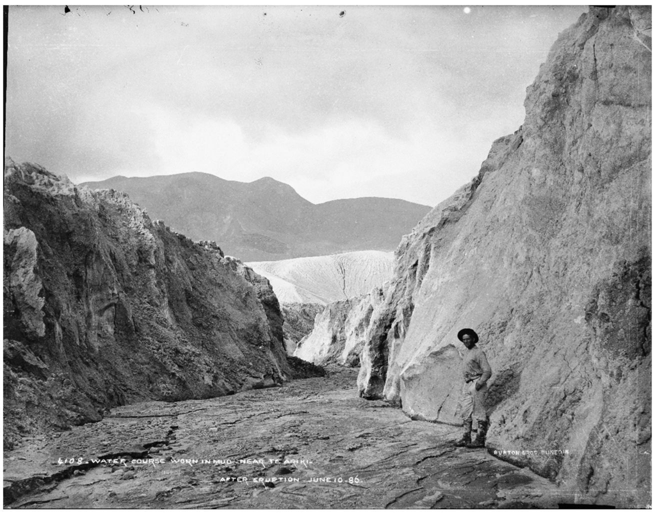

Figure 12. Lower Kaiwaka Channel soon after eruption, the ejecta depth of ~9 m is scaled from the figure (Te Papa).

Figure13. The ejecta was 16–18 m deep near Waimangu, note the figure for scale (Te Papa).

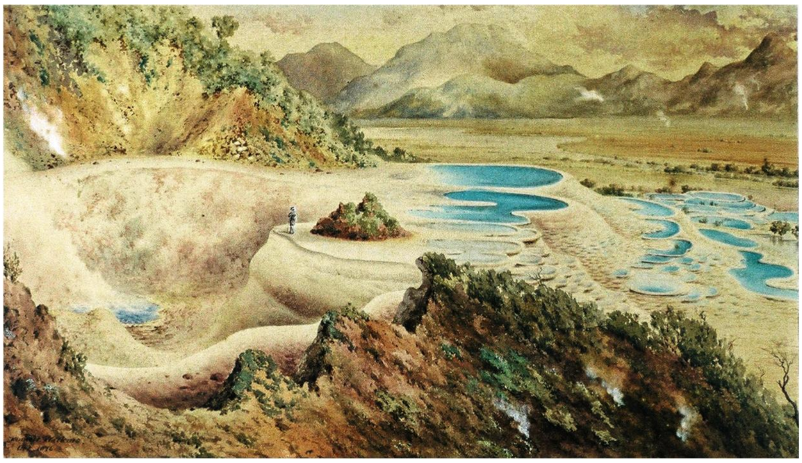

Figure 14. The Tarata Spring Basin (Kennett Watkins 1847–1933) courtesy of Stuart Burns, the Rotorua Energy Charitable Trust.

Figure 15. Taken from Te Tarata spring platform's north side shows the (emptied) basin and Lucy's Isle from below Watkins's position in **Figure 14** (MOTAT PHO-2018-22.23). The photograph is ascribed to Charles Spencer (1854−1933). The figures are darkroom embellishments by Spencer, adding retail sales interest.

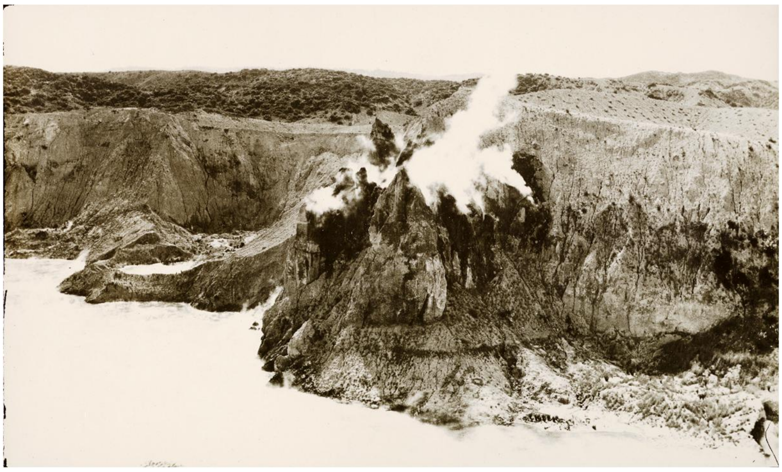

Figure 16. An unknown Rotomahana crater location, possibly from Te Rangipakaru looking northwest to the overflow and the Northern Pinnacles, where Keam opined the Rotomahana eruption may have commenced (Te Papa) Note the crater lake forming.

Figure 17. The Northern Pinnacles. The topmost pinnacle resembles **Figure 16** (Te Papa).

Figure 18. The Rotomahana photographers. Their leather saddlebags contain photographic and processing equipment (Te Papa).

4.7. The old and new paradigms and the overflow topography

While the line 3 imagery may not help triangulate the White Terrace or Aka Mānuka locations, it provides a strong empirical test of the old paradigm. Since 1887, the cardinal article of the Smith-Keam paradigm is that the old lake lies wholly inside the new lake and its overflow marks the exit of the old lake by the Kaiwaka Channel. While Smith et al.[22] reported a forty-foot (12.2 m) descent for the Kaiwaka, Keam[34] guessed it was 1–2 m only and the old lake was at 291–292 m a.s.l. If he was correct, the Kaiwaka Channel bottom should be visible in **Figure 8** at 290–291 m a.s.l. as the line 3 stations cross the location accepted for the Kaiwaka since 1886 i.e., at a third of the way along the one-mile descent[22]. It should be as obvious as the Black Terrace

Crater and Te Tuhi's Stream on the White et al.[20] 2020 lines 1 and 2, HVSR Vs = 400 v/s. It should be most visible from the medial stations which bracket the lake overflow down the claimed-Kaiwaka course.

A redeposit-stream bed interface here ought to be as visible in the Tromino passive seismic data as e.g., the British Geological Survey (BGS) HVSR profiles of a buried channel at Doncaster or at Shakespeare Beach, Dover, where the chalk bedrock surface underlies the beach sand deposits[35].

4.8. The Kaiwaka Channel course under old and new paradigms

The Hochstetter paradigm positions the Kaiwaka entry 440 m west of today's overflow. The Smith-Keam Kaiwaka entry is ~420 m south of this on an azimuth of ~174°. Greater accuracy is impossible as the Smith-Keam paradigm does not provide coordinates for the Tarata spring. From their claimed entry, the Kaiwaka course measures ~2133 m (1.33 miles) versus the known one-mile course—an error of 0.33 miles (33%). The Hochstetter paradigm correctly measures the Kaiwaka course at one statute mile. This further demonstrates the old paradigm's flaws and more evidence that the old lake cannot lie entirely within the new. Instead, the new lake overlaps the old lake, sharing a common north-western shoreline[14].

4.9. Line 3 findings in 2023 versus lines 1 and 2 findings in 2020

In 2023, under the old paradigm, we expect similar seismic evidence of the Kaiwaka Channel bed in line 3 data in **Figure 8**, as we see for Black Terrace Crater and Tuhi's Stream bed in White's **Figure 6**, line 1 HVSR Vs = 400 m/s stations[20]. The line 1 and 2 data were recorded on successive days and are regarded as repeatable (Tom Dronfield, personal communication, 2023). This increases confidence in the line 3 data taken the next day. The line 1 and 2 imagery show clear evidence of Black Terrace Crater. This was reported at 180 m diameter and in White **Figure 6** occupies ~200 m across the 1899150 to 1899350 eastings[20]. Interestingly, there are upstream (and probable downstream) acoustic contrasts showing Tuhi's Stream extensions at 1899050–1899150 and 1899350–18899430 eastings.

Hochstetter described Te Ngāwhā a Te Tuhi thus: 'A little beyond the lake, in a small side valley, lies the Atetuhi[36]; …'. In geomorphology, the term side valley has a precise meaning i.e., a valley close to mountains and with a low Strahler order[13]. The White line 1 and 2 acoustic imagery is more consistent with the Crater erupting through Te Tuhi's Stream bed than beneath Te Ngāwhā a Te Tuhi, its fountainhead in a side valley. The 1886 eruption sequence here proceeded upstream under Te Tuhi's Stream exit on 10 June, and under what became Black Terrace Crater on 31 July 1886. There were no further eruptions along Te Tuhi's Stream[13]. This is negative evidence for Te Ngāwhā a Te Tuhi surviving upstream from Black Terrace Crater.

White's acoustic basement extension in their **Figure 6** indicates the pre-eruption Tuhi's Stream bed, which emerged from Te Ngāwhā a Te Tuhi (Black Terrace) base at 310–315 m a.s.l. and descended to 303 m a.s.l. at its lake exit[20]. The seismic imagery shows it entered the Black Terrace Crater at ~308 m a.s.l. and exited at ~304–305 m a.s.l. White's second acoustic interface at 340–330 m a.s.l. probably indicates the post-eruption Tuhi's Stream in **Figure 10** herein, which eventually filled Black Terrace Crater, forming a pond on period mapping up to C. 1894[37]—after which time erosion infilled the pond and the crater was lost from cartography until 2017 when the PAWTL2 Project researched its location.

Returning to **Figure 8** herein, below the medial line 3 stations 9–12 there are no significant interfaces between the surface and 220–240 m a.s.l. At 220–240 m a.s.l., that acoustic basement is beneath the deepest ejecta and old lake topography and we are again likely descending into the noise envelope. This is strong empirical evidence that refutes the old paradigm. Given similar passive seismic evidence from lines 1 and 2 at the Black Terrace Crater site, White et al.[20] reported:

Our work here provides unequivocal evidence that the Black Terrace Crater is positioned along what is now the Lake Rotomahana access road…

The line 3 evidence at the overflow, taken at the same time on the same ejecta with the same shear wave velocity of 400 m/s provides equivalent evidence that the Kaiwaka Channel does not lie beneath the overflow. This velocity is commonly applied, e.g., by the British Geological Survey to identify a paleochannel[35].

Smith in 1887 opined the old Lake Rotomahana lay at 329 m a.s.l. and in 1894 revised this to 309 m[37]. Under the old paradigm, we might expect to also find stream bed evidence at this altitude in line 3. There is none. Nineteenth-century altimetry was primitive[12]. There is no evidence of the Kaiwaka flowing below the overflow. This finding empirically contradicts the central old paradigm tenet i.e., that old Lake Rotomahana lies entirely inside new Lake Rotomahana—for the assumed Kaiwaka location at the overflow caused the belief the old lake lay inside the eruption crater, after the 1887 claim by delineator Alpha Harding (1856–1945). This mistaken overflow topography has no implications for the new paradigm which holds the Kaiwaka lies 440 m west of the overflow.

4.10. Corroboration of the Kaiwaka Channel evidence

Passive seismic data are often validated by e.g., boreholes or another method. In the study of White et al.[20], there were no available borehole data and the Black Terrace Crater passive seismic data were validated by historic records, cartography, georeferencing, GPR and the author's seminal field research[18]. An average shear wave velocity of 400 v/s was applied and this married with the other data sources:

To convert the HVSR frequency peaks (f0) to depths, shear wave velocities of the strata must be measured or estimated. Here, an estimated average shear wave velocity (Vs) of 400 m/s was applied … to calculate interface depth (h). Independent depth measurements (such as drill hole data) are generally used to refine the Vs estimate[20].

As the ejecta around the Black Terrace Crater and the overflow were deposited at the same time i.e., 3:30–5:30 am on 10 June 1886 from the same eruption, and as the sites are1400 m apart, the Vs of 400 m/s validated at Black Terrace Crater is validated at the overflow.

4.11. Statistical significance testing

While the error margin with the acoustic basement in **Figure 8** practically precludes it being the Kaiwaka bed, statistical significance testing was undertaken on the passive seismic data from line 3. Given the 12 data points satisfy the prerequisites for Student's t-test, a one-sample t-test was applied to the data under both old and new paradigms. Here, we compare the mean from the sample stations to a fixed value, the reported channel altitude under both paradigms. The sample mean is 241.092 m, the standard deviation is 14.840 m and $n = 12$. The test result under both paradigms has a P value <0.0001. The difference between the acoustic basement elevation and the Channel elevations claimed under the old paradigm is extremely statistically significant. This leaves open the chance of machine malfunction or operator error. The author audited the 65 line 3 traces and the data appear internally consistent and comparable with similar traces from days one and two of the 2018 survey and with BGS findings. The only error noted in the raw data lay with isolated altitude readings which appeared to lead to repeat traces. These outliers would not affect the acoustic data gathering. The author experienced similar difficulty i.e., obtaining GPS satellites over the Rotomahana Basin due to the surrounding high country. Having excluded machine and operator error, we reject the null hypothesis that the Kaiwaka paleochannel is located under the Lake Rotomahana overflow.

5. Conclusions and discussion

The passive seismic evidence from the Lake Rotomahana overflow provides bright-line empirical evidence the upper Kaiwaka Channel does not lie at this location. This means it is either destroyed or lies at another location. Recent topographic research established that features adjacent to the Kaiwaka Channel survived the 1886 Tarawera eruption and lie buried outside the 1886 crater[14,38]. The Channel therefore must lie elsewhere.

The findings in this paper rely on empirical evidence i.e., the absence of evidence for the Kaiwaka Channel at its reported location. This could suggest an antimetabole: absence of evidence is not evidence of absence. However, in this case, we have empirical passive seismic evidence of the overflow stratigraphy (and that of Te Tuhi's Stream and Black Terrace Crater) that logically contradicts the old paradigm core. Moreover, there is positive survey evidence of the Kaiwaka Channel 440 m away to the west of the overflow[10,38]. This properly triangulates with pre and post-eruption topography[14].

In scientific paradigms, a genuine contradiction occurs only when experiments lead to contradictory results[39]. The empirical Kaiwaka Channel evidence from the 2018 line 3 data, validated by the repeatable line 1 and 2 findings, triangulation and statistical significance testing; forms a genuine contradiction of the Smith-Keam paradigm. It also furnishes strong empirical evidence verifying the Hochstetter paradigm. As Thomas Kuhn noted in 1962, such paradigm shifts are typical in science[40]. The adoption of the new Hochstetter paradigm will lead to better-directed field research around the Rotomahana Basin. It also allows the correct Māori placenames to be reinstated for sites around the basin identified in this research. Since the 1886 eruption, place naming has been largely suspended by traditional landowners. The long days of loss are at an end. The regional history can now be rewritten and consideration given to restoring the lost wonder to public view.

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Conflict of interest

The author declares no conflict of interest.

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