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The BLiSS model: Four-way triangulation of a buried 293-m horizon at the White Terrace site, Taupō Volcanic Zone

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Abstract

Following the 1886 Mount Tarawera eruption, the Pink and White Terraces, New Zealand's Eighth Wonder of the World, were widely assumed to have been destroyed and/or submerged in the new Lake Rotomahana, which formed in the Rotomahana crater. This research records how independent historical, geological, topographic, and geophysical evidence can be combined to solve a problem that none of these could solve alone. This study presents an interdisciplinary forensic examination of the Te Tarata (White Terrace) site using a four-way triangulation model, i.e., BLiSS—engineering boreholes, high-resolution light detection and ranging, passive seismic (horizontal-to-vertical spectral ratio) exploration, and Ferdinand Hochstetter's and Josiah Martin's terrestrial survey datasets (together with altimetry). The convergence of these four independent datasets is consistent with a structural boundary at 293 m above sea level, corresponding to the pre-eruption Rotomahana Basin surface. This research suggests that the 1859 Rotomahana Basin landscape, including the White Terrace location, remains largely *in situ*, enrobed with hydrothermal ejecta. These findings are consistent with Nairn's canonical eruption geometry of the Tarawera eruption. The pattern of fissures, vents, and surge directions that Nairn mapped across the basin was incapable of accounting for the destruction of the White Terrace at its surveyed location. The four research skeins conclude that at the White Terrace latitude, longitude, and altitude coordinates, the pre-eruption landscape remains largely unaffected by eruptive changes, apart from burial on the Lake Rotomahana floor, which was ejected over the coordinates by a sequence of hydrothermal eruptions. The White Terrace coordinates appear to be buried beneath tens of metres of soft hydrothermal sediments.

Keywords: Passive seismic; Boreholes; Light detection and ranging; Geomorphology; Terrestrial surveying; Taupō Volcanic Zone; White Terrace; Tarawera

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1. Introduction

The coupled 1886 Tarawera and Rotomahana eruptions were the greatest regional trauma in living memory. The Rotomahana eruption buried the Rotomahana Basin and its geothermal ecosystem under 50–70 m of tephra and "Rotomahana mud." Previous search efforts relied on the horizontal approximations of discredited historical records, and the geometry of the subsurface basin remains incompletely resolved.[1,2]

The fate of the White Terrace (also known as Te Tarata) following the 1886 Tarawera eruption has been regarded by many as resolved, with the feature assumed to be destroyed and/or submerged. Recent reconstructions of historical surveying and eruption historiography have reopened this question.[2-4] This paper extends that examination into the geomorphic domain through analyses of borehole, light detection and ranging (LiDAR), seismic, and terrestrial surveys. The White Terrace lay on the northern end of the Steaming Ranges before the eruption (Figure 1).

The residual northern Ranges are today termed the Tarata Peninsula on Lake Rotomahana. LiDAR shows some 23 erosion channels along this stretch of the Rotomahana littoral. Two have significant near-circular heads, and each has a neck with a tail configuration. These "teardrop" features coincide with the surveyed coordinates of the buried White Terrace spring. The western end of this coastal stretch coincides with the pre-eruption entry to the Kaiwaka Channel, draining the old lake. It is hypothesised that the littoral area shows evidence of discharge flows from the Tarata Spring in the hours following the 1886 eruption, leaving the eroded ground visible under LiDAR.

It is generally accepted that the Tarata Spring would almost certainly have kept pumping during and following the Rotomahana eruption:

Once established, a geothermal system is robust, and its total fluid up-flow at depth can become dynamically almost steady-state. It can survive major disruptions - even quite large volcanic eruptions through part of the same three-dimensional region that it occupies.[5(p30)]

This study adopted a vertical forensic methodology, treating the modern landscape as a series of surficial layers that reveal the buried 1859 landscape and its central enrobed feature, the White Terraces—the New Zealand Eighth Wonder of the World. Recent reconstructions have identified a laterally coherent subsurface horizon at 293 m above sea level (asl), derived from cartographic analysis, terrestrial survey, and altimetric studies. Herein, borehole, LiDAR, seismic, and survey data provide a four-way triangulation of this 293 m asl surface.

The objective of this study is to determine whether the independently derived 293 m asl surface can be resolved from passive seismic horizontal-to-vertical spectral ratio (HVSR) data calibrated with borehole data, and whether any surface manifestation can be obtained using LiDAR, aerial photography, and site visits.

Early surveys of the Rotomahana region provide a framework for subsurface reconstruction. Ferdinand Hochstetter[3] 1829–1884) performed large-scale mapping in 1859 using compass traverses, elevation estimates, photography, and lake levels, producing the earliest coherent representations of the pre-eruption landscape. Abbay[6] (1844–1924) reported on the White Terrace to the Geological Society in 1878. In 1887, Josiah Martin[7] (1843–1916) gave the Society what became the final and most detailed pre-eruption survey of the White Terrace. Following the 1886 eruption, Percy Smith[8] (1840–1922) undertook a plane-table-type survey of the devastated Rotomahana Basin, recording topographic relationships and elevations. Considerable geomorphological work has been undertaken by generations of investigators, notably by Ian Nairn and Ron Keam (1932–2019). Further topographic and altimetric data have recently been published by Bunn,[4,9,10] Warbrick,[11] and Bunn and Nolden.[3,12]

Reconciliation of these pre- and post-eruption surveys, when combined with modern cartography and altimetry, enables reconstruction of a consistent subsurface at ≈293 m asl. This surface is therefore not a geophysical inference but a geometrically derived boundary grounded in independent borehole, LiDAR, seismic, and survey data.

2. Methodology

The methodology of the BLiSS (engineering boreholes, high-resolution LiDAR, passive seismic [HVSR] exploration, and Ferdinand Hochstetter's and Josiah Martin's terrestrial survey datasets [together with altimetry]) model is summarised in Figure 2.

The model includes elements of volcanic and fluvial geomorphology, geomorphometry, and process geomorphology. To resolve the subsurface profile, four independent data streams were integrated:

(i) Engineering boreholes: Historical data from the abandoned 1960s Rotorua Lakes Hydroelectric Scheme, now largely forgotten and unexamined.
(ii) Surficial symptoms (LiDAR): LiDAR-derived digital elevation models of the Rotomahana Basin provide high-resolution terrain data from topographic mapping, identifying altimetry, surficial anomalies, enrobed high points, and drainage and erosion features.
(iii) Diagnostic imaging (passive seismic): HVSR analysis using Tromino™ unit seismic data to map impedance contrasts between the hydrothermal eruptive overburden and the lithified basement.
(iv) Topographic survey mapping: beginning with survey coordinates from the only pre-eruption terrestrial survey of the Tarawera massif, Lake Rotomahana, and the Pink and White Terraces by Hochstetter and followed by Smith after the eruption. Spatial relationships, topographic alignments, and

geomorphic features were examined using the Google Earth Pro™ virtual globe platform (Google Earth Pro, version 7.3.6, Google, United States of America), incorporating satellite imagery, digital elevation visualisation, elevation profiling, and intervisible line-of-sight measurements.

Figure 1. Digitally assisted colour reconstruction based on eyewitnesses, photographs, artwork, and the Waiotapu/Waimangu geothermal sites. The solar angle was selected to optimise the reflection and refraction of the White Terrace. Guide Alfred Warbrick is in the foreground. Based on Burton Brothers (1885), Museum of New Zealand Te Papa Tongarewa; digital reconstruction assisted by ChatGPT.

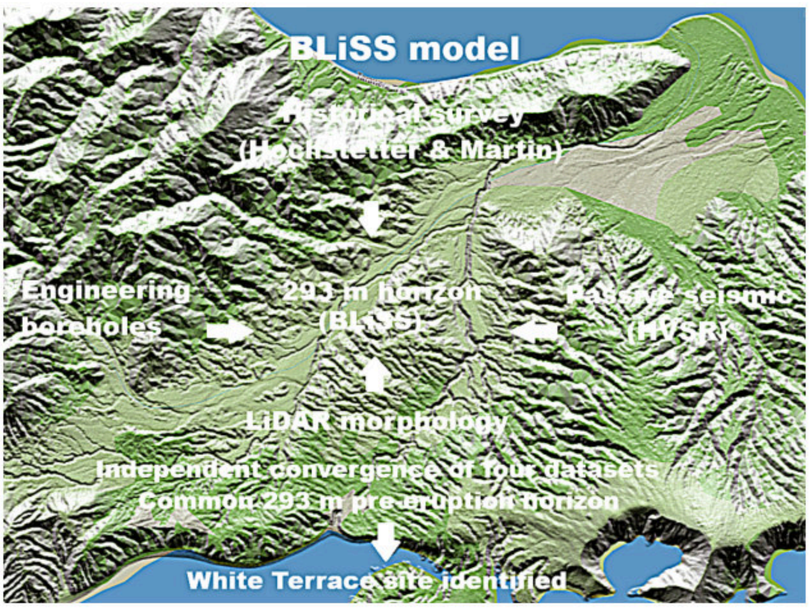

Figure 2. The BLiSS model. Based on data/map from Land Information New Zealand and Bunn.[1]
Abbreviations: HVSR: Horizontal-to-vertical spectral ratio; LiDAR: Light detection and ranging.

3. Results

3.1. Engineering boreholes

The first wing of the BLiSS model comprised borehole data. The engineering boreholes at Lake Rotomahana (notably BH1, BH4, and BH5) provided the stratigraphic floor for the study. These drillings were for the planned 1960s Rotorua Lakes Hydroelectric Scheme. The Rotomahana drillings would have been carried out by Ministry of Works civil engineers at Rotomahana and Tarawera in the late 1960s for the planned hydroelectric infrastructure. As stated, "details of the core samples, depth and thickness appear to have been lost when the Ministry of Works was privatised in 1988,"[13(appendix 4)]. Searches have failed to locate these borehole records in the New Zealand Borehole Database. Riley Consultants published some of the borehole schematics in their 2003 Rotomahana isthmus study,[13] including the key boreholes BH1, BH4, and BH5 in Figure 3.

The series of boreholes (BH1–BH5) at Rotomahana were intended to identify competent bedrock for dam or spillway foundations. BH1 and BH2 were drilled into the faulted terrain (*ft)* member (including redeposited Tarawera ash, scoria, and alluvium). BH3 and BH4 were on the Rotomahana ash/pumice (*arp*)–*ft* boundary, and BH5 was on the *arp* member (including Rotomahana pyroclastics and explosion breccia).[14]

This development was aborted after the Lake Manapouri hydroelectric scheme was abandoned amidst political and environmental controversy, resulting in the loss of the Rotorua drill cores and data. For forensic reconstruction, these borehole data are invaluable because they represent infrastructure-grade testing. The records indicate a consistent, narrow refusal range of 292–293 m asl. In the Rotomahana Basin, this horizon is significant. It matches other independent seismic and survey data discussed in **Sections 3.3** and **3.4**, and triangulates the lithified silica sinter of the pre-eruption landscape—the floor on which the White Terrace was anchored.

Three of the five Rotomahana drillings employed in this research were boreholes BH1 (292.7 m), BH4 (293.0 m), and BH5 (292.0 m). In **Section 3.3**, borehole BH4 helps calibrate the passive seismic surveying in the Rotomahana Basin. This borehole cluster indicates a competent, high-density horizon—the pre-eruption basin floor at 292–293 m asl. As discussed in **Section 3.4**, this level is 10 meters below the pre-eruption surface at 303 m asl of Lake Rotomahana. This 293 m horizon coincides with the pre-eruption depth-sounding of the old lake floor, i.e., 303 m – 9.8 m ≈ 293 m.[11] It is consistent with the latest published lake altimetry and the botanical reconstruction of its littoral.[9,11,12]

In Figure 4, BH4 predates Nairn's[14] 2002 stratigraphic mapping of the Rotomahana Basin by 35 years, and coincidentally locates on the boundary of two members. As discussed, Nairn marked these as *arp* and *ft,* which has implications explored in **Section 3.2**.

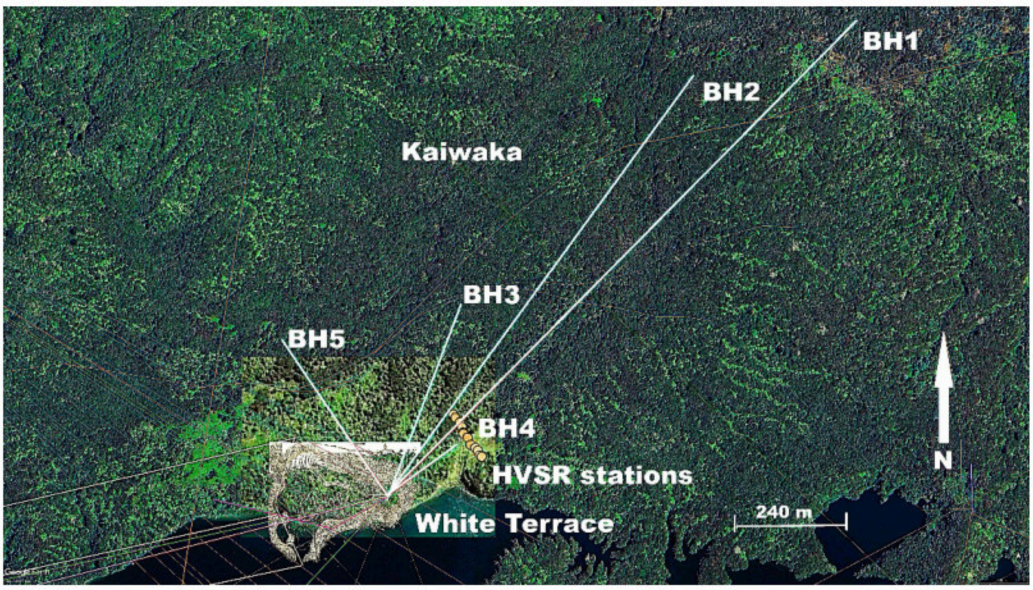

Figure 3. Boreholes BH1–BH5 over the isthmus, with the Line 3 horizontal-to-vertical spectral ratio (HVSR) stations and the White Terrace overlaid. Based on datasets from Land Information New Zealand, Riley,[13] Martin,[7] and Bunn.[1]

Figure 4. The northern Lake Rotomahana littoral, with passive seismic stations marked with orange discs. Borehole BH4 (the red diamond) and the surveyed location of the White Terrace (the white diamond) are marked. Map from Google Earth; marked based on data from Resource Potentials Pty Ltd, Nairn,[14] and Bunn.[1]

In Figure 4, borehole BH4 abuts the passive seismic stations discussed in **Section 3.3** and penetrates the same stratigraphy as the medial stations. From the boreholes' engineering rationale, it is reasonable to conclude that the three boreholes (BH1, BH4, and BH5), terminating at nearly identical depths, reached the same refusal horizon. BH4 at the *arp–ft* boundary was thus used to calibrate the seismic data, as BH5 reached the same refusal depth over the *arp* member. Additionally, the *arp* and *ft* members shared the 293 m stratum in BH1.

There is also supporting borehole evidence from nearby Lake Tarawera. In 1975, James Healy[15] (1910–1994) reported a 1970 borehole at the Tarawera River entry with 1886 Tarawera eruption ejecta down to 291–292 m. There was the same *ft* layer at the same level. This borehole was almost certainly another engineering borehole for the hydroelectric scheme.

In 2013, another nearby borehole was drilled beside the Tarawera River entry, BN-1000134 (Bore No. 3), which delivered a core containing 5 m of 1886 ejecta, i.e., from 293–298 m asl.[16] This was the same layer as the *ft* at Rotomahana and at the same 293 m level. Tschritter and White[16] reported that the second layer was Kaharoa pumice alluvium, some 7 m deep, dating from ≈1314 AD. This 293 m surface at Rotomahana seemingly matches or possibly extends 10 km north–east to the Tarawera River entry.

3.2. Light detection and ranging

The second wing of the BLiSS model comprised LiDAR to examine surface morphology and the potential for conformal draping of buried features. The Land Information New Zealand (LINZ) LiDAR accuracy is: vertical: ±0.20 m; horizontal: ±1.00 m. Boundary cells might have reduced accuracy, and 360° lighting was examined. The field investigations were conducted in 2017, as no research access is currently permitted.[17]

The land-search area for the White Terrace spring is located on the north-western Lake Rotomahana littoral.[18] It extends for 360 m, from the west at the true Kaiwaka Channel entry to the lake overflow. The area includes the channel, a gully, a cluster of features at the White Terrace coordinates, and the lake overflow. The littoral experienced ash falls of 45–55 m. Figure 5 shows its ash cliffs at ≈355 m asl.

3.2.1. Transect latitude, longitude, and altitude coordinates

For this vertical interdisciplinary analysis, the new Lake Rotomahana features were compared with those of the pre-eruption lake in Figure 6. The old lake elevation lay at

Figure 5. Ash cliffs near the White Terrace survey location. Photo by the author (2017).

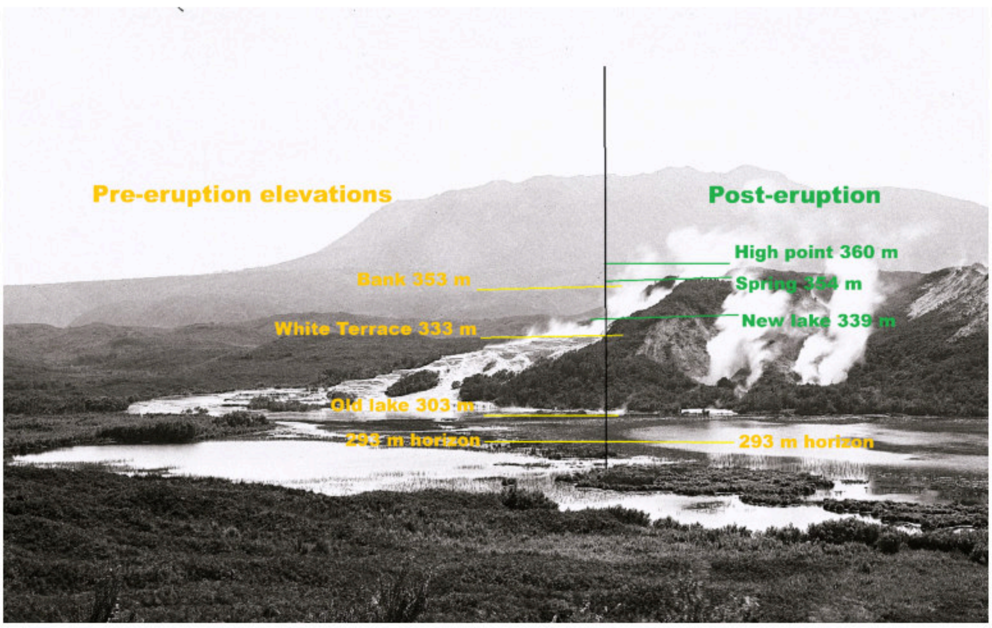

Figure 6. Rotomahana pre- and post-eruption elevations (approximate scale 1 cm = 10 m). Key pre-eruption elevations are shown in yellow. Post-eruption altimetry is shown in green. The optical axis is at an azimuth of 60°. Image from Burton Brothers (1885); data from Bunn.[1]

303 ± 1–2 m asl in its rise and fall, i.e., 55–59 m below the littoral today of 340–360 m asl.[9]

From Hochstetter's[3] 1859 survey and recent topographic analyses,[1,3,15] this study seeks to relate today's topography to pre-eruption topography, accounting for eruption-related changes. The Rotomahana Basin, before the eruption, had an M-shape, with the central Steaming Ranges lying north–south and flanked by lakes with lateral flats, leading to Kumete Ridge on the west and the Tarawera massif on the east.[1] The Ranges were bisected by the eruption rift, and its northern stump is termed the Tarata Peninsula. It provides a pre- and post-1886 navigation datum.[1] In Figure 1, the Ranges reached their maximum height behind the spring, at 358–360 m asl.[2] The embankment fretted, and the eruption would accentuate this. Hence, the highest point may refer to the Ranges today. The littoral is a narrow ejecta plateau. The ejecta depth is 40–60 m.[5,13]

Figure 6 contains the key reference altimetry. The old Lake Rotomahana was a shallow pond. Its modal depth was 1–2 m, with a maximum of 10 m.[9]

The Lake Rotomahana littoral was examined between longitude 176.4306° E and 176.4354° E. Erosional–depositional forms were examined for any exhibiting rimmed depressions, circularity, and a peak elevation. Drainage morphology was also considered. Two such sites (Sites One and Two) were identified with a wide gully.[17]

Before LiDAR, research was restricted to site visits and map contours. Figure 7 shows a nearby rill and illustrates the dense bush cover. This contrasts with the open plateau west of the spring. It has a 3–7 m drop from east to west. Figure 8 shows a surface sinter sample from the vicinity.

Figure 7. Upslope view of a rill near the survey location. Photo by the author (2017).

Figure 8. A siliceous sinter sample recovered during the 2017 fieldwork. Reprinted from Bunn.[17]

3.2.2. The Lake Rotomahana littoral: from the Kaiwaka to the overflow

In Figure 9, from west to east, firstly lies the true Kaiwaka Channel entry (yellow arrows) at 38.2556° S, 176.4317° E. The lake overflow is at three o'clock. In 1886, surveyor Percy Smith mistakenly associated this with the old lake overflow. His error was confirmed by recent seismic research and by Hochstetter's survey showing the old lake overflow lay ≈440 m west.[1,2]

3.2.3. The central gully

Centrally, a wide, shallow gully is visible (pink ellipse in Figure 10). Recalled from the 2017 fieldwork as the access path onto the plateau, the gully extends from 339 m to 348 m in Figure 10 at 38.2561° S, 176.4332° E.[17] Its significance was not recognised during the 2017 fieldwork.

To understand the likely formation of this gully, it is necessary to consider the events of the night of June 10, 1886, when the eruption occurred. The Rotomahana

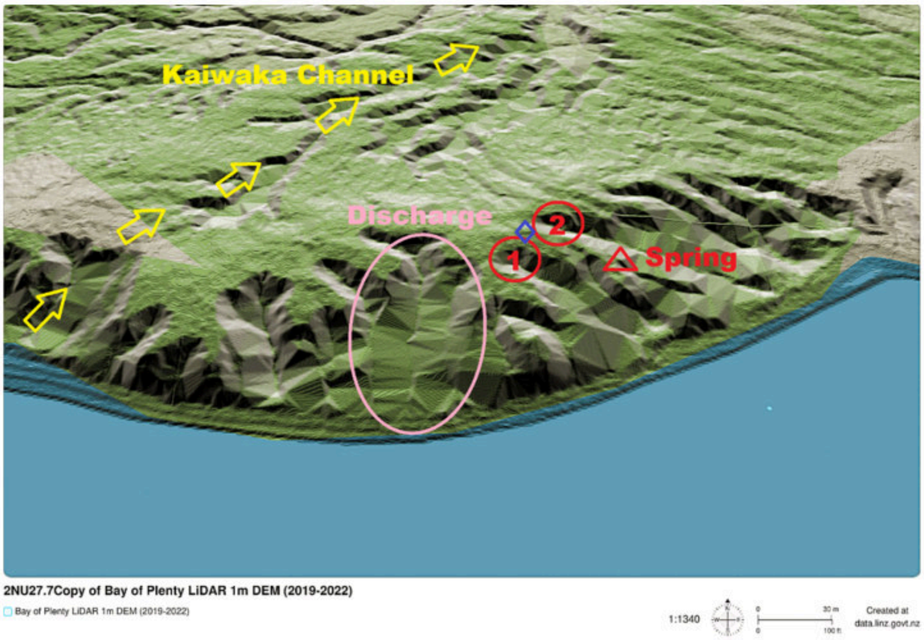

Figure 9. The littoral between the true Kaiwaka entry and the lake overflow. The image shows slope-aligned erosional forms, a central gully, and a cluster of features. Image from Land Information New Zealand; modified by the author.

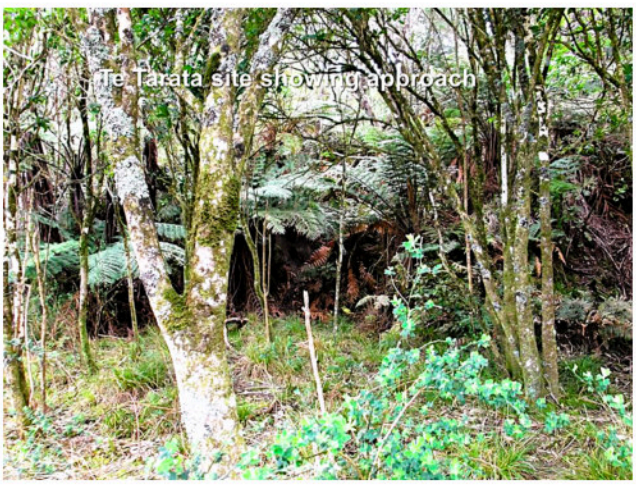

Figure 10. The wide, shallow gully entrance viewed from the shore in 2017. The Department of Conservation asked the field team not to disturb the vegetation at the entrance, to avoid attracting unwelcome visitors. Reprinted from Bunn.[17]

eruption phase lasted from approximately 3.20 a.m. to 5.30 a.m.[19] The lake bed underwent a sequence of hydrothermal eruptions after an initial eruption near the Waikanapanapa Valley. Based on Nairn's[19] research, the White Terrace would have received less exposure to the base surges. It received a series of hydrothermal deposits consisting of hot, dry, coarse and fine sands (Figure 11). Springs in the district became more active, as did the White Terrace spring. One base surge passed near the White Terrace. Through the Coandă and Venturi effects, together with Bernoulli's principle, this surge would have contributed to a pressure drop over the spring, almost certainly causing it to erupt.[1] The spring held approximately 14 ML[7] and had a maximum discharge rate of ≈4.5 ML/hr. It likely discharged 7–9 ML during the eruption and continued discharging for up to two hours afterwards. Its basin could sustain approximately five hours of continuous discharge at the maximal rate.[1,7]

We must now consider where these discharges travelled. Before these discharge data became available, the author presumed these flows travelled towards Lake Tarawera after reaching the Kaiwaka Channel (Figure 11). However, the Martin[7] dataset leads to a different conclusion (Figure 12).

Figure 11. Kaiwaka mid-section aligned at an azimuth of 75°, showing the sandy deposits. The camera is positioned between BH2 and BH3. Photo by the Burton Brothers, provided by Museum of New Zealand Te Papa Tongarewa.

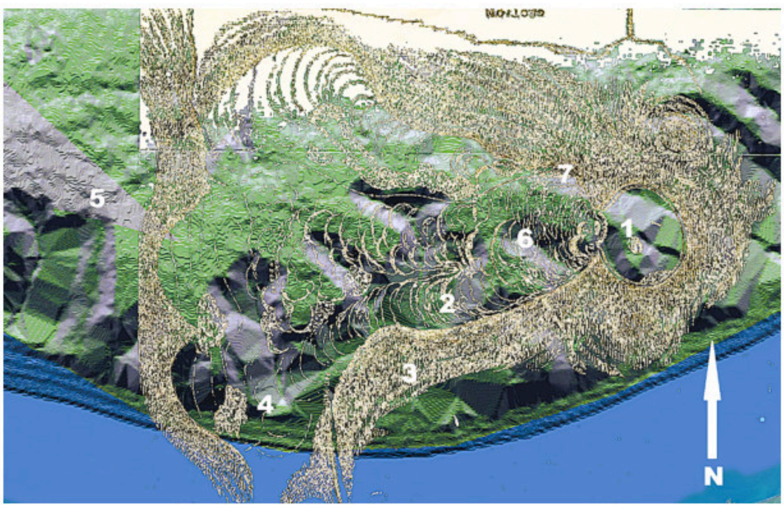

Figure 12. Martin's map of the White Terrace overlaid (to scale) on light detection and ranging of the lake littoral. Note: 1: Tarata Spring; 2: Hot Waterfall; 3: Gully; 4: Terrace discharge path; 5: Kaiwaka Channel entrance; 6: Site One; 7: Site Two. Based on the datasets/map from Martin,[7] Land Information New Zealand, and Bunn.[1]

Lucy's Islet divided the discharge into northern and southern streams. The main Terrace discharge was to the south. The southern flow would take the path in Figure 12 along features 1–6–2–3–4. Martin[7] connected this flow to sinter deposits reaching towards Ngahapu and Tekapo, as mapped by Hochstetter and August Petermann (1822–1878).

During the eruption, the discharge would be expected to sluice away the sandy deposits over the terrace. For up to three hours afterwards, the spring could continue discharging, with, e.g., the northern flows contributing to clearing the Kaiwaka Channel in Figure 11. The southern flows would help excavate the gully.

3.2.4. The eastern cluster

East of this main gully lies a cluster of features. The residual spring flows probably contributed to the cluster of Sites One and Two at the Tarata Spring coordinates. This section of the littoral is presented in Figure 13. The plateau slopes down to the lake by rills and small gullies, forming drainage channels under dense vegetation. These channels are shallow, linear, and confined, and cannot be easily negotiated on foot. Downslope, they can give way to broader sub-circular hollows.

The principal features analysed in Figure 13 are two circular hollows, morphologically distinct from the rill–gully network to their east and west. The local high point and the Tarata Spring coordinates are also presented.

3.2.5. Site One

In Figure 13, Site One corresponds to a teardrop-shaped composite depression at 38.2557° S, 176.4337° E. It consists of a near-circular head and neck, a rim, and an elongated tail. The near-circular head axis is misaligned with the main ovoid axis, indicating a composite rather than a purely erosional form. The sites' dimensions are in Table 1.

Table 1. Sites One and Two dimensions

Dimension	Site One	Site Two
Head diameter (m)	18	15
Head axis (°)	25	–
Rim elevation (m)	357–358	357–358
Head floor (m)	353	354
Rim extent (°)	250	150
Neck diameter (m)	13	11
Tail diameter (m)	21	22
Tail axis (°)	140	120

The Site One tail gradient is approximately 6.3°, suggesting that the depression may represent a compound landform, within which a sub-circular element is preserved. One interpretation is that the head represents a primary structure modified by downslope processes, including erosion, slumping, or partial infilling, which contributed to the present elongation.

The radial symmetry of the head is consistent with it forming by upwelling water under pressure, rather than from simple plateau drainage. The elongated tail and rim indicate post-eruption downslope movement of material towards ≈140° azimuth. Possible explanations include hydrothermal collapse or LiDAR processing artefacts. While these mechanisms could produce closed or partially closed depressions, the coherence and independence of the head argue against them. Another possibility is that the circular feature reflects modification or partial preservation of a hydrothermal structure. Given the historical significance of the White Terrace, this interpretation warrants consideration.

3.2.6. Site Two

In Figure 13, Site Two is positioned 11 m from Site One at 38.2555° S, 176.4339° E. It may represent a secondary hydrothermal vent or a different level of preservation or burial compared to the primary spring.

Site Two also consists of a teardrop-shaped depression with a circular head and neck, a rim, and a tail. The head has a near-circular head axis, less aligned than that at Site One, and a main ovoid axis, indicating a composite rather than a purely erosional form. The sites' dimensions are presented in Table 1.

While comparable, in Site Two, the head is less circular, the neck is less defined, and the rim is discontinuous over ≈150° before transitioning into diffuse slope morphology. Despite this, its proximity to the high point and its correspondence with Site One indicate that both occur within a shared micro-topographic domain rather than as independent, isolated forms. The paired occurrence is more consistent with variable expression of a localised geomorphic control acting on slope geometry and material heterogeneity than with simple erosion channels.

Although 23 drainage rills occur along the littoral, the remaining 21 lack a bulbous, circular head with a defined neck. Nonetheless, Sites One and Two could still be considered variations in architecture that were otherwise unremarkable. However, the proximity of two other features in this small area suggests the location is atypical for the littoral.

3.2.7. The high point

Given the ejecta enrobing the terrain, the highest point

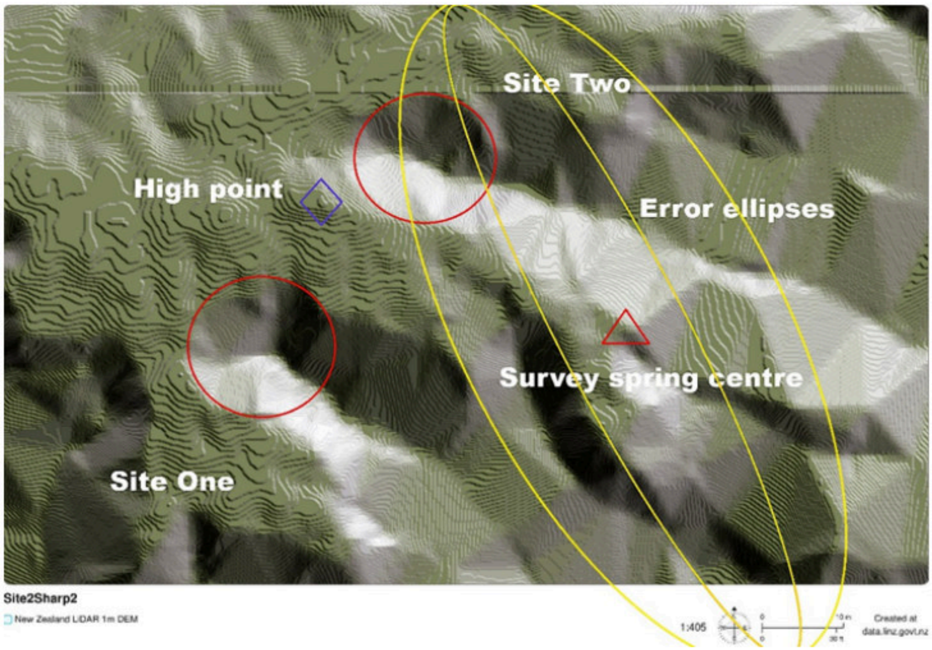

Figure 13. The cluster contains four distinctive features: two circular depressions (Sites One and Two), a littoral high point (blue diamond), and the survey location of the White Terrace spring (red triangle). The Tarata minimax survey error ellipses are marked (yellow). Based on data/map from Land Information New Zealand and Bunn.[2]

on the littoral may be associated with buried pre-eruption features. The highest point (360 m) in this part of the littoral is close to the two sites at 38.255556° S, 176.43377° E, with drainage channels to the north–west and the south–east. This point and its bi-directional drainage are unusual. This highest point is approximately 41 m north–west of the White Terrace. In relation to the spring coordinates, it is located near the north pyramidal peak at the spring platform entrance.

The LiDAR data from west of the spring coordinates provide further supporting evidence. The White Terrace was 240–249 m long. Fieldwork, confirmed by aerial photography, showed that the plateau west of the spring coordinates is poorly vegetated: "... low-density vegetation extending west from the ellipse. This follows the terrace orientation and length. It may indicate low-soil cover and/or shallow rock or sinter."[2(p25)]

3.2.8. White Terrace survey coordinates

The fourth feature in the cluster is the White Terrace spring location at latitude 38.2557° S and longitude 176.4342° E. In Figure 13, the red triangle indicates the spring, and the yellow ellipses indicate its minimax survey error ellipses. The major axis and azimuth of each method were in close agreement at ±52.9 m and 346.6°, respectively. There was an insignificant difference in the minor axis (±6.69 m versus ±17.45 m) at azimuth 76.6°. In Figure 13, the two error ellipses overlap with Site Two.

Hochstetter,[20] Petermann,[10] and Martin's[7] large-scale cartography recorded the White Terrace as a *sextant sector* shape, opening due West, with the spring platform at the apex (Figure 14).

Martin's[7] 1887 Terrace map had not been studied because it was behind a paywall, making it prohibitive for independent researchers. It now provides valuable details on the Terrace's shape, dimensions, area, slopes, construction, weight, geyser timetable, lamination, development, thickness, discharge directions, and volumetric flows.

The cluster sites are located close to each other. The edges of Sites One and Two are 11 m apart. The highest point is 41 m from the Tarata Spring. The spring is located 44 m from Site One and 34 m from Site Two. Site One and the Tarata Spring are located at the same latitude, i.e., 38.2557° S. They differ in longitude by only 0.0005376°, which is 47 m at this latitude. When the White Terrace was surveyed in 1859, latitude measurements were more accurate than longitude measurements.[20] Thus, the small difference in longitude is unremarkable.

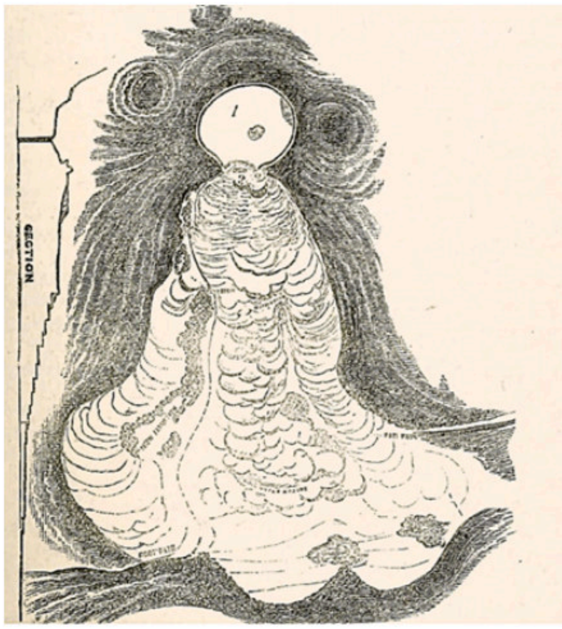

Figure 14. Martin's large-scale map of the White Terrace on an east–west axis. Reprinted from Martin[7].

3.2.9. Pareidolia risk

A hazard for investigators at the Rotomahana Basin is pareidolia—"the tendency to perceive meaningful spatial patterns where the underlying data are insufficiently determinate."[2(p15)] At Rotomahana, investigators face ambiguous visual information, cultural attachment, and confirmation bias. The author, at Rotorua, once diagnosed a government scientist with "Terrace Fever," a malady with no cure. An Australian explorer recently expressed the malady as "Touching history like that for the first time is addictive, and like no other feeling that I can think of."[21(p72)] Furthermore, it has been stated, "The best defence is forensic triangulation of terrestrial survey, cartographic, photographic and geomorphological evidence, to prove a reproducible consilience, with independent datasets converging on a single spatial solution..."[2(p30)]

To minimise pareidolia, the author examined the adjacent shoreline from longitude 176.4298° E to 176.4354° E and assembled terrestrial survey, cartographic, altimetric, aerial photographic, ground photographic, and geomorphological evidence. Additional data could be obtained through passive seismic tomography, soil sampling, and thermal measurements in future study.

3.2.10. Black Terrace, Black Terrace Crater, and the Pink Terrace

At Rotomahana, three Terraces comprised the New Zealand Eighth Wonder of the World, though the third, the Black Terrace, was often overlooked. For completeness, and because it is the only one of the three consistently identified by every investigator since 1886 as lying buried on land, its survey location is included in Figure 15. Hochstetter's[3,22] survey places the Black Terrace at 38.2574° S, 176.4165° E (circled in red), beneath the forest road. This road follows a major post-eruption erosion path through which 1886 ejecta were washed from the southern face of Kumete Ridge, and little of significance remains visible at the surface today.

East of the Black Terrace coordinates is a feature circled in blue in Figure 15. It is 34–49 m from Hochstetter's[22] survey location of the Black Terrace, which is within the expected accuracy of a compass survey. The feature is approximately 3 m deep. Given the erosion from Kumete Ridge, this is likely to be an excavation associated with subsequent forestry road construction. Farther east is the distal seismic station (circled in yellow) of Line 1, discussed in **Section 3.3**.

Continuing east along the forestry road is the Black Terrace Crater site (Figure 16). This site represents the final stage of the 1886 Rotomahana eruption and is well documented.[1,23] It is also affected by Kumete ejecta erosion, and the multiple small pits are likely to have resulted from processes such as fallen trees.

The Pink Terrace survey location is shown in Figure 17, at latitudes 38.2613° S–38.2623° S and longitude 176.4216°

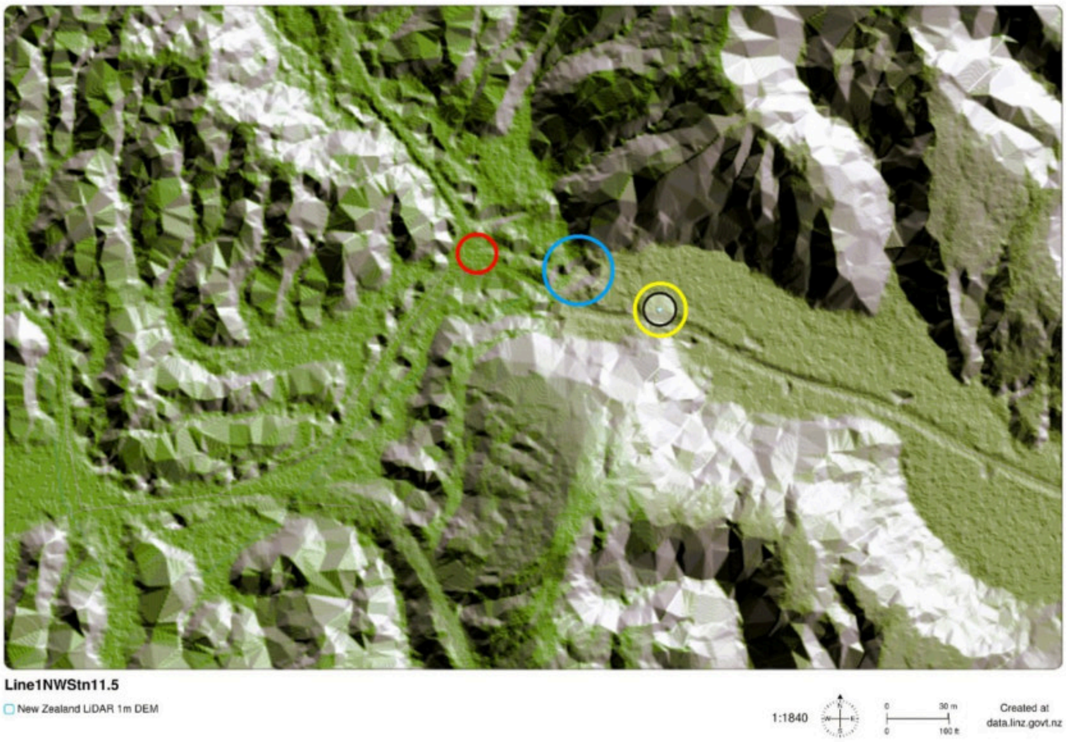

Figure 15. 3D light detection and ranging (LiDAR) of the Black Terrace location based on Hochstetter's [3] survey. The Black Terrace site is circled in red. A prominent feature located to its east is circled in blue. The distal seismic station discussed in **Section 3.3** is circled in yellow. Based on data/map from Land Information New Zealand and Bunn.[22]

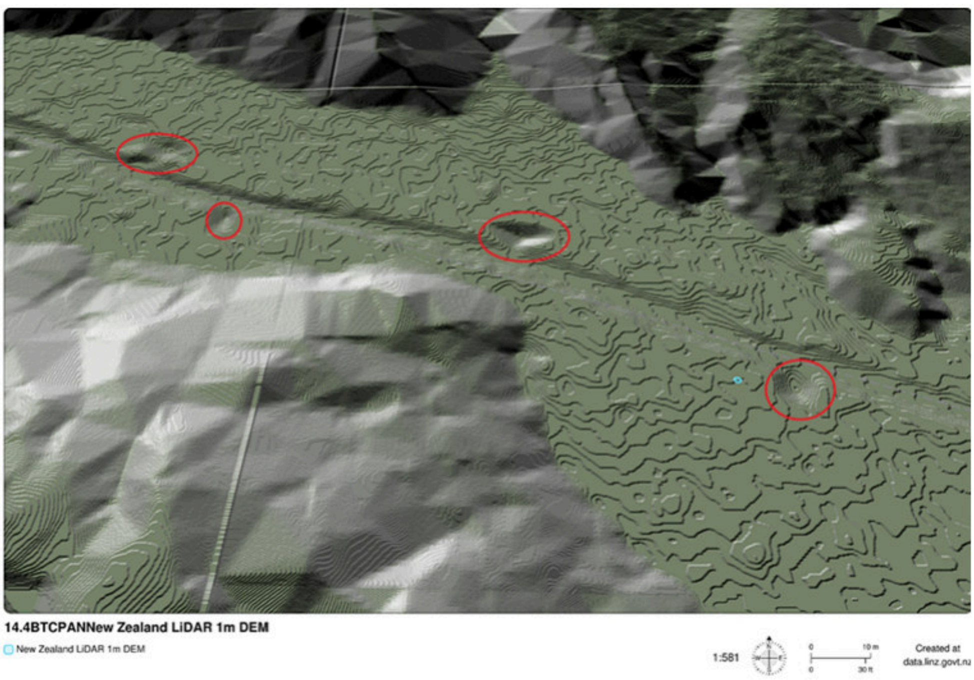

Figure 16. The Black Terrace Crater area, showing multiple small depressions. Based on data/map from Land Information New Zealand and Bunn.[22]

Figure 17. The Pink Terrace survey coordinates are circled in red. Based on data/map from Land Information New Zealand and Bunn and Nolden.[3]

E. The location is near the shoreline, where the cliffs reach 370 m in elevation. The Terrace Spring is at approximately 328 m; hence, the site is buried at a depth of approximately 34 m. LiDAR reveals little of significance at the surface.

3.3. Seismic

Horizontal-to-vertical spectral ratio analysis does not directly image lithology or geological units. Rather, it identifies acoustic impedance contrasts associated with changes in shear-wave velocity. Geological interpretation therefore depends upon independent calibration. In this study, calibration was provided by the engineering boreholes, particularly BH4, together with the mapped stratigraphic framework. Passive seismic technology originated in the 1970s.[24,25] The Tromino system is a cost-effective instrument that has been adopted in disciplines beyond geophysics and engineering. Its application to the Rotomahana Basin ejecta has been tested without borehole calibration.[23] In this study, it was applied to the detection of paleochannels, for which its proponents suggest that "passive seismic surveying for depth of cover mapping will likely become a common tool..."[25(p5)]

The HVSR resonance equation is:

$$fo = \frac{V_s}{4H} \quad (1)$$

where fo is the fundamental resonance frequency (Hz), V_s is the average shear-wave velocity of the soft layer (m/s), and H is the thickness of the layer above the impedance contrast (m).

3.3.1. Line 3 Tromino stations across the Lake Rotomahana overflow

Twelve Tromino stations in Figure 4 were placed along Line 3 on a north–west azimuth, crossing the Lake Rotomahana overflow. In the pre-1886 landscape, the line traversed the Orangiaho area, north of the White Terrace spring. Borehole BH4 lies adjacent to medial station 12 and is on the *arp–ft* member boundary.[14]

At Rotomahana, depth estimates were derived using the quarter-wavelength approximation. Two velocity models were evaluated: 200 m/s for near-surface materials and 400 m/s for more compacted deposits. Formal reinversion was not possible because the archived field records are no longer available. The research therefore adopted the next-best geophysical approach: recalibrating the depth conversion against an independently constrained borehole horizon and presenting bounded velocity models to bracket the expected subsurface conditions. The two models were originally derived from advice provided by Resource Potentials Pty Ltd™ for Tromino datasets, based on the anticipated presence of sand- and clay-rich ejecta. They are also consistent with British Geological Survey usage of a similar velocity range for another buried paleochannel.[25,26]

In Figure 18, comparison with the BH4 refusal demonstrated that the original velocity conversion underestimated the reflector elevation. The conversion was therefore calibrated in the shallow velocity domain against the independently constrained BH4 refusal horizon. Because HVSR depth conversion depends on assumed shear-wave velocity, two independently calibrated velocity domains were evaluated rather than adopting a single constant shear-wave velocity. The shallow model (approximately 185–200 m/s) is constrained by the BH4 refusal horizon at 293 m asl. For example, at station 12, $V_s = 4 \times 0.94\ (\pm 0.17) \times 49.3 = 185.4$ m/s

Below this boundary, the conversion uses the independently calibrated deeper velocity (approximately 400 m/s), derived from the Black Terrace Crater model.[22,23] Rather than implying a unique velocity solution, the paired models define a plausible range of subsurface conditions. The persistence of the principal reflector across this range increases confidence that the interpreted horizon is not an artifact of a particular assumed velocity.

Once converted, the 293 m asl impedance boundary corresponds spatially with the mapped contact between *arp* and *ft* identified by earlier geological mapping.[14] The convergence of passive seismic data, borehole refusal elevations, and mapped stratigraphy supports interpretation of the 293 m asl horizon as a significant regional subsurface beneath the Rotomahana Basin. The absence of a buried Kaiwaka paleochannel beneath Line 3 at this depth is also a positive geological result, because the same survey programme resolved a buried paleochannel along the Black Terrace Stream.[22,23,27] Figure 19 shows the upper reaches of the narrow, shallow Kaiwaka Channel as they existed before the 1886 eruption.

3.3.2. Line 1 at The Black Terrace and Black Terrace Crater

The Tromino dataset also included an (unpublished) Line 1 shear-wave velocity chart based on a 200 m/s model for the area of the previously identified Black Terrace Crater location, shown westward along the littoral in Figure 16.[22,23,27] The site is located within the major erosion pathway descending from Kumete Ridge. The pre-eruption surface was at 310–315 m asl, with Black Terrace Stream descending to enter the lake at 301–303 m asl. The Black Terrace Crater was the final phase of the 1886 eruption.[22] A shear-wave velocity of 400 m/s was used to identify the crater elevation.[23]

Unlike at the overflow, the seismic data at this location provide evidence of a buried paleochannel (Figure 20). This interpretation is supported by ground-penetrating radar data: "... a western section located to the west of the inferred Black Terrace Crater margin that contains shallow graded beds dipping from west-to-east with shallow, superimposed pond-like features..."[23(p3)]

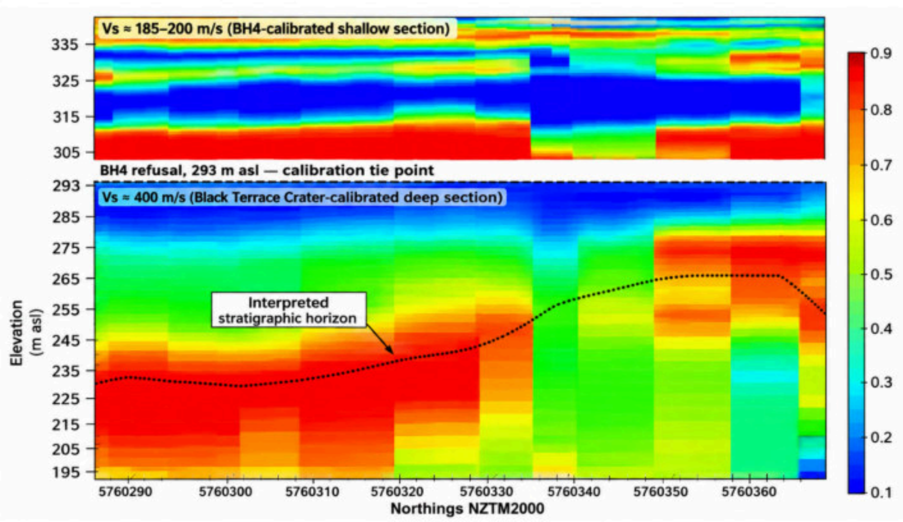

Figure 18. Two-layer horizontal-to-vertical spectral ratio (HVSR) depth conversion model for Line 3 (Pink and White Terraces). Above the BH4 refusal horizon (293 m above sea level [asl]), depths were converted using a BH4-calibrated shallow shear-wave velocity (V_s = 185–200 m/s). Below this horizon, depths were converted using an independently calibrated deep velocity (Vs = 400 m/s), derived from the Black Terrace Crater. This stratigraphically constrained velocity model replaces a single constant shear-wave velocity assumption and provides a more robust basis for interpreting subsurface boundaries. The two-layer velocity model reflects the distinct geological character of the lake sediments and underlying volcanic crater fill. Data sources: Resource Potentials Pty Ltd, Bunn.[27]

Figure 19. The pre-eruption upper reaches of the Kaiwaka Channel. Photo by the Burton Brothers, provided by Museum of New Zealand Te Papa Tongarewa.

This comparison provides an internal calibration within the same survey programme. The Black Terrace Stream section in Figure 20 demonstrates that a paleochannel can be expressed in these passive seismic data, whereas the Rotomahana overflow line does not show equivalent features. As previously noted:

> 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.[27(p14)]

Figure 21 helps explain the historical confusion between the present-day overflow and the pre-eruption Kaiwaka Channel. It shows that the overflow is a low-lying strip between the surge current to the west and the northern stump of the Steaming Ranges to the east. The area was sheltered from much of the hydrothermal activity by the Steaming Ranges. It is located adjacent to the west-facing bay, recently identified as the pre-eruption Ngāhutu Valley, the widest and deepest valley along the Ranges.[10] After the eruption, ash was eroded from the now-submerged valley, leaving a natural low-lying area. Occam's Razor suggests that this geomorphological setting provides a parsimonious explanation for the present-day overflow, 140 years after the eruption.

3.4. Hochstetter's 1859 terrestrial survey

This section summarises the terrestrial survey mapping conducted by Ferdinand Hochstetter in 1859.[1,4,20] The mapping provided the only pre-eruption survey of the Tarawera massif and the old Lake Rotomahana and was the first survey of the Pink and White Terraces. Hochstetter became known as the "father of New Zealand geology." He used vernier compasses: a 10′ instrument suitable forgeological mapping and reconnaissance surveys, and a 2′ instrument for more precise surveying and geologicalmapping. He also conducted the first barometric survey of approximately 200 high points on the North Island, including the first altimetry surveys of Lakes Tarawera and Rotomahana. His survey data were digitally repatriated in 2010 by Sascha Nolden, after which Nolden and the author reconstructed the survey from 2016, completing six iterations by 2023.[3] Although surveyors from Rotorua and Taupō assisted with earlier iterations,[28] no successful replication of the Bunn and Nolden[3] survey reconstruction has yet been achieved. The author has continued to apply Hochstetter's survey to topographic, altimetric, and demographic questions.[2,4,10,29]

The significance of Hochstetter's[3] survey is that it challenges the generally accepted interpretation of the 1886 Tarawera eruption. This interpretation holds that the Pink and White Terraces were destroyed during the eruption and that their former sites now lie beneath the new Lake Rotomahana. Bunn and Nolden's[2,12] reconstructions of Hochstetter's survey instead place the White Terrace location on land, raising the possibility that the site could be excavated.

3.4.1. Pink and White Terraces location

Hochstetter's[3] survey bearings uniquely resect the

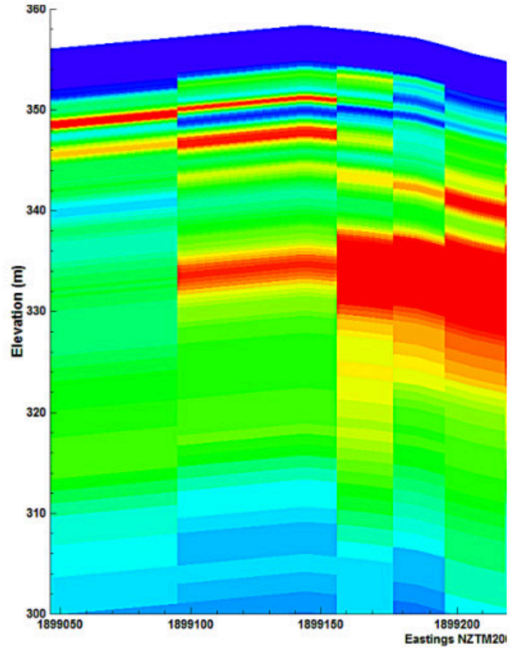

Figure 20. Detail of unpublished Line 1 shear-wave velocity of 200 m/s image showing the buried Black Terrace Stream paleochannel. Data sources: Resource Potentials Pty Ltd, Bunn.[27]

Figure 21. The northern Steaming Ranges, lake overflow, and single surge current. Based on map/data from Land Information New Zealand, Nairn,[14] and Bunn.[1]

coordinates of the Pink and White Terraces. His survey diary and folio data, together with later pre-eruption reports of the Terraces, enable the latitude, longitude, and altitude of the White Terrace to be determined with reasonable accuracy. The LiDAR and geospatial analyses, together with Google Earth–based geomorphological mapping, are a significant advance in the study of the present-day surface at Rotomahana.

The altitude of the White Terrace site has recently been refined by coupling Martin's[7] 1885 dataset with Hochstetter's[3] 1859 data. This analysis indicates that the Steaming Ranges embankment rises approximately 46–51 m above the lake. Martin's[7] recorded White Terrace height of approximately 30.5 m is therefore adopted. The Terrace was approximately 240–249 m long, with an overall slope of approximately 7°, corresponding to a height of 30.5 m. As the Terrace matured, the accretion of silica sinter formed a massive and stable structure that was more resistant to erosion than the surrounding littoral.

In Figure 22, Hochstetter's White Terrace site is marked according to the final, sixth iteration of the Bunn and Nolden[3] reconstruction. This site is located using his original 8.1670° bearing (22.2070° after declination adjustment) from Observation Station 21 to the centre of Tarata Spring. The bearing was plotted on Google Earth using Hochstetter's[3] April 30, 1859, survey map and then georeferenced across the basin. The mapped location of Tarata Spring was superimposed on the bearing, confirming the consistency of the bearing with the spring location and its latitude.

The Hochstetter/Martin/Burton geometry predicts a present-day White Terrace spring interface at an elevation of 331–335 m asl and an embankment interface at 353–356 m asl, without allowance for subsidence. This implies that the embankment surface may be close to the present-day ground surface and could therefore be accessible for site investigation. Although regional subsidence occurs throughout the Taupō Volcanic Zone, generally estimated at 5–20 mm/year, no significant ground deformation specific to the Tarawera–Rotomahana area has been observed (Brad Scott, personal communication by email, Dec 12, 2025).

For compass survey accuracy to be statistically and practically significant, an error of ±1°–2° is considered appropriate.[30] To assess whether Sites One and Two overlap with the centre of the Tarata Spring, the angular differences between their locations and the bearing from Hochstetter's Observation Station 21 were examined. Observation Station 21 was approximately 1,737 m from the target locations. The angular difference between Site One and the Tarata Spring bearing is 1.286°. The difference for Site Two and the high point is smaller. These locations therefore fall within the acceptable survey-error margin and may overlap. They may reflect surface remnants of the Tarata Spring.

3.4.2. The White Terrace mass and implications

No historical boreholes were drilled at the White Terrace. This section presents the first estimate of the mass of the White Terrace sinter, derived from four independent lines of evidence: the mapped sinter surface area, the Terrace age, published sinter accumulation rates, and contemporary eyewitness accounts of rapid sinter encrustation.[1,7,10,11,27,31]

In Table 2, the White Terrace area was reported by Hochstetter[20] and Abbay[6] as 3 acres 12,140.6 m^2) and later by Martin[7] as 7.25 acres (29,339.75 m^2). For comparison, this study measured the area from historical large-scale maps using the polygon tool in Google Earth Pro.[10] The 1859 Hochstetter[10] map yielded an area of 46,213 m^2, while the 1861 Petermann[10] map yielded 57,289 m^2. These two map-derived estimates may better represent the likely original area and were therefore used throughout this analysis.

Table 2. Estimates of the White Terrace dimensions

Dimension	Hochstetter	Abbay	Martin
Year	1859	1875	1885
Height (feet)	~80	~100	100
Apron (feet)	–	–	800
Terrace (feet)	–	–	800
Spring (feet)	60–80	90–100	165–200
Rim (feet)	–	4-6	6
Platform (feet)	–	–	130
Cliff (feet)	30–40	~50	15–50
Ruihi (feet)	12	12	10
Ranges (feet)	200	–	–
Area (acres)	3	~3	7.25

Notes: Hochstetter was perhaps more interested in the spring physics than the Terraces. Abbay appears to have followed Petermann's map. Martin's evidence indicates a clinometer and most likely the stepping method or a steel tape.

In the absence of borehole data, sinter thickness is estimated from the age of the White Terrace spring and published silica-sinter accumulation rates. The White Terrace spring emerged approximately 5000 BCE, providing approximately 7,000 years for potential sinter accumulation before the 1886 eruption.[32,33] Published accumulation rates for active silica-sinter systems typically range from 1–5 mm/year,[7,31] yielding a thickness of 7–35 m. Cooper's eyewitness account provides evidence of more rapid deposition:

> The process of incrustation… is so rapid that anything left on the edge of one of the baths where the water will be constantly flowing over it, becomes completely encrusted in a few weeks.

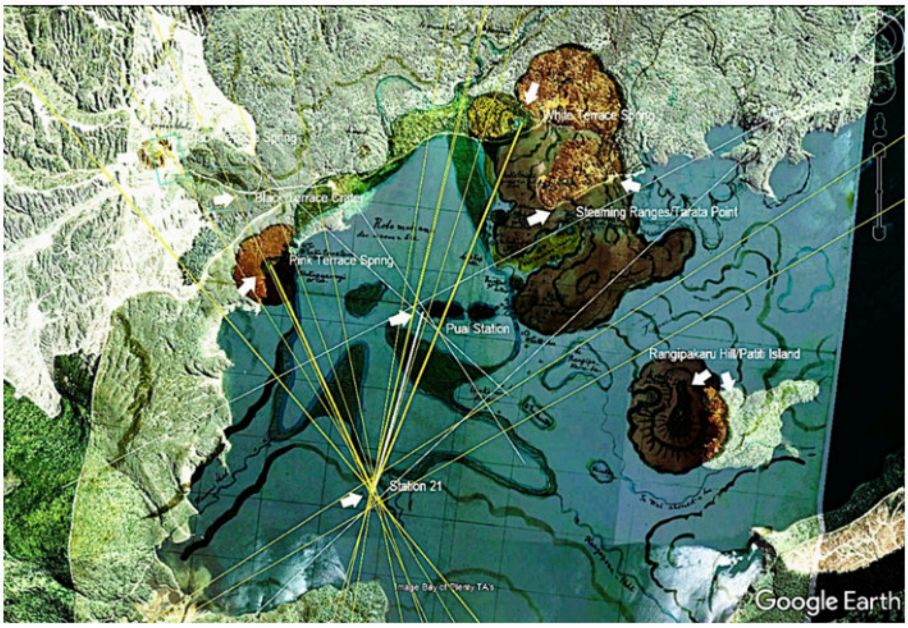

Figure 22. Hochstetter's survey map and bearings georeferenced over Google Earth. Maps from Google Earth and Bunn and Nolden.[3]

> A young duck was once found here, in a state of perfect preservation, entirely covered as with a coating of hoarfrost with the deposit of the waters…[11(p32)]

Cooper's observation that complete encrustation occurred within "a few weeks" (3–6 weeks) implies local sinter growth rates of 5–17 mm/year in active flow zones. Applying a conservative whole-Terrace average growth rate of 3–10 mm/year over 7,000 years yielded a thickness range of 21–70 m, with a modal estimate of 35 m based on a growth rate of 5 mm/year. The lower bound of 21 m is consistent with Hochstetter's[20] reported Great Geysir shaft depth of 75.5' (≈23 m). Hochstetter also noted that the thickness of the Great Geysir deposits was 19.4 m (762"). A lower thickness estimate would account for periods when the Terrace remained dry or when the flow rate fluctuated.[7]

The White Terrace sinter was considered an active opal-A deposit at the time of the 1886 eruption. Published bulk density values for opal-A siliceous sinter ranged from 1,500 kg/m^3 to 1,800 kg/m^3, with a mean dry density of 1,650 kg/m^3. The porosity of opal-A sinter was approximately 20%, corresponding to a water-saturated density of approximately 1,850 kg/m^3. Both dry and saturated masses are reported in Table 3; the Terrace sinter would have been water-saturated under active-flow conditions.

The White Terrace mass is calculated as:

$$Mass = Area \times Thickness \times Density \quad (2)$$

Table 3 presents results across both area estimates and three thickness scenarios, for dry and saturated conditions.

The gross mass of the White Terrace sinter was estimated at 1.6–6.6 million tonnes (dry) or 1.8–7.4 million tonnes

Table 3. Estimated gross mass of the White Terrace sinter (tonnes) across three thicknesses

Parameter	21 m (3 mm/year)	35 m (5 mm/year)	70 m (10 mm/year)
Hochstetter dry (t)	1,601,000	2,669,000	5,338,000
Hochstetter wet (t)	1,795,000	2,993,000	5,987,000
Hochstetter wet + Basins (t)	1,833,000	3,031,000	6,025,000
Petermann dry (t)	1,985,000	3,308,000	6,617,000
Petermann wet (t)	2,226,000	3,710,000	7,421,000
Petermann wet + Basins (t)	2,264,000	3,748,000	7,459,000

(wet), with a modal estimate of 3.00–3.75 million tonnes (wet). Water saturation increased the dry sinter mass by 10%–12%. Including an allowance for the platform and terrace basins, the gross mass range was 1.83–7.46 million tonnes (wet). The major source of uncertainty is sinter thickness, which spans the estimates by a factor of four. The sinter was almost certainly thickest in the upper-middle section, given the deposition rates, temperatures, and pre-spring topography of the Steaming Ranges.

In Table 4, the mass of the White Terrace sinter deposit is compared with other structures. A concrete building with an approximately 50,000 m^2 footprint and 21 m height, along with an average density of 200–300 kg/m^3, would weigh approximately 300,000 tonnes. The White Terrace was estimated to weigh 5–6 times as much as a concrete structure of similar size.

Table 4. Mass comparison with familiar structures

Structure	Estimated mass (t)
Sydney Opera House	≈161,000
Empire State Building	≈365,000
White Terrace, modal, wet	2,000,000–4,000,000
Great Pyramid, Giza	≈6,000,000

At the central wet-mass estimate of approximately 3 million tonnes, the White Terrace would have had about half the mass of the Great Pyramid of Giza. Given this inferred mass, the Terrace constituted a substantial siliceous body that is unlikely to have been wholly transported during the eruption. From an engineering perspective, the Terrace spring would have acted as a pressure-release valve; however, the 1886 hydrothermal eruptions were likely sufficiently energetic to overwhelm any effective pressure reduction provided by the spring.

After the initial phreatomagmatic eruption(s), which Keam[33,34] posited occurred near the Waikanapanapa Valley, groundwater would have rapidly flashed to steam as pressure decreased toward atmospheric conditions, generating a sequence of hydrothermal eruptions that culminated in the Black Terrace Crater eruption on July 31, 1886,[22] As these eruptions progressed northward and westward towards what became the crater rim, i.e., today's lake shore, their intensity likely diminished, with the final eruptions failing to reach the southern edge of the White Terrace. By this stage, the basaltic magma body had already expended much of its primary mechanical energy in June.

4. Discussion

The spatial validity of the White Terrace reconstruction rests on the convergence of four independent lines of evidence. Each dataset compensates for limitations in the others, providing mutual reinforcement. This four-way triangulation supports the conclusion that even 140 years of burial may not entirely obscure the structural integrity of the 1859 landscape when appropriate diagnostic tools are applied.

4.1. Boreholes

The engineering data from the 1960s Rotorua Lake Hydroelectric Scheme boreholes provide an important independent subsurface constraint. Unlike standard geological probes, these boreholes were drilled as part of an engineering feasibility study for infrastructure development. They all exhibited refusal at 292–293 m asl. One interpretation is that refusal marks the depth at which the heavy industrial drilling encountered material too competent to penetrate further, potentially corresponding to or lying close to the competent foundation beneath the White Terrace.

The political controversy that halted the project effectively preserved these subsurface data. Today, they provide an important link between the 1859 survey and modern passive seismic observations, supporting the possibility that elements of the pre-eruption landscape of the Rotomahana Basin survived the 1886 eruption.

4.2. Light detection and ranging

With LiDAR, researchers can simultaneously consider the pre- and post-eruption landscapes as a reworked, hybrid environment and examine the sequence and effects of the eruption. The littoral contains a central gully and a cluster of features that are consistent with findings from Hochstetter's[3] and Martin's[7] surveys. The Kaiwaka feature, gully, and Sites One and Two are consistent with continued spring discharge during and after the eruption. The evidence presented in Figures 12, 13, and 18 indicates that a coherent pre-eruption geomorphic surface persists beneath the northern Rotomahana littoral at approximately 293 m asl and corresponds spatially with the reconstructed White Terrace locality.

An erosional model is insufficient to account for the observed littoral morphology. The Kaiwaka feature, gully, cluster, spring location, and high point are more consistent with a model involving fluid discharge or other substrate modification.

This LiDAR and topographic evidence provides a basis for future research in the Rotomahana Basin and may help address the evidentiary requirements identified by the traditional landowners. If and when fieldwork resumes, the mapped features should facilitate targeted field inspection and soil sampling.

4.3. Seismic

The spliced shear-wave velocity data from the overflow at 200 m/s and 400 m/s provide no evidence of a buried paleochannel and are consistent with the borehole, survey, and LiDAR findings. As expected, shear-wave velocity increases with depth, reflecting the transition from loose, recently redeposited ejecta near the surface to more consolidated material or older ejecta at depth.

The seismic evidence supports the presence of a subsurface boundary near 293 m asl. The correspondence between the HVSR impedance boundary and consistent borehole refusal elevations across five widely spaced sites indicates that this surface is regionally stable. Its coincidence with the mapped *arp–ft* boundary suggests that the interface may represent a buried pre-1886 geomorphic surface, a major stratigraphic contact, or the upper surface of older, consolidated terrain beneath younger Rotomahana infill deposits. Although its precise lithological character remains uncertain, the surface appears sufficiently coherent to provide a useful regional datum for future geomorphological and geophysical interpretation.

No persuasive evidence of a preserved Kaiwaka paleochannel was identified along Line 3. This finding is consistent with Hochstetter's[3] survey, which places the Kaiwaka approximately 440 m westward along the littoral. The results support the value of integrating passive seismic HVSR profiling with independent borehole elevations and existing stratigraphy.

4.4. Terrestrial survey and altimetry

The 1886 mud deposits mantling the present-day landscape are thinnest over the 360 m high point and thickest over the 293 m basin floor, where they reach approximately 67 m. This differential deposit thickness, together with long-term variations in compaction, may account for the present-day "surface symptom" of the 360 m topographic dome. The findings presented here are mutually reinforcing. The borehole, LiDAR, and passive seismic HVSR data, together with Nairn's[14] stratigraphy, Hochstetter's[3] survey, and Martin's[7] survey, indicate that elements of the pre-eruption landscape in parts of the Rotomahana Basin may have survived beneath the 1886 Rotomahana deposits.

The likely survival of the White Terrace location can be deduced from a combination of circumstantial and negative evidence. One indicator is the absence of post-eruption siliceous sinter.[10] If the Terrace had been destroyed and incorporated into the eruption deposits, some redistribution of its sinter might be expected across the basin; however, no such deposits have been identified. Another line of evidence is Nairn's[14] established model of the Tarawera eruption, in which the distribution of fissures, vents, and surge directions across the basin does not readily indicate destruction of the White Terrace at its surveyed location. In addition, the Terrace location was sheltered from the principal vents of the Banded Island Basin and Great Crater Basin by the Steaming Ranges. Figure 12 shows that the present crater–lake shoreline appears to conform to the reconstructed Terrace outline.

The BLiSS model focused on the 293 m asl surface as a key datum for locating the White Terrace. This interpretation increases the plausibility that the Terrace remains buried and potentially recoverable while placing the reconstruction within a broader geological framework. Hodgson and Nairn[35] also identified a pre-eruption surface at 293 m asl at Tarawera, stating that "The lake elevation after the syn-Kaharoa flood is based on the c. 290 level before the 1886 eruption."[(p494)] Similarly, Keam[34] accepted Nairn's 8,000-year history of Tarawera, " ...the level of Rotomahana can be assumed to have been no more than about two metres above the 290 m elevation that Hodgson and Nairn [≈292 m]..."[(p21)] Although Keam's estimate of the pre-eruption Lake Rotomahana elevation appears to have been inaccurate, his recognition of the significance of the 293 m surface at Rotomahana remains relevant.

In 2012, Geological and Nuclear Sciences Limited, which had previously accepted the conventional interpretation of Terrace destruction, acknowledged the possibility that the Pink Terraces had survived the eruption: "... the Pink Terraces are still there, and, apparently, intact... because they were far enough from the rift not to get blown to bits or collapse into it. A follow-up study in 2012 confirmed that."[36(p46)]

The evidence triangulated at the overflow does not support the presence of a buried paleochannel at this location. This finding reinforces the terrestrial survey evidence that places the Kaiwaka Channel approximately 440 m west of the overflow. The recurring 293 m asl elevation across the independent datasets supports the interpretation that the 293 m drilling refusal in BH4 could mark the contact between the *ft* fall tephra and the underlying *arp* base-surge breccia.

Together, these findings suggest that the pre-eruption Kaiwaka drainage system may remain buried beneath 60–70 m of 1886 deposits. One interpretation is that the post-eruption overflow is a new post-eruption drainage feature, configured by the altered topography and distribution of hydrothermal eruptions.

Two lines of future investigation could strengthen these conclusions. First, targeted percussion drilling with sediment recovery at two or three sites along the present overflow could sample material above the refusal horizon, allowing lithological discrimination between *arp* breccia and potential channel gravel and providing a direct test of the *ft*–*arp* contact. Second, a short HVSR survey line perpendicular to the inferred Kaiwaka Channel at its proposed western location would provide independent geophysical evidence for a buried channel and complement the existing Line 3 data from the overflow.[37]

5. Conclusion

The BLiSS model combines multiple geological and geophysical observations that collectively support the survival of the White Terrace, making it a more plausible interpretation than its destruction. The White Terrace may today appear as a buried structure that was overtopped by the final stages of the 1886 eruption, leaving its platform buried under ≤30 m of muddy overburden. It may remain in this position, resting on its pre-1886 landform at 293 m asl, along with other sections of the Rotomahana Basin. LiDAR suggests that, while the surrounding volcanic deposits compacted over the shallow lake floor, the massive silica-sinter structure associated with the approximately 330 m spring platform may have resisted this compaction. Differential compaction may have preserved a subtle surface expression, or "ghost," of the Terrace's 75 m diameter platform or embankment. The 360 m dome is a potentially conforming surface expression of the buried spring architecture, while the littoral also appears to conform to the reconstructed Terrace outline.

The consistent borehole refusal at 293 m asl provides an important subsurface datum for the investigation. This elevation aligns with Alfred Warbrick's[11] depth-sounding at 293 m. Together, these observations support the interpretation that the *arp*–*ft* boundary at this location represents the original 1859 basin floor. The correlation between the HVSR impedance boundary and refusal elevations across five boreholes indicates that this surface is regionally coherent and is consistent with Nairn's[14] stratigraphy. No evidence of a buried Kaiwaka paleochannel was identified along Line 3.

The study supports integrating passive seismic HVSR profiling with borehole elevations and stratigraphy. In combination, these datasets provide a substantially stronger basis for subsurface interpretation than any individual method.

It is noteworthy that boreholes BH1 and BH5 are 1,200 m and 400 m, respectively, from BH4 and exhibit the same 292–293 m asl horizon. On the balance of probabilities, the White Terrace site, located 164 m from BH4, may also lie on this 293 m asl surface. In this case, a structure resting on this surface may have survived the 1886 eruption, albeit buried in ash. Boreholes at the Tarawera River exit, drilled both during the same period and more recently, also exhibit refusal elevations of 291–294 m asl, indicating that this pre-eruption surface extends over a considerable area.[9,15,16] This lateral reproducibility is more consistent with a continuous stratigraphic horizon than with a localised feature. The physical characteristics of the *arp* unit provide further support: base-surge explosion breccia is sufficiently competent to cause percussion-drilling refusal, whereas the overlying *ft* unit, comprising airfall and redeposited ash and scoria, is softer and more easily penetrated.

This study suggests that catastrophic phreatomagmatic events, such as the 1886 eruption, do not necessarily obliterate the underlying topography. By integrating HVSR geophysics, LiDAR morphology, terrestrial surveying, and archived engineering boreholes, this research provides a framework for resolving aspects of the 140-year uncertainty surrounding the fate and location of the Pink and White Terraces. The four-way triangulation also reduces the risk of pareidolia that affected previous interpretations.

The BLiSS model illustrates how independent historical, geological, and geophysical evidence can be combined to address a problem that cannot be solved by any single dataset. Collectively, the findings challenge the post-1886 interpretation that the White Terrace was destroyed and that its former location corresponds to the present-day lake overflow, which has historically been confused with the Kaiwaka Channel. The possibility that the White Terrace survives *in situ* offers a blueprint for the non-invasive mapping of other buried cultural and geological heritage sites in active volcanic zones. The evidential strength of the BLiSS model is further supported by the spatial alignment with Hochstetter's[3] 1859 survey, which provides a topographic pre-eruption map, and with the reconstructed geometry of the buried structure. If future research identifies preserved sinter at the survey location, targeted recovery could become possible, with potential implications for the interpretation and future heritage tourism of the Terraces.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

This is a single-authored article.

Availability of data

The key data are included in the paper. The author may be contacted for any clarification.

Further disclosure

A preliminary report on one part of the seismic data was published in *Smart Tourism* in 2024, titled "The Eighth Wonder of the World in New Zealand: Seismic studies confirm the new Hochstetter paradigm" (doi: 10.54517/st2174). The Grammarly Free version provided a spell-checker. Portions of the literature search, drafting, and image reconstruction were assisted by OpenAI's ChatGPT (GPT-5.5 2026). All sources were independently verified by the author. The research methodology, interpretations, findings, conclusions, and critical perspectives are those of the author.

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