Dr Hochstetter's Lost Survey

The Pink and White Terraces at Lake Rotomahana

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Introduction

The first survey of the central North Island was undertaken in 1859 by a team led by Dr Ferdinand von Hochstetter, who was visiting New Zealand with the Austrian Novara expedition. The colonial government commissioned surveyors Julius Haast and Drummond Hay, along with cartographer Augustus Koch, to join Hochstetter in a 21-strong party. The project took three months and surveyed 10,000 square miles (259,000 hectares) and 200 peaks across the North Island.

As it is an important part of the New Zealand surveying profession's history, and uniquely involves our lost eighth wonder of the world, the authors set out to include it in the country's survey estate.

Hochstetter based his survey method on the approach used by the 1856 Pandora coastal survey of New Zealand. (Byrne 2007) This was executed "…by means of the Azimuth-compass, a system of triangulation which I based on Captain Drury's nautical coast-survey". (Hochstetter 1867:20)

The 19th-century marine surveying technique is summarised thus: "The first part of the work... laying off a suitable base line... The next thing to be done is... a process called 'triangulation'. Each end of the base line is made a station for observations, and from these stations angles are measured... The first point chosen is then plotted off on its true bearings from both ends of the base line...". (Brown 1953:191-192)

Hochstetter could not know that his survey would be the only one of old Lake Rotomahana and of the Pink and White Terraces, which had achieved worldwide fame as New Zealand's eighth wonder of the world and within a decade was producing the first tourist boom for the young country. He predicted the Tarawera eruption but could not know this would destroy a lake he much enjoyed – given the 24 pages of his diary devoted to his two days at Lake Rotomahana.

Hochstetter was realistic about the accuracy of his survey mapping, commenting later: "It stands to reason that a map which contains nearly 2500 miles [10,000 square miles] and embraces more than the fourth part of the Northern Island, executed by the assistance of a compass alone, within the period of three months, can make no pretensions to a trigonometric exactness. It is, however, the first map which gives a correct view of the rivers and mountain systems, and of the lakes in the interior of the Northern Island, and will be useful until some better and more complete map takes its place." (Hochstetter 1867: 49-50) Nothing ever did take its place for the vicinity of Lake Rotomahana.

Later that year, he returned to Europe but retained links with New Zealand until he died in 1884. His survey field diaries and mapping remained in Europe. In 1886, the Tarawera eruption destroyed the old Lake Rotomahana and the Pink and White Terraces and despite Māori first responders reporting that the Pink Terrace had survived, four later government-commissioned reports (Hector 1886, Smith 1886, Hutton 1887 and Thomas 1888) concluded that the terraces had probably been destroyed. Their survival or demise was debated in the media until the eruption survivors died out, and after World War II, there was little to question this presumption until 2011 when a GNS Science marine team reported finding the Pink Terrace deep under today's Lake Rotomahana, in a crater lake 10 times larger and 12 times deeper than the old lake. After two further missions to the lake, GNS resiled from its many media announcements and reported in 2016 that both terraces were probably destroyed. (De Ronde et al 2016:1)

In 2015, researcher Rex Bunn met the authority on Hochstetter, Dr Sascha Nolden, who was curating Hochstetter's estate in Basel, Switzerland. On 23 February 2016, Nolden passed to Bunn diary pages from his Rotomahana visit. Bunn noted the compass bearings and considered the possibility of reconstructing the 1859 survey to establish the terrace locations and resolve continuing uncertainty of their survival or demise. Bunn and Nick Davies, of Cheal Consultants, met soon afterwards and examined the survey bearings.

The following is a summary of the interdisciplinary research. The diary did not contain sufficient bearings and landmarks to accurately coordinate the Pink and White Terrace locations via resection methods. It did however; provide sufficient data along with Hochstetter's manuscript map (termed the method-of-squares map), for us to reverse engineer his surviving survey data, retrace his footsteps and establish the field of view from his two observation stations around old Lake Rotomahana.

From these stations, (Stations 21 and 22), there are 13 bearings on 10 surviving landmarks which enable us to reconstruct Hochstetter's survey baseline. The reciprocal bearings from his 10 landmarks to the two observation stations, establish the latitude and longitude coordinates of these stations. From these stations, further diary bearings can then be projected to the Pink and White Terrace spring locations.

Finally, Hochstetter's method-of-squares (MoS) map is georeferenced over Google Earth (V 7.3.1.4507 © Google 2018) to provide intersections for the Pink and White Terrace spring locations. The approach was assisted by Nolden providing access to Hochstetter's field sketches, copious notes, artwork, correspondence, lectures and books. The method-of-squares map was derived on the basis of a 19th-century survey method which is also a technique employed by artists to establish scale on a canvas. The survey baseline provides scale and orientation to the Hochstetter MoS map.

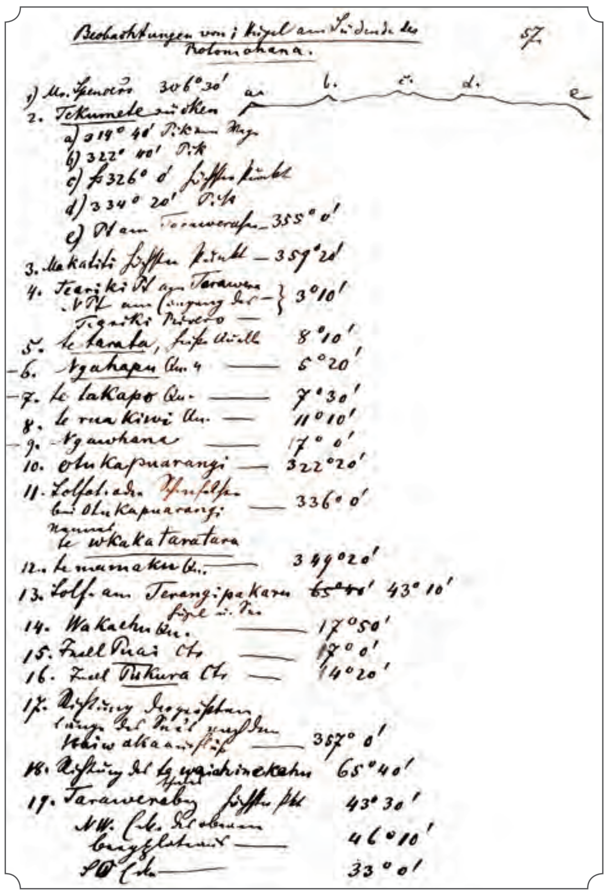

Figure 1: Page 57 from Hochstetter's Diary (Hochstetter Collection Basel).

The first survey iterations in 2016 relied on topographic maps and ruled bearings, using essentially the latitude and longitude of identified landmarks. These included trig stations, but there were no trig stations in this region in 1859, nor were there any maps or previous surveys. It was terra incognita.

In 2017, Bunn finally resolved the altimetry of the old Lake Rotomahana. Due to the non-availability of barometric altimeters before 1928, 19th-century altimetry used Bourdon pressure gauges which were inaccurate and could not be calibrated given the remote location of the sites, poor communications and the lack of aerodromes. Bourdon gauges used in this application were compromised by hysteresis, imprecision, lagged mechanical response, inconsistency, temperature and humidity effects. Thus, every previous terrace researcher (who throughout the 20th century and early 21st century were principally geologists) had been reduced to guessing that old Lake Rotomahana was one to two metres above Lake Tarawera, as water flowed from one to the other down the Kaiwaka Channel. Being unable to account for altitude, further geographic information system research was impossible. With latitude, longitude and altitude data computed during 2017, the location of the terraces and their likely distances underground were able to be first estimated.

In 2018, to improve the accuracy of Hochstetter's terrace and lake locations, Bunn went back to the field diary, zero-based the landmark identification and re-analysed every bearing and each bearing dataset. It was recognised that a GIS model approach was of limited application, as the new Lake Rotomahana, said to contain the old lake, was about 10 times larger and 12 times deeper than the old lake; nearly all close-in landmarks were destroyed, and landform changes from the eruption, overlain with chronic erosion, had significantly changed the topography around the new lake. The landmarks and peaks used by Hochstetter might also have altered in the past 132 years since the eruption and 160 years since the survey.

To determine this, Davies and Bunn adopted a fourth criterion – Hochstetter's field of view (FOV). Building on the 2017 altimetry, we could now estimate Hochstetter's FOV from his observation stations, and establish his landmarks with greater precision and accuracy than when relying on latitude, longitude and altitude.

In March 2018, after more study of the Hochstetter data by Cheal Consultants in Rotorua, it was realised the crucial Hochstetter bearings on Mt Tarawera had been misidentified in 2016. This reflects the colonial confusion in the naming of the mountains. The traditional names of Wahanga, Ruawahia and Tarawera were frequently concatenated as Mt Tarawera. Hochstetter, we realised, in referring to the highest point on Taraweraberg, Ruawahia, was in fact referring to the highest point on Tarawera Peak, the smaller mountain constituting the south-western section of the Tarawera massif. Site, photographic, cartographic and desk research over February to March 2018 placed this beyond doubt. Hochstetter's bearing (Bunn terms it his master-bearing) establishes both stations 21 and 22 by providing ideal cross bearings taken on Koa Peak, an overlooked part of Mt Tarawera but undoubtedly the highest available peak on the massif to Hochstetter on April 29, 1859. The landmarks and bearings are discussed below.

Hochstetter's landmarks and bearings

While his notebooks contain many compass bearings, only two pages contain bearings at Lake Rotomahana. Among these, all close-in landmarks below Te Tarata along the Steaming Ranges (later termed Pinnacle Ridge by Keam), i.e. the geothermal tourist features, were lost in the eruption and their sites are not discernable in today's landscape. The surviving landmarks with bearings from Hochstetter's observation station 21 are listed below and shown in Figure 1, taken from his diary.

The 10 surviving survey landmarks include:

- Rev S. M. Spencer's home at Te Mu
- Five peaks along Te Kumete Ridge
- A peak on Makatiti Plateau
- Three bearings on Mt Tarawera

Azimuth 1 – Rev S. M. Spencer's parsonage at Te Mu (bearing 306° 30′).

The house no longer stands at Te Mu. We knew Hochstetter stayed there before and after his Rotomahana visit, and was familiar with the location. Bruno Hamel photographed the residence in 1859. The Te Mu block subdivision plans survive and show the parsonage on a ridge above Te Wairoa. The intervening country rises to c. 500 MASL and the parsonage could not have presented in a line of sight from Station 21. In 2016, Bunn presumed a surrogate location and Hill 505 above the parsonage appeared the best candidate. It assisted with a fair resection only.

In 2018, with better altimetry and with Google Earth's ability to explore oblique views, Bunn made two more field visits to Te Mu, climbing up past the parsonage elevation and examining the skylines to the NW and SE. Clearly the parsonage was below the skyline, yet it also appeared in bearings from observation stations 18 and 20, the latter above Kakerangi (Oneroa). Given the relative elevations, a considerably higher surrogate peak must have been involved, i.e. ≥600MASL. Hochstetter had labelled these bearings as 'Rev. Spencer's' for his own usage, for the peak he actually used had no name. The answer became clear after identifying the probable Kakerangi location above Oneroa. By triangulating bearings from Station 21 and Station 20, the intersection lay on Hill 2410, the location of the 1970s trig 7693. From skyline analysis, this peak at 698m, with defined convexity and visible above the skyline from both stations; was indeed the parsonage surrogate. From Station 21 it is a run of ~10km. The reciprocal passed through the established Station 21 locus. Clearly, Hochstetter had noted this peak, probably while walking up Lake Rotokakahi and selected it for future use. It was one of 200 he used and he appears to select peaks with a pronounced point of reference and ones that were just visible along a skyline, perhaps as an aid in finding the true highest peak along an array of similar peaks.

Azimuths 2-6 – Five peaks along Te Kumete Ridge

Five bearings are given along this ridge as below:

- Bearing One –Peak on the way or Peak on the route/track 314° 40′
- Bearing Two – Peak 322° 40′
- Bearing Three – Highest Point, 326° 0′
- Bearing Four – Peak 334° 20′
- Bearing Five – Point on Lake Tarawera 355° 0′

Peaks one to four were clustered, lending themselves to a gap analysis. Peak Three, Te Kumete is the middle of five peaks and the best identified with two trigs. After the eruption, Te Kumete remained visible in the post-eruption reports and at the same altitude as now – 558m.

Peak One was interpolated by gap analysis as a saddle below a high point on the western escarpment of Te Kumete Ridge. This was consistent with the Te Wairoa-Rotomahana overland route described by Hochstetter. Peak Two is a 520m peak west of Te Kumete. Peak Four is Hill 515 today and Peak Five is the unnamed point below Mataneho Point. In 2016, Bunn used Mataneho Point. Either can be said to abut Te Kumete Ridge, while the unnamed peak meets the FOV (field of view) requirement and the reciprocal strikes the 2018 locus.

Azimuth 7 – A peak on Makatiti Plateau

This bearing was problematic in 2016. Bunn erred in selecting Hill 873 as the landmark, based on a Hochstetter sketch showing only one left-hand peak on the plateau. Under our FOV approach, Bunn located images by George Valentine and Frank Coxhead showing the pre-eruption Makatiti Plateau skyline as in Figure 2. This Coxhead photograph was shot from ~326MASL, i.e. almost the same elevation as Station 21, and from ~1600m north of Station 21. Valentine was perhaps the best terrace photographer and we can discount rectilinear distortion in his image, given he used a large format 12″ by 10″ camera with almost certainly a Dallmeyer Rapid Rectilinear lens. (Bunn 2016 and Hall 2004: 27) This Coxhead image was shot seven years earlier but is technically comparable to the Valentine image and the rendition of Makatiti Plateau is identical. This bearing runs for ~15km.

Figure 2: Makatiti Plateau in 1878-1880 (Photo by F. A. Coxhead, Te Papa 0.031022).

The Hochstetter 'Peak 873' can be seen away to the left of the wide feature in Figure 2. However, this was not the highest peak. There are two candidates for this, and these lie close together above the Coffee Cups. These correspond to today's trigs ALU9 and RGMK. If we project the reciprocals from these trigs to Station 21, the rays pass close to Station 21 and at an equal distance either side of the locus. The trigs are barely 1° to 2° apart along this bearing. We conclude Hochstetter's Makatiti landmark lay between today's trigs.

Azimuths 8-10 – Three bearings on Mt Tarawera

These bearings were taken on a mountain which erupted in 1886. However, the upper mountain plateau of Mt Tarawera was largely unchanged after the eruption, save for the fissure. Ruawahia remained the highest point and the south-eastern and south-western edges remained defined, as did Koa Peak.

As Ian Nairn reported: "In general, the mountain did not look greatly different prior to the 1886 eruption, except that there were no craters on the summit." (Nairn and Houghton 1986:202) This was particularly the case over the plateau edges which Hochstetter had used, and again Nairn advises: "The 1886 basalt deposits... rapidly thin to c.1m only a few hundred metres away from the fissure". (Nairn and Houghton 1986:204) Also, Smith in his 1886 eruption report provides pre- and post-eruption skyline views of the Tarawera summit, assuring that pre-eruption high points remained visible and were also post-eruption high points. (Smith 1886:43) (See also Figure 3)

These three bearings were important, for they provided right-angled crossing with the Te Kumete bearings, for optimal loci accuracy. They comprise as written:

- Taraweraberg (mountain) 43° 30′ Mount Tarawera highest point
- NW 46° 10′ [north-western corner of the upper mountain plateau]
- SW 33° 0′ [south-eastern corner of the upper mountain plateau]

In 2016, these bearings were misconstrued following the colonial confusion over the mountain names at Tarawera. The three named peaks, Wahanga, Ruawahia and Tarawera, were colloquially termed Tarawera, i.e. the massif. While Ruawahia was, and remains, the highest peak along the massif; it was not in Hochstetter's FOV either from Station 21 or Station 22 on April 29,1859. Fortunately, photographic evidence exists to confirm this.

Figure 3 was taken on April 29,1859 by Hochstetter's photographer Bruno Hamel on Puai Island, the location of Station 22. The view looks up beside the Waikanapanapa Valley, as shown in Figure 8. Along the central skyline are shown two peaks on Mt Tarawera, with the Steaming Ranges in the foreground. The right-hand peak (arrowed) is the characteristic head of Koa Peak, with its arrowhead shape and out-thrust eastern ledge. To its left (arrowed) is Tarawera Peak peeping over the skyline, as if the shot were composed to show these two skyline features.

This photo is from the earliest photo shoot at Lake Rotomahana. As with terrace photographs, we know neither the camera, lens, nor in most cases the plate size. The lens was possibly a Chevalier landscape lens. Most plates from this era were lost and the terrace photo estate now comprises mainly prints and these are often cropped, precluding them from photogrammetry. There appears to be only little distortion in this image and it does not impede our interpretation of relative elevations. The inclination is ~6.64°, and Station 22 was set back ~50m from Hamel's location and at ~-2m altitude. Given the 6.2km run to Koa Peak, this set-back made negligible difference to perspective, i.e. from 6.64° to 6.60° inclination. Tarawera Peak is lower than Koa Peak from this line of sight, confirming that:

- Hochstetter could see Mt Tarawera from his Puai observation station Station 22, but not Wahanga or Ruawahia, ruling them out of contention for the highest point or highest peak.
- He could only see Koa and Tarawera peaks on Mt Tarawera.
- Koa Peak was higher than Tarawera Peak and was the highest point he could see from Station 22.
- The pre-eruption peak form of Koa Peak is near identical to the post-eruption form (in early 20th-century photos), and the form today.
- The shot was taken from the eastern end of Puai Island.
- Due to Puai's small size (76m by 30m), manuka bush cover and seven or more huts, the only all-round view for Station 22 lay at the western end. The ~50m set-back, offset by ~2m lower elevation gave a marginally better skyline to Koa Peak.
- We can exclude Pukura Island as the site of Station 22.

The photographic evidence shows Koa Peak bearing on Mt Tarawera was the landmark Hochstetter first used from Station 22.

Figure 3: Steaming Ranges with Koa and Tarawera peaks behind (Tarawera arrowed left and Koa right). Photograph by Bruno Hamel, 1859 (Hochstetter Collection Basel, HCB 2.7.31 Copy 2).

Hochstetter also specified the highest point on Tarawera from Station 21, and it's important to check his FOV from that station as well. In Figure 4, Koa Peak is shown clearly to the right of the massif. Tarawera Peak is next left at 1050m and is higher than Koa at 1024m in this view. Tarawera Dome is down at 824m. However, we know the rim ash on Tarawera was ≤60m deep (Nairn and Houghton 1986:204). This places Tarawera Peak below Koa Peak elevation today, once we account for ash residue. We conclude Koa was the highest peak in view on Mt Tarawera that day in 1859 and also note Ruawahia is just visible above the skyline to the left. As with Tarawera Peak, once we deduct the eruption ash cover of ≤52m (Smith 1886:204), Ruawahia is no longer in our FOV, leaving Koa Peak as the Hochstetter landmark from Station 21.

Hochstetter's remaining landmarks on Tarawera were the corners of the upper mountain plateau. Given Nairn and Smith's reports above, one can be reasonably certain these plateau edges remain defined, especially on the eastern flank. The drop-offs were plotted along the western edge 900m contour below Hill 949 and the eastern edge along the 1000m contour adjacent to Koa Peak.

declination of 13.44° gave a mean error of -0.32° and range 3.78°. The 1859 Mt. Ngongotaha IGRF correction of

Figure 4: Mt Tarawera and Koa Peak taken near Station 22 (Photograph by Ingrid Fisher 2016).

14.01° gave a mean error of 0.25° and range 3.78°. The Ngongotaha validation indicated the IGRF model gave the lowest average error, but the Admiralty data gave the smallest range. We elected the IGRF correction.

Figure 5: Mt Ngongotaha Survey Validation to Motiti, Whakaari and Mokoia islands (Bunn, Google Earth 2018).

The Tarawera bearings contain an author's correction. Hochstetter overwrote SW 33° to SE 33°. This was a transposition error, as the correction ought to have applied to the NW bearing. A simple spatial analysis from Koa clarified this. The eastern escarpment is close to Koa: it is ~4 times further to the western edge. The corrected bearings are below:

- Taraweraberg (mountain) 43° 30′ Mount Tarawera highest point
- NW 46° 10′ [north-western corner of the upper mountain plateau] – should read NE 46° 10′ [north-eastern corner of the upper mountain plateau]
- SW (overwritten SO for SE, *ost* in German is *east*) 33° 0′ [now south-eastern corner of the upper mountain plateau] – should read as originally written SW 33° 0′ [south-western corner of the upper mountain plateau]

Station 22 was located on Te Puai Island and this station has only three surviving bearings – to Tarawera's highest point Koa and to two points on Kumete Ridge, the highest point and a SW peak about 15° to the west. This latter peak proved to be the same peak as his Peak One used later that day from Station 21. These bearings are shown in green on Figure 8.

For declination correction, a validation was performed on the next segment of Hochstetter's survey, from Mt. Ngongotaha, a location without recent volcanism and local magnetic variation. Bunn passaged declination through a set of nine reliable bearings on close and distant landmarks, examining the mean error and variance in Figure 5.

The 1855 Admiralty correction of 14.48° gave a mean error of 1.34° and range 1.67°. The 1859 Auckland IGRF

Findings

This survey iteration includes every bearing on a surviving feature. It incorporates data from Station 20. It updates the Tarawera bearings to Koa Peak, and the Spencer, Matanehо and Makatiti landmarks. It uses a four-stage algorithm:

Stage 1. Locate 10 surviving landmarks and prepare 13 reciprocal bearings from 1859 true north.

Stage 2. Resect locations of observation stations 21 and 22 in today's landscape.

Stage 3. Plot 1859 bearings for Te Tarata and Te Otukapuarangi from Station 21.

Stage 4. Georeference method-of-squares map over terrace bearing arrays. The intersections of the Tarata and Otukapuarangi bearings and the MoS locations confirm the spring locations with the best possible accuracy from Hochstetter's data.

The MoS map rediscovered in 2010 with the diary is Figure 6. Its 3cm squares represent ~240m, reflecting the lake length of ~1620m. The map scale is 1:8000. This is close to the old imperial scale of an inch to 10 chains.

Figure 6: Hochstetter's method-of-squares (MoS) map (Hochstetter Collection Basel, HCB 3.5.10).

Figure 7 is a compound illustration with the second unpublished Hamel photograph (at top) containing annotations by Hochstetter. Five peaks are numbered from left to right. These peaks are south-east of the lake, where no diary bearings were recorded. This implies there are other sections of Hochstetter's survey to be discovered. Below the fifth peak is the location for Station 21. An arrow (below the numeral 5) appears to mark the spot. There is a triangle beside the arrow marking Station 21. Bunn checked Hills 1 to 5 against today's skyline and the plotted Station 21 location, and there is a close fit as shown in the Figure 7 bottom image, and with the MoS map.

The four survey stages are portrayed in Figure 8. The yellow rays comprise the surviving feature 10 bearings from Station 21. The green rays comprise the surviving feature 3 bearings from Station 22. The Koa Peak and plateau bearings are from the right, providing good crossing by Hochstetter's design. The Kumete

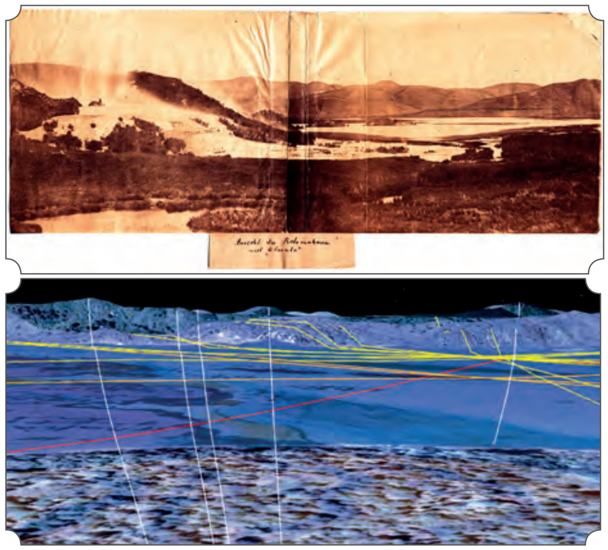

Figure 7: Top, View of Rotomahana with Te Tarata, with Hochstetter's annotations including Station 21 below Peak 5. Photograph by Bruno Hamel, 1859 (Hochstetter Collection Basel, HCB 2.7.23 Copy 2)

Bottom image: reproducing the bearings (in white) to Peaks 1-5 and Station 21. Note the Peak 5 bearing passes over Station 21 in both images (Courtesy of Google Earth, used with permission).

bearings radiate down from the ridge at left, converging on both loci. The Station 21 locus (with 10 bearings) has an ellipse of ±61m by ±35m. The Station 22 locus has an ellipse of ±9m by ±1.5m. The locus for station 21 is at ~-38.2705, 176.4268 and for station 22 is at ~-38.2628, 176.4296. The survey baseline is ~830m.

In Stage 3, we return to the diary and plot the bearings to the Pink and White Terraces' springs from Station 21. In Figure 8, the red rays are these bearings. In Stage 4, we establish the coordinates of the terrace springs by georeferencing the MoS map over these bearings: their intersections marking the terrace spring locations. This fourth stage is also shown in Figure 8.

Figure 8: Close-up of the Iteration Five resection, 10 bearings (yellow) on Station 21 and three bearings (green) on Station 22. The two red bearings are to the Tarata and Otukapuarangi Springs, from Station 21 (Bunn April 2, 2018).

Discussion

The field of view approach introduced in this article contributes a step-wise advance in our understanding of the terrace locations and their potential survival. It uses all Hochstetter's bearings which survived the eruption and integrates these to optimise survey accuracy.

However, the survey is made by compass only, and therefore cannot be claimed to have a trigonometric accuracy as Hochstetter advised. Given that it is the only survey of New Zealand's eighth wonder of the world, however, we are bound to try our best to obtain the maximum possible terrace location accuracy, without compromising the integrity of Hochstetter's original survey data.

Of the three major terraces on the old lake, the Pink and White spring locations appear to lie on land, while sections of their terraces lie on land and over the new lake which follows the alignment of the 1886 eruption crater between the Pink and White Springs. This indicates it's likely only parts of these terraces may have survived in position, proportionately more of Tarata than Otukapuarangi. The Black Terrace location lies wholly on land, as does Black Terrace Crater.

In Figure 8, the terrace locations are Te Otukapuarangi, ~-38.2612, 176.4218 (1899398.056 mE, 5759663.701 mN) and Te Tarata ~-38.2557, 176.4343 (1900514.765 mE, 5760233.640 mN). Note each red ray strikes the terrace spring with an error of ≤1°. This is impressive accuracy from Hochstetter's compass survey and given the steps in the reverse engineering algorithm. The close fit between the MoS map and diary bearings increases confidence in the terrace locations.

This latest survey resection can answer other questions about the lost landscape of the old lake. The old lake size and area has been unclear till now. Colonial records in Figure 9 show a minimum length of 1300m with an area of 75 hectares and a maximum length of 1600m with an area of 115 hectares. The old lakelet would thus have been 50-80% of the area of nearby Lake Tikitapu. These lakes were of similar shape and length. Our estimated old lake length is ~1600m. This agrees with Warbrick's area of 115 hectares, corresponding to a lake length of 1630m. It was indeed only a shallow lakelet, pond or lagoon and really not a lake at all – but it did hold the eighth wonder of the world.

In Figure 9, the MoS map was drawn by Hochstetter in the shape of an equilateral triangle, with a swampy, semi-inundated area to the south-east. In his first sketch of the lake, after looking 200m down onto it, side on from Te Kumete Ridge; he planned his future station 21 on the point where the altitude intersects the base. This shifted slightly by his fourth sketching in the MoS map, but remains close (refer diary page 53). This helps explain the absence of a true north or magnetic north arrow on his map. The map wasn't drawn with a north/south axis – the lake was drawn as he first saw it from above. He placed Station 21 at the base of the lake for artistic and geometric reasons, much as Smith had done a year before when he made the first western sketch map of the old lake. (Smith, 1858)

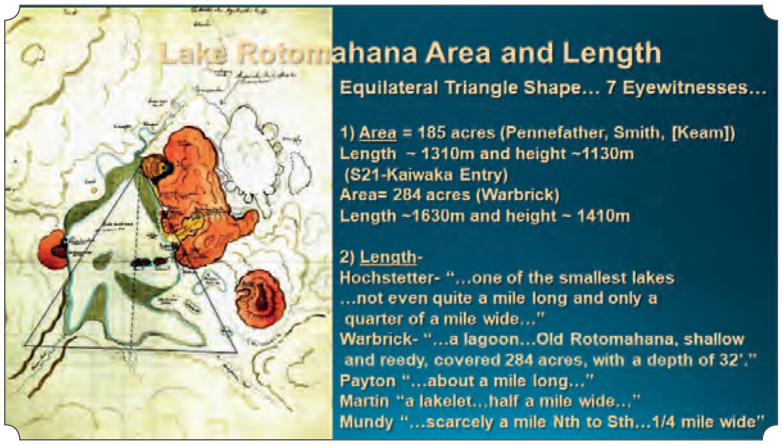

Figure 9: Old Lake Rotomahana: How Hochstetter drew his map (Bunn, 13/3/2018)

NB: This recognition provides a fascinating corollary, as the old lake has vanished; its true orientation can only be measured by resecting the Hochstetter survey bearing sets, plotting the spring bearings and then georeferencing the MoS map over Stations 21 and 22 as above. Only then will the diary bearings for Tarata and Otukapuarangi align with the springs. Stage 4 shows the lake axis lay at ~31°E from true north.

The Ngongotaha validation and our resections show Hochstetter provided generally accurate bearings. Some are not and we explore this. Key locations, e.g. the terraces and his Puai Island Bed & Breakfast were generally accurate and in his FOV, regardless of wind and weather. Other features were essentially holes in the ground surrounded by bush and invisible from metres away. Hochstetter used a surrogate and the obvious one is the steam plume. Figure 10 is a third unpublished Hamel photograph showing plumes from Ngahapu and Tekapo deflected by the strong south-west wind which interfered with his compass sightings and photography, his passage to the lake on April 28 1859 and marooned him at Te Mu for three days afterwards.

It is unsurprising that there are observational errors when we take an aerial view of these hole-in-the-ground features versus Hochstetter in 1859 gazing through his compass sights across the lake, locating features beneath shifting plumes and steam clouds.

Figure 10: Steaming Ranges under a strong sou-wester during Hochstetter's visit, showing the difficulty of taking bearings on hidden holes in the ground (Photograph by Bruno Hamel, 1859, (Hochstetter Collection Basel, HCB 2.7.32 Copy 2).

Conclusions

This survey iteration discloses the Pink and White Terrace locations with maximum possible accuracy. With each iteration, the quality of resection has improved, and now includes all surviving bearings in the analysis. This was not solely due to improved statistical analysis or better software. It reflects the interdisciplinary approach over 2016-2018, numerous field visits, the help of generous volunteers and growing competence with the historiography of the new and old Rotomahana lakes and the Māori and western histories of the area.

Error propagation

For the Topo50 map, LINZ advises accuracy about the terrace locations is +/-22m. Contours and streams in this area have not been updated since the 1970s and in backcountry regions, it's possible for locations to err by +/-44m. As a result, the authors used Google Earth for resection. Published studies on Google Earth accuracy and precision indicate the optimal error measure is to compare a GE distance against a known local landmark. The authors measured local error around Rotorua via the Rotorua Airport main runway 18R/36L (*www.aip.net.nz/pdf/NZ-RO_51.1_51.2.pdf*). This is 2114m (including extensions) and the GE measure is 2116m –. an error of +2m. This indicates an error contribution of ~6-10m over the longer runs to Rev Spencer's and Koa Peak.

Error ellipses were constructed for Station 21 and Station 22 as in Figure 8. The 10-bearing Station 21 ellipse major axis lies at 330° TN (true north) with an error of ±61m and the minor axis at 60°TN with an error of ±35m. The Station 22 ellipse major axis lies at 323° TN with an error of ±9m and the minor axis at 53°TN with an error of ±1.5m. It's worth noting the innermost 4 bearings of the Station 21 bearing dataset (i.e. Rev Spencer's, Peaks 4 and 5 and Tarawera NE), form a second, quasi-concentric Station 21 error ellipse, however we do not have the expected error for each of these observations. While the Station 21 major axis error of ±61m and the Station 22 error of ±9m are statistically significant, when searching for a structure such as Te Tarata occupying ~13 acres, they are insignificant in practice. The ~6707m^2 10-bearing Station 21 ellipse area compares with the Station 22 area of ~42 m^2.

The empirically determined errata include observational error to landmarks, random error from wind and steam clouds, error in resection, compass error (due local magnetic variation and inclination), declination error, i.e. actual to IGRF model, landmark displacement since 1859 by natural forces and Google Earth error. It is difficult to accurately apportion these, beyond making provisions. For example, the New Zealand Walking Access Commission advises a provision of 1-2m/km for pre-1870 surveys and for longer runs, e.g. for Koa Peak, this implies a 6-12m error. Clearly, the Station 21 10-bearing precision was affected by random error. Equally, the observations from Station 22 were taken with greater precision.

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