DECLINE IN RATE OF (SILICA) SINTER DEPOSITION IN THE TOKAANU DOMAIN, LAKE TAUPO (NZ)

Manfred HOCHSTEIN[1], Harry KEYS[2] & Ron KEAM[3]

[1]Geology Programme SGGES and IESE, University of Auckland
[2]Department of Conservation, Private Bag, Turangi
[3]Physics Department, University of Auckland

SUMMARY - Impressive quantities of (silica) sinter had deposited in a small area of the Tokaanu-Waihi geothermal field more than 135 years ago. The resulting sinter flats derived from large outflows of a few boiling pools and geysers discharging mainly deeply derived NaCl-type water. The exposed sinter deposits decreased in area from at least 15,000 m^2 in 1870/73 to c. 5,000 m^2 in 1940 and to less than 800 m^2 in 2007. Other thermal springs away from the old 'source' pools do not deposit sinter. The discharge rate of unmixed deep thermal water in the Tokaanu Thermal Park has declined since the 1870s and is now on the order of 3 kg/s, including c. 2 kg/s produced by a bath-house well. The discharge of unmixed and mixed thermal waters in the park is about 10 kg/s. Because of this decline, resumption of sinter deposition over the original area does not appear to be feasible but conservation of the remaining deep natural water supply is required instead and may result in localised restoration.

1 INTRODUCTION

The Tokaanu-Waihi geothermal field occurs in rugged terrain beneath the SE slopes of the Quaternary, inactive Kakaramea-Tihia andesite volcano. It hosts a liquid-dominated, high-temperature reservoir with a sub-surface extent of at least 12 km^2 and discharges mainly dilute NaCl water from springs and hot pools in the foothill region near the southern shore of Lake Taupo (level c. 356 m). At elevations above 380 m and possibly up to 1000 m only steam is discharged by patches of hot ground. The total natural heat loss is c. 75 MW.

Geological and geochemical surveys (Healy, 1942; Mahon & Klyen, 1968; Robinson & Sheppard, 1986) have shown that mineralized water (with TDS up to 6 g/kg) has discharged in a small area (c. 0.2 km^2), the Tokaanu Domain, also part of the Tokaanu Thermal Park and administered by DoC since 1987. About 7 to 8 MW heat is discharged by all manifestations in the Domain (Hochstein, 2007). Thermal water from a large pool and a bore in the Domain has been used during the last 40 years to supply the public Tokaanu bath-house. The Park contains overgrown sinter flats and patches of exposed (silica) sinter deposits, a rare type of thermal manifestation (Keam et al., 2005). Rapid growth of thermal vegetation (kanuka) over once bare sinter flats points to a long-term decline of thermal activity. Our study was made to assess sinter deposition during historic times and the feasibility of sinter restoration. Since the exact locality and level of manifestations in the Domain were poorly known, they were also mapped using a tacheometric survey.

2 SINTER FLATS AT TOKAANU

Across the Tokaanu – Waihi field, significant sinter deposition has occurred only in the Tokaanu Domain and as minor deposits on the Waihi foreshore. These deposits were noted in 1859 by Hochstetter (1863). The extent of sinter flats in the Tokaanu Domain is known from photos taken between c. 1870/73 and 1885, detailed geological mapping in 1940, and graduate student studies between 1985 and 2000.

The first historic photo showing an exposed sinter flat near the present day Taumatapuhipuhi geyser site (Figure 4 in Appendix) was taken between 1870 and 1873 by D.L. Mundy (1875). Alfred Burton photographed larger sinter deposits further to the west from a higher elevation in 1885 (Figure 5 in Appendix). A sketch map by Hill (1891) shows the extent of active manifestations in the Domain. Another sketch map is included in a guide book by Allen (1894); it shows the approximate extent of sinter flats at that time, albeit at a distorted scale. Using a map of the Domain by Healy (1942) as reference, the extent of historic sinter flats has been reconstructed (noted by 'Si' in Fig.1).

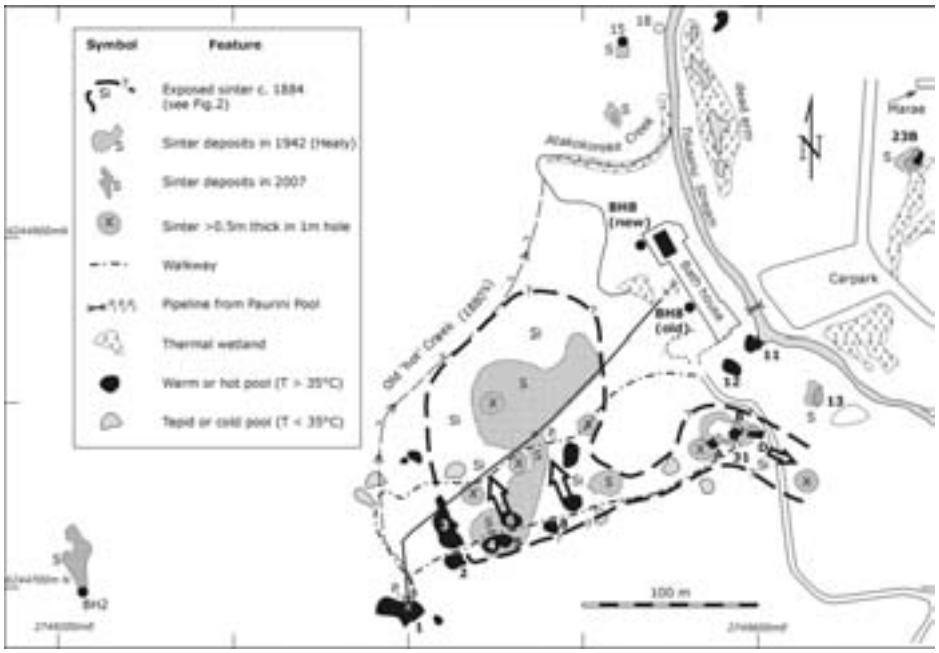

Figure 1: Tokaanu Domain: sinter deposits between c. 1870/85 and present

2.1 Setting of the historic sinter flats

In the following, the numbering scheme of Healy (1942) and Mahon and Klyen (1968) is used when referring to well defined manifestations. The large pool (Nr.1), called in 1890's the 'Toretiti (or Torotiti) Pool', had an overflow which discharged into the hot 'Atakokoreke stream'. According to Allen, most of the hot pools close to sites Nr.2 to Nr.8 along the southern margin of the Domain were boiling (confirmed by Mundy's photos) and discharged hot water via 'rivulets' flowing over a flat surface towards the hot stream. Most of the thermal pools were in bare, open ground. Two almost circular, sinter-lined depressions collected hot water from pools Nr.5 and Nr.6 and were used as natural public baths between 1875 and 1913. The likely lateral extent of the historic western sinter flats is confirmed by the occurrence of sinter in a few, widely spaced, c. 1 m deep holes. Sites with a thickness > 0.5 m are shown in Fig.1 (Zhang Lan, 1987). That study confirms also the existence of a sinter apron around the 'Hoani' pools (Nr. 31). The total area of exposed sinter flats in the 1880s was at least 15,000 m^2, including some inactive patches exposed by human activity. The maximum discharge rate of the thermal water

which flowed over the flats was probably on the order of 30 - 100 kg/s. The first Tokaanu bath-house was constructed in 1913 near the present public baths. The natural overflow of the 'Toretiti' pool was channelled by an open ditch to the bath house following the path of the present pipe line shown in Fig.1.

A geological reconnaissance survey of the Tokaanu-Waihi area was made between 1928 and 1934 (Grange, 1937). Characteristics of the Tokaanu sinter flats were not described in detail although reference is made to sinter lined basins hosting three hot pools, centred on the Hoani Pool (Nr.31B) which occasionally exhibited ebullient eruption activity. According to Grange, the new Taumatapuhipuhi Geyser (Nr.13) was active from at least 1928.

2.2 Tokaanu sinter deposits in 1940

A detailed survey of the Tokaanu-Waihi area was undertaken in 1940 by Healy (1942) who numbered (from Nr.1 to Nr.15) important manifestations in the Domain. One of Healy's aims was to check whether the reported high amount of boron in the hot spring waters was an economic resource. Healy also mapped the exposed sinter deposits in the Tokaanu Domain (see Fig.1). Apart from relicts of the large sinter flats described by Allen and deposits around the sinter lined basins (Nr.31), Healy found smaller, active sinter deposits around the Taumatapuhipuhi geyser (Nr.13), near an ebullient pool (Nr. 14, close to Nr. 23B) on the Marae, and around the Korokoro boiling spring (Nr. 15). The total area covered by exposed sinter (S in Fig.1) was c. 5,000 m^2. About half of the older deposits had been overgrown and were covered by swampy ground. The southern, previously 'boiling' pools (Nr.2 to Nr.8) had cooled to 70-90 ^oC except for pool Nr.6 which still produced boiling water. The overflow rate of the hot pools had declined since the 1880s; the natural overflow from pool Nr 1 (c. 5 kg/s) was now transferred to the old bath-house by a wooden flume. It was replaced later by a pipe line (see Fig.1). The total outflow from pools Nr.2, Nr.3, and Nr.6 was c. 4 kg/s and was transferred by a wooden flume and later by a second pipeline to the old bath house (erected in 1911/13 and rebuilt since).

In 1942 two holes, BH-2 and BH-3, were drilled in the Domain to depths of 97 m and 108 m respectively. Both wells were productive but were shut in. However, before 1950 the casing of BH-2 was damaged, the well started to discharge and deposited sinter. Some remedial work was done but free discharge of probably a few kg/s has continued. Photos taken in 1952 by Ron Keam still show areas of open, bare sinter flats in the Domain.

2.3 Recent sinter deposits

By 1987 the total area with exposed sinter deposits in the Domain had decreased to < 800 m^2 and most of it was confined to the c. 500 m^2 large sinter apron which had formed down-slope from bore BH-2 (see Fig.1). The outflow from the southern pools (Nr.2 to Nr.8) had decreased to c. 1 kg/s in 1987; in 2007 this outflow had ceased and pool temperatures had decreased further to 45-60 ^oC (at Nr.6 to 65 ^oC). Minor sinter deposition was still occurring at the margin of pools Nr.5, Nr.6, Nr.31 (B and D) and at the geyser Nr.13. The outflow from the old Tuwhare pool (Nr.14 near Nr. 23B) had ceased. The total discharge of thermal water (mixed and unmixed) from the Domain and the Marae had decreased from c. 33 kg/s in 1940 to c. 10 kg/s by 1987, with a sub-total of c. 3 to 4 kg/s being produced by the rogue bore BH-2 and the new bath-house well BH-8. Production from BH-8 caused a change in style of eruptions and a decline in activity of the Taumatapuhipuhi geyser (Nr.13) when the well was opened in 1966. The natural outflow from pool Nr.1 has remained unchanged (c.5.5 kg/s at 62 ^oC).

3 GEOCHEMICAL CHARACTERISTICS

A geochemical survey of all thermal pools and springs of the Tokaanu-Waihi system was undertaken in 1966 by Mahon and Klyen (1968) who included additional sites (Nr.16 to Nr.33) in their study. The molecular proportions of anion constituents point to a dilution pattern for all thermal waters discharged across the whole Tokaanu-Waihi area with the least diluted water occurring in the Domain. Additional chemical and isotope analyses in 1979 by Robinson and Sheppard confirmed the model that rather undiluted, deep thermal NaCl water is discharged only in a small area of the Domain and that elsewhere these waters are diluted by shallow steam condensates and heated ground water. In both studies the historic names of many pools were retained, names already used by Allen (1894) and listed in bold cursive in the inset of Fig.2. Some inconsistent re-naming occurred after 1985.

3.1 Spatial distribution of thermal waters at Tokaanu

To recognize the spatial distribution of diluted thermal waters, their chloride concentrations can be used directly. In the following, three main types and two intermediate types of thermal waters are used for pattern recognition, namely:
Type I: Cl > 2.7 g/kg (HCO_3 < 0.05 g/kg); Type I/II: 2 g/kg< Cl < 2.7 g/kg;
Type II: 1 g/kg < Cl < 2 g/kg; Type II/III: 0.6 g/kg <Cl< 1 g/kg;
Type III: Cl < 0.6 g/kg (HCO_3 > 0.20 g/kg).
A dilution pattern of thermal waters discharged in the Tokaanu Thermal Park is shown in Fig.2. At sites with more than one analysis, the more recent ones (period 1979 to 1999) were used. All sites with type I and type I/II water occur within the area outlined by Fig.2. Comparing information in Fig.2 with that in Fig.1 shows that sinter has been deposited only by type I and type I/II thermal water. Near the margin of Fig.2, intermediate type I/II water is now discharged by the rogue bore BH-2 (2.1 g/kg Cl) and also at site Nr.23 B. Least diluted, deep thermal water discharge occurs in two zones covering an area of only 0.02 km^2.

3.2 Historic analytical data

Around 1882 some of the boiling pools and springs in the Domain were sampled and analysed (Mahon and Klyen, their Table 6). Although analytical methods have changed, the Cl data of older analyses (using standard titration methods) can still be compared with present day data. A comparison shows that the old boiling pool Nr. 3 and the then active geyser Nr. 15 discharged type I water which was enriched in Cl (up to 3.9 g/kg). Pool Nr.1 was close to boiling in 1882 and produced a large overflow of type II water with c. 1.9 g/kg Cl. Near the present Tuwhare pool (Nr.23B), the Cl content decreased from c. 2.7 g/kg in 1882 to 2.3 g/kg in 1966. The changes can be explained by the decline of deep boiling.

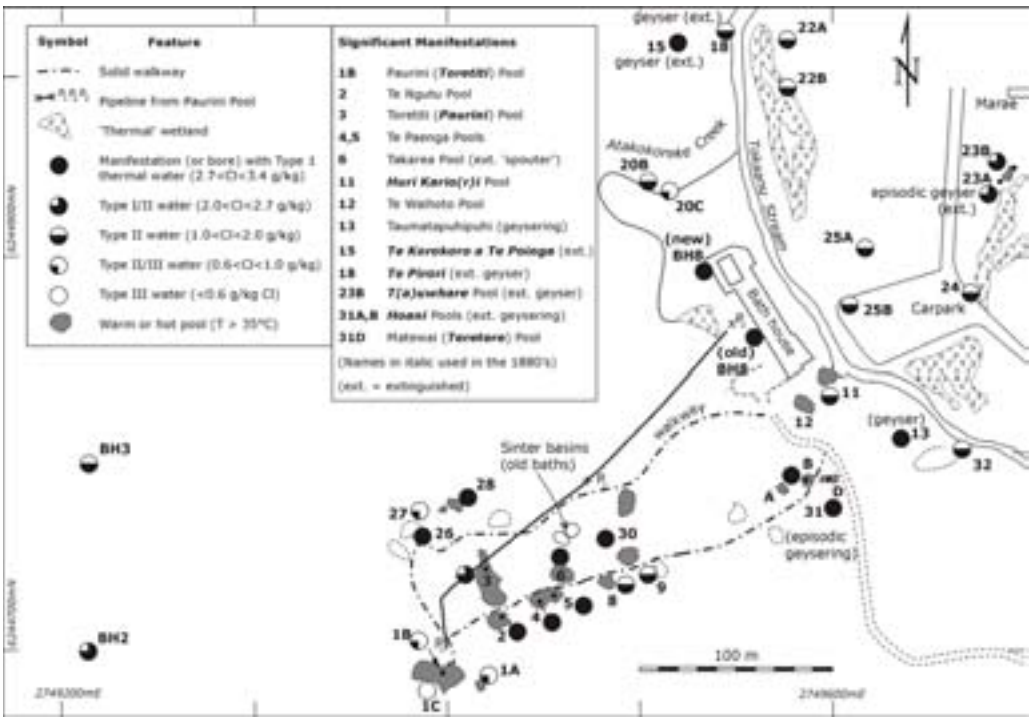

Figure 2. Tokaanu Domain: pattern of Cl-concentration of springs and pools

3.3 Solute SiO2 concentrations

Depending on equilibration with respect to quartz or lower temperature polymorphs, such as chalcedony and amorphous silica, thermal water can become saturated at depth with SiO_2 and, upon cooling, it deposits silica sinter at the surface.

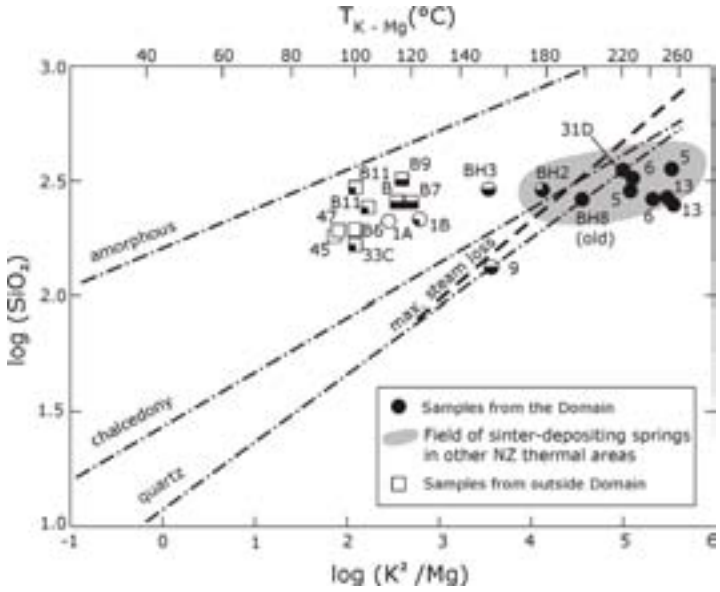

Figure 3. Plot of log (K^2/Mg) versus log (SiO_2); constituents in mg/kg

The approximate temperature of thermal water at depth at the last (re-)equilibration stage can be obtained from a log (K^2/Mg) versus log (SiO_2) plot (Giggenbach and Glover, 1992). As shown in Fig.3, type I thermal waters plot within a temperature field of 200 $^oC < T_{K-Mg} < 250\ ^oC$ and are almost fully equilibrated with quartz. Thermal waters associated with active sinter deposition in other thermal areas of the Taupo Volcanic Zone plot in the same field as type I waters from Tokaanu (Fig. 3). Thermal water discharging type II and type III waters derive from mixed and diluted water in the shallow reservoir with T_{K-Mg} between 100 and 140 ^oC. Selected analyses of

thermal waters of types II and III from shallow wells outside the Domain, and analysed by Robinson and Sheppard (1984) and Severne (2000), were added to Fig.3. The figure shows that type I hot water in the Domain is surrounded by diluted and mixed waters of type II and type III which do not deposit sinter. Hence, only type I water could be used to stimulate natural sinter deposition.

4 FEASIBILITY OF RESTORATION OF SINTER DEPOSITS

The arguments listed show that extensive sinter deposition in the Tokaanu Domain was associated with the overflow of a few boiling pools that discharged rather undiluted deep thermal water (type I), produced by local deep boiling. Manifestations elsewhere around the Domain and over the Waihi-Tokaanu reservoir discharge diluted thermal waters which do not deposit sinter. In the Domain, the natural discharge rate of type I water had already declined to c. 4 to 5 kg/s in 1940 before the BH-2 and BH-3 wells were drilled. We estimated that the copious outflow of type I water was on the order of 30 - 100 kg/s before the first photos of exposed sinter flats were taken in the 1870's. The natural outflow of type I water had dropped to c. 1 kg/s in 2007. Additional production of type I water (c. 2 kg/s) has occurred since 1966 when well BH-8 was commissioned. This water is used to heat an open-air swimming pool (Zarrouk and Keys, 2008).

Only an increase in the production of type I water by additional bores or overflows from pools with type I water within the Domain could renew sinter deposition. In view of the decline of the natural outflow of this water type and the declining temperatures of prospective hot pools, production from any additional bore would only hasten the pressure drop in the shallow reservoir causing further decline in what little up-flow remains. However, it is possible to reduce fluid production from the bath-house bore and to stabilise the resultant pressure drop (Zarrouk and Keys, 2008). While this would not restore sinter deposition it would slow the decline in the natural up-flow of type I water.

5 SUMMARY AND DISCUSSION

Historic photos and published data show that sinter deposition was widespread in the Tokaanu Domain in the 1870's covering an area of at least 15,000 m^2. The deposits derived from overflows of a few boiling pools whose discharge had decreased rapidly, as shown by plant re-growth that covered most deposits by 1940. Subsequently, the exposed sinter flat area shrunk from c. 5,000 m^2 to less than 800 m^2 in 2007. Sinter was only deposited from rather undiluted, highly mineralized (TDS c. 6g/kg), over-pressurized thermal water discharged in a small enclave (c. 0.02 km^2) of the Domain also known for its geyser activities. The natural outflow rate of this water type had dwindled to c. 1 kg/s in 2007. Other peripheral manifestations in the Domain and those across the much larger (c. 12 km^2) Waihi-Tokaanu field discharge thermal waters which are diluted and mixed with steam condensates and heated groundwater but these waters do not deposit sinter. In view of the small extent of the resource hosting the highly mineralized water, restoring extensive sinter deposition does not appear to be feasible and use of this precious water for heating of a swimming pool should be reduced to a minimum.

A gradual, overall decline in deep reservoir pressure is indicated for the last 135 years. This may be associated with secular changes of its heat source characteristics. Short-term changes in activity of manifestations have been observed for several geothermal prospects in the Taupo Volcanic Zone, usually induced by exploitation. Intermediate-term changes of such activity have not been described. The decay in sinter deposition rate at Tokaanu appears to be an example

primarily of natural changes not triggered by exploitation occurring over a period on the order of at least a few hundreds of years.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Allen, G.F. (1894) Willis' guide book of new routes for tourists: Auckland-Wellington. A.D.Willis, Wanganui, 176 pp.

Giggenbach, W.F.& Glover, R.B. (1992). . .Water and gas discharges from the Rotorua Geothermal Field, NZ. Geothermics 21, 121-140.

Grange, L.I. (1937) The geology of the Rotorua-Taupo subdivision, Rotorua and Kaimanawa subdivisions. NZ Geological Survey Bulletin 37, 138 pp.

Healy, J. (1942) Boron in hot springs at Tokaanu, Lake Taupo. NZ Journ. Science and Technology B24, 1-17.

Hill, H. (1891) Ruapehu and Ngauruhoe. Transactions of the NZ Institute 24, 603-623.

Hochstein, M.P. (2007) Assessment of the Tokaanu-Waihi Geothermal Field and its classification in the Regional Plan. DoC Technical Report Series 27, pp.49-75.

Hochstetter, F.v. (1863) Waihi and Tokaanu, in: Neu-Seeland. Cotta Verlag Stuttgart, pp. 229-234.

Keam, R.F., Luketina, K.M., Pipe, L.Z. (2005) Definition and listing of significant geothermal feature types in the Waikato Region. Proc. World Geothermal Congress 2005, paper 0209, 12 pp.

Mahon, W.A.J. & Klyen, L.E. (1968) Chemistry of the Tokaanu-Waihi hydrothermal area. NZ Journ. of Science 11, 140-158.

Mundy, D.L. (1875) Rotomahana and the boiling springs of New Zealand. Sampson, Marston, Low and Searle, London, 16 plates, 39pp.

Robinson, B.W. & Sheppard, D.S. (1986) A chemical and isotopic study of the Tokaanu-Waihi geothermal area. Journ. Volc. Geotherm. Research 27, 135-151.

Severne, C.M. (2000) The Tokaanu-Waihi Geothermal System. PhD thesis, Univ. of Auckland, Main Library, 407 pp.

Zarrouk, S. & Keys, H. (2008) Assessment of present take and utilisation of the Tokaanu bath-house, Lake Taupo (NZ). Proc. 30th NZ Geothermal Workshop.

Zhang Lan (1987) The fluid geochemistry and hydrothermal alteration in Tokaanu Geothermal Field. GI Project Report 87.28, Univ. of Auckland, Engineering Library, 32 pp.

APPENDIX (HISTORIC PHOTOS OF TOKAANU SINTER FLATS)

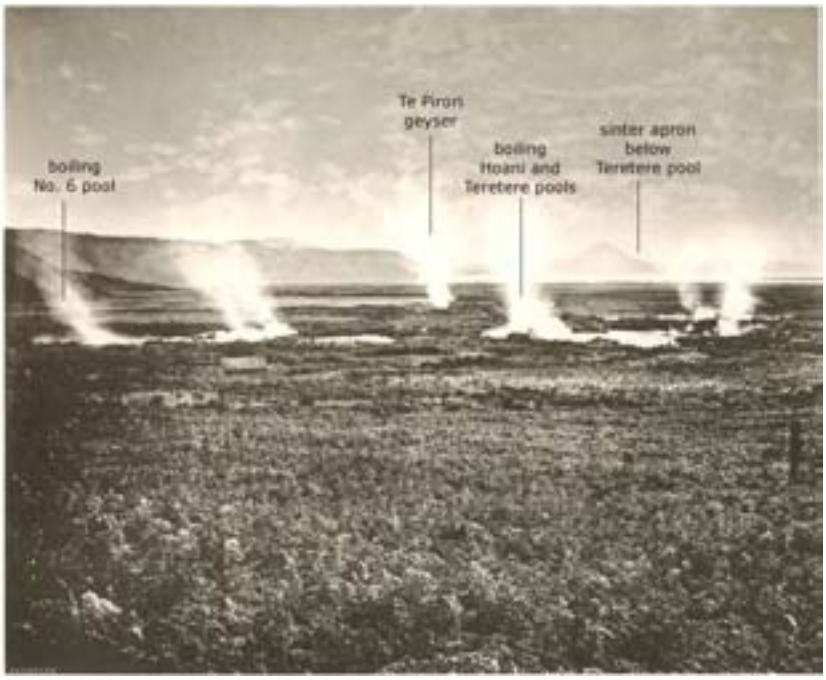

Figure 4: Eastern half of Tokaanu Domain, photo taken in 1870/73 by Mundy

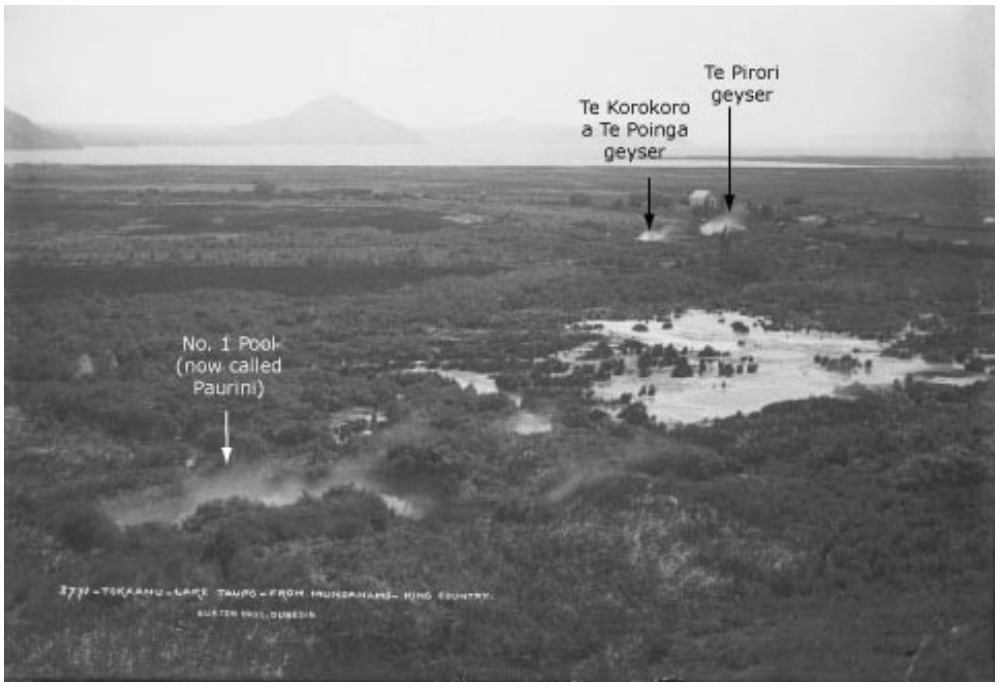

Figure 5: Western half of Tokaanu Domain, photo taken in 1885 by A.Burton