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STEAMING GROUND AT RED CRATER AND IN THE TE MARI CRATERS, MT TONGARIRO GEOTHERMAL SYSTEM (MEW **ZEALAND**)

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ABSTRACT

Surface manifestations at Red Crater, Mt Tongariro, consist of steaming ground, a few fumaroles (T max = 94.5°C) and numerous steaming vents. The steaming ground covers a total area of about 8000 m^2. Cooled condensates enriched in Si02 drain into the Oturere Valley. The total natural heat loss at Red Crater was estimated to be about 20 MW. Steaming ground in the Te Mari craters covers an area of about 3000 m^2; maximum temperatures of 95.5°C were observed in most of the steam vents. The natural heat loss is of the order of 5 MW. Steam discharged in both areas is at local boiling point temperature.

The manifestations at Red Crater, in the Te Mari craters and the Ketetahi fumarole field (36 MW) are fed by steam escaping from the Tongariro geothermal system, a vapour dominated system which underlies the three thermal areas.

Introduction

Three separate areas with steaming ground and fumaroles occur around Mt Tongariro, namely Red Crater, the Te Mari craters and the Ketetahi fumarole field (see Fig. 1). The setting of the manifestations has been described by Gregg (1960). The steaming ground ,at Red Crater and in the Te Mari craters occurs in explosion craters which have been active in historical time. Phreato-magmatic explosions between 1869 and 1896, which formed the Upper Te Mari Crater, and the activity of Red Crater between 1855 and 1859, have been described by Gregg (1960). There is no evidence of any major eruption from the Ketetahi fumarole field.

Massive, older lava flows of olivine-andesite also erupted from the Te Mari craters and Red Crater (Grindley et al. 1965; Mathews 1967; Topping 1974). These craters, together with other eruption centres at South Crater and the active volcano Mt Ngauruhoe, lie along a 025" trending fracture zone. Other active faults in the area exhibit a similar strike (see frontispiece in Gregg, 1960, and Fig. 1 in Moore and Brock, 1981).

Because of the close association of two of the fumarole fields with recent volc'anic activity, it was thought until about 1970 that the steam discharged in the three thermal areas was of magmatic origin (Wilson 1960). Gas analyses by Giggenbach (1975) showed that the composition of gases sampled at Red Crater, Central Crater, and at Ketetahi showed affinity to gases discharged over some hot water systems in the Taupo Volcanic Zone. This finding led to the hypothesis that all surface manifestations around Mt Tongariro originate from a coherent geothermal system, the Tongariro system, and that all recent eruptions at Red Crater and in the Te Mari craters must have involved molten rocks which ascended through this geothermal system.

To test the hypothesis that a coherent geothermal system underlies Mt Tongariro, resistivity and magnetotelluric surveys were made in 1976 and 1978 which showed that an area of at least 15 to 20 km^2 is underlain by rocks with low resistivities of about 3 ohm-m at depths greater than 200m (Hochstein and Bromley 1979). The vertical resistivity structure was interpreted in terms of a 300 to 500m thick condensate layer which caps a reservoir with intermediate resistivity and which, in turn, is underlain by a highly conductive (brine?) layer. Since this structure is similar to that of explored vapour dominated systems in Java, namely Kawah Kamojang and Darajat (Hochstein 1975), it was inferred in 1979 that the Tongariro system is a vapour dominated system.

Recently published stable isotope analyses of gases from Red Crater and Ketetahi have confirmed the geophysical model of the Tongariro system (Lyon and Stewart 1985). Isotope geothermometers (CH_2-H_2 and H_2-H_2O vapour) indicate equilibrium temperatures of about 230 to 290°C, which are similar to an inferred temperature of about *240°C* in the vapour dominated reservoir if it were capped by a 300m thick condensate layer (Hochstein, 1975). Some contamination by magmatic gases is indicated by the relationships between N_2, He, and Ar, which show some affinity to those of gas samples from Mt Ngauruhoe and White Island, both active volcanoes.

The Red Crater fumarole field

Whereas detailed maps of the Ketetahi fumarole field have been published (Wilson 1960; Moore and Brock 1981), no description of the Red Crater fumarole field or the steaming ground in the Te Mari craters has been presented. During the 1976 geophysical reconnaissance survey, all fumarole fields were mapped by the author, but the data were mislaid. Preparations for the 1986 International Volcanic Conference led to the discovery of some of the 1976 data.

The surface manifestations at Red Crater and Te Mari were mapped using a compass-tape survey; vertical control was established by an Abney level. Temperatures were measured with a Cr-A1 thermocouple and checked with maximum thermometers. Steam velocities were measured with a pitot tube and a pressure transducer. Water samples taken from nearby lakes and creeks were analysed for total acidity (as H_2SO_4), SiO_2, and Cl.

Steaming ground

The areal extent of steaming ground at Red Crater was determined by measuring ground temperatures at 0.2m depth. The total area where the ground temperature is greater than 70°C (i.e. steaming ground sensu strictu) was found to be about 8 x 10^3 m^2; this ground is shown by hatched lines in Fig. 2. The area of steaming ground at Red Crater is only half that of all steaming ground at Ketetahi (about 16 x 10^3 m^2). The area with steaming ground at Red Crater is elongated in the direction of 045"; the direction of the median axis of the Red Crater fissure is about 030". No steaming ground was found at the bottom of

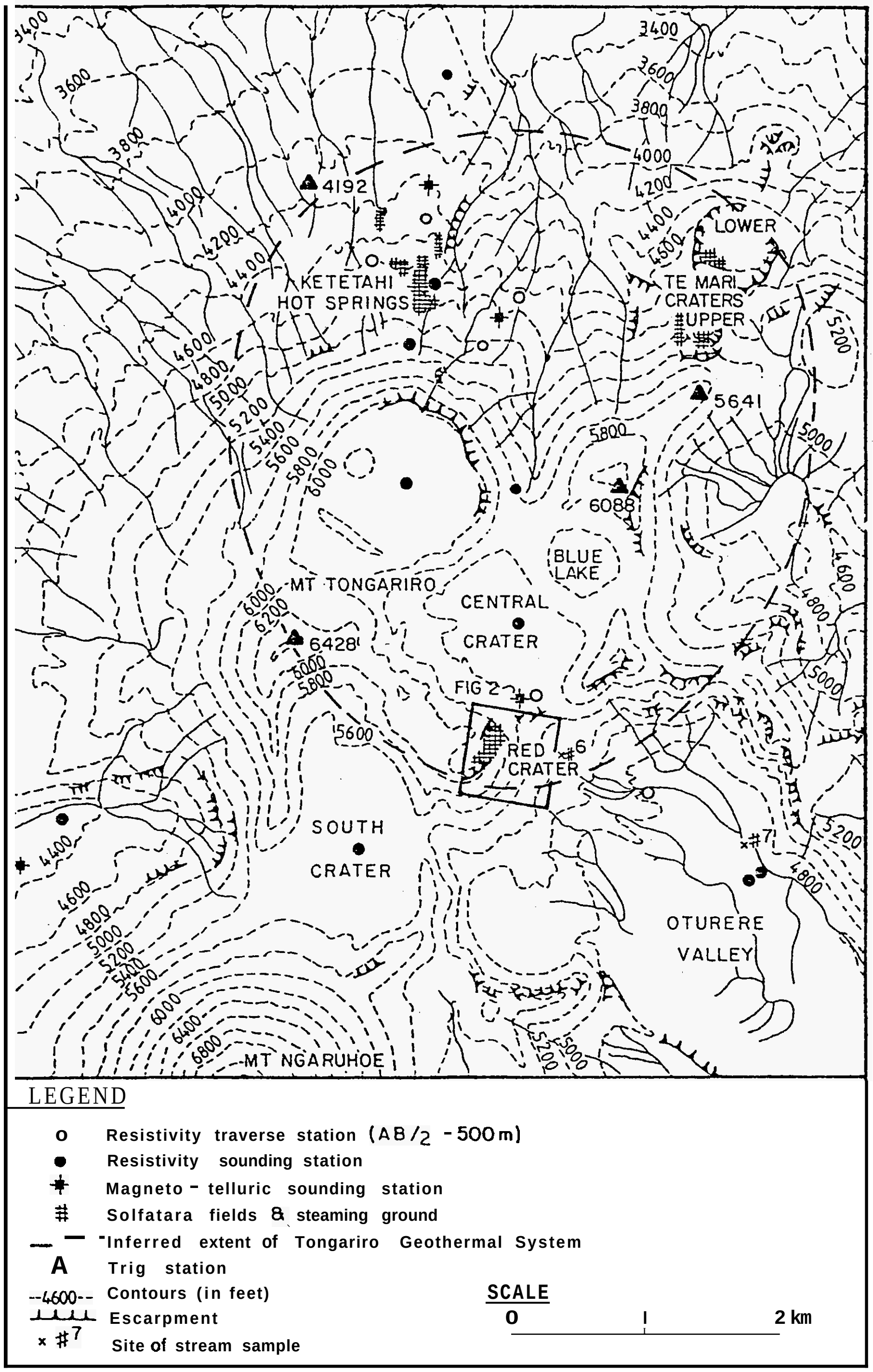
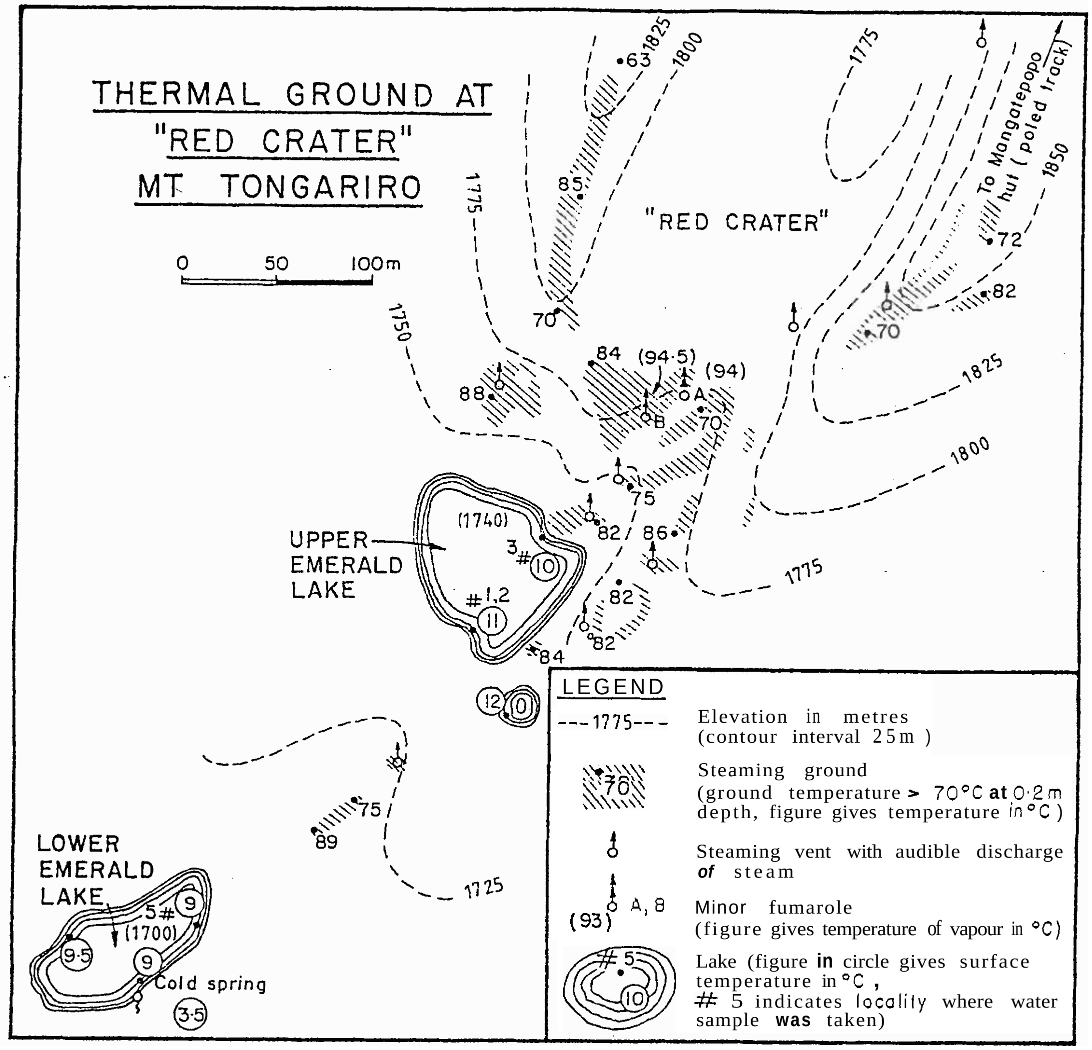


Fig. 1: Topographic map of the Mt Tongariro area showing the locality of the thermal areas at Ketetahi, in the Te Mari craters and at Red Crater; the approximate lateral extent of the low resistivity condensate layer which caps the Tongariro thermal system is also indicated (taken from Hochstein and Bromley, 1979).



the valley inside the fissure although steaming ground occurs on each ridge of the valley, pointing to an enhanced natural draught of steam which presumably moves laterally beneath the valley floor. The same phenomenon was also observed in the Te Mari craters. Minor sulphur deposits can be found over most steaming ground especially near steaming vents.

Fumaroles and steaming vents

The mean surface elevation of the Red Crater fumarole field is about 1775m; it is therefore the highest field with geothermal manifestations in the Taupo Volcanic Zone. The local boiling point temperature at this altitude is about 94.1°C assuming a standard atmosphere; the theoretical mean annual temperature is about 3°C using a wet adiabatic lapse rate of -7°C/km. Observed temperatures in the two major fumaroles and some larger stearn vents were found to lie between 94 and 94.5°C, i.e. the steam discharged is at local boiling point temperature. Ground temperatures at 1m depth outside the thermal ground were 4 ± 1°C.

Pleasured discharge velocities of steam were used to distinguish between fumaroles and steaming vents. We classified discharge features as "fumaroles" if the discharge velocity at about 0.1 to 0.2m depth inside the vent was greater than 20 m/s. Steam vents were further subdivided into "noisy" vents (with steam velocities between 5 and 20 m/s) and "quiet" vents.

Noisy vents are marked by an audible discharge of steam. Using this classification, it was found that two fumaroles and seven noisy vents *(see* **Fig. 2**) occur in the Red Crater field. Fumarole A (see Fig. 2) discharged steam at a velocity of about 45 ± 10 m/s (this fumarole was sampled on 9.9.73 by Giggenbach); fumarole B discharged steam with a velocity of about 30 m/s.

A weaker fumarole, referred to as "Central Crater fumnarole" by Giggenbach (1975) lies near the bottom of a steaming cliff on the lower slopes in the SW corner of Central Crater, about 450m to the NW from fumaroles A and B shown in Fig. 2; a small patch of steaming ground occurs on the upper slopes above this fumarole. Since no other thermal ground occurs in the Central Crater, it can be inferred that these manifestations are fed by some lateral steam flow from Red Crater. The gas composition of the Central Crater fumarole is almost identical to that of samples from fumaroles A and B in Red Crater (Lyon and Stewart 1985).

Explosion crater lakes

Two lakes, the Upper and Lower Emerald Lake, and a lakelet near the upper lake, are most likely explosion craters which were created by phreatomagmatic or hydrothermal explosions during one of the recent eruptions of Red Crater. The bottom of the two lakes dips steeply inwards with slopes of 30 to 40" about 3m from the shoreline. The upper lake and the lakelet are acidic (pH between 3.5 to 4) whereas the water of the lower lake had a pH value of 5. The temperature of the upper lake was slightly higher (10 to 11°C) than that of the lower lake (9 to 9.5°C).

Chemical analyses of the lakes and of a small stream which emerges about 100m below the lower lake and which drains into the Oturere Valley are listed in Table 1.

The data can be interpreted by a model where some steam with minor H_2S enters the upper lake. No steamheated water or condensate enters the lakes since the SiO_2 concentration is about the same for both lakes. Steamheated water and condensate, however, is discharged at a lower level by the stream draining into the Oturere Valley (sample 6 in Table 1) and whose SiO_2 concentration is 92 mg/kg. The Oturere Stream in the Oturere Valley also contains a significant proportion of steamheated groundwater and condensates as indicated by the rather high SiO_2 concentration.

No explosion breccia was found at the surface around the two larger lakes. A thin, fresh, dark lava flow lies on top of a 1.5 to 2 km thick pumice layer near the SW edge of the Lower Emerald Lake. The pumice has been identified (G.P.L. Walker, pers. comm.) as Taupo pumice (ca 100 AD). The section is exposed in a small cliff about 15m from the lake shore.

Table 1: Incomplete chemical analyses of lakes and streams in the Red Crater Area

(all concentrations in mg/kg)

Sample No.	Acidity as H_2SO_4	Si02	Cl^-	pH (laboratory)
1	74	20	8	4.0
2	74	18	8	4.0
3	74	15	8	4.0
5	8	22	6	5.0
6	nil	92	4	8.2*
7	nil	60	4	8.2*

Note: For locality of samples 1,2,3,5 see Fig. 2; sample 6 was taken from a small stream below the Low Emerald Lake, sample 7 from the Oturere Steam (see Figure 1).
* change in pH due to loss of CO_2 when water boiled.

Natural heat loss

The natural heat loss is made up by steam directly discharged in fumaroles and vents and which was found to be about 6.5 ± 2 MW; Some steam is discharged by steaming ground (about 5 MW) using the empirical relations of Dawson (1964). The heat loss of steaming ground is a minimum value since the high average wind speed at Red Crater will induce higher evaporative losses which have been neglected in this assessment. The minimum heat loss is therefore about 11.5 MW. Since the surface activity at Red Crater is not significantly different from that of the Ketetahi fumarole field, it was assumed that the heat loss is proportional to the area with steaming ground; using this proportionality and a heat loss of about 36.0 MW for Ketetahi, it was inferred that the total heat loss at Red Crater is probably of the order of 20 MW (Hochstein and Bromley, 1979).

Steaming ground in the Te Mari Craters

A field map compiled in 1976 showing the steaming ground in these craters has been lost. Maximum temperatures of 95.5°C were measured in three "noisy" steam vents along a steaming cliff in the Upper Te Mari Crater (see Fig. 1). The local boiling point temperature is 95.2°C at 1450m. Similar temperatures were measured on the SW side of the Lower Te Mari Crater (Sulphur Lagoon) where minor sulphur deposits occur on the surface. Temperatures of up to 90°C were observed at numerous small vents in steaming ground which occurs near the crest of the E and N rim of the upper crater. The temperature of steam escaping on the western flank was significantly lover (50 to 70°C). The total area of steaming ground associated with the Te Mari craters was found to be about 3 x 10^3 m^2. It has been estimated that the total heat loss of these features is of the order of 5 MW (Hochstein and Bromley 1979).

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References:

DAWSON, G.B. (1964): The nature and assessment of heat flow from hydrothermal areas. NZ Journal of Geology and Geophysics, vol. 7, 155-171.

GIGGENBACH, W. (1975): The chemistry of the Tongariro fumaroles. NZ Volcanological Record No. 4, 55-56.

GREGG, D.R. (1960): The geology of the Tongariro Subdivision. New Zealand Geological Survey Bulletin No. 40, DSIR Wellington, 152 pp.

GRINDLEY, G.W.; EWART, A.; DIBBLE, R.R.; HEALY, J. (1965): Tongariro National Park, pp 79-99, in THOMPSON, B.N. ; KERMODE, L.O. ; EWART, A. Ed, New Zealand Volcanology, Central Volcanic Region. DSIR Information Series No. 50, DSIR Wellington.

HOCHSTEIN, M.P. (1975): Geophysical exploration of the Kawah Kamojang geothermal field (West Java). Proceedings 2nd UN Symposium on Development and Use of Geothermal Resources 1975, vol. 2, 1049-1058. US Govt. Printing Office, Washington, DC.

HOCHSTEIN, M.P.; BROMLEY, C.J. (1979): Resistivity structure of the Tongariro Thermal System, North Island, New Zealand. Proceedings of the NZ Geothermal Workshop 1979, 20-28, and 271-273. Geothermal Institute, University of Auckland.

LYON, G.L.; STEWART, M.K. (1985): The Tongariro geothermal system - stable isotope chemistry. Geothermal Resources Council, Transactions, vol. 9, pt. 1, 333-337.

MATHEWS, W.H. (1967): A contribution to the geology of the Tongariro Volcanic Centre. Unpublished PhD thesislodged in the Library, Victoria University of Wellington.

MOORE, P.R.; BROCK, J.L. (1981): A physical and chemical survey of Ketetahi Hot Springs, Mt Tongariro, New Zealand. NZ Journal of Science, vol. 24, 161-177.

TOPPING, W.W. (1974): Some aspects of Quaternary geology of the Tongariro Volcanic Centre. Unpublished PhD thesis lodged in the Library; Victoria University of Wellington.

WILSON, S.H. (1960): Physical and chemical investigations of Ketetahi Hot Springs, pp 124-143, in: GREGG, D.R: New Zealand Geological Survey Bulletin No. 40, DSIR Wellington.