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CONTINUING CHANGES IN SURFACE ACTIVITY AT CRATERS OF THE MOON THERMAL AREA, WAIRAKEI

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ABSTRACT

Changes in thermal activity, including steam eruptions, the appearance of new fumaroles and the ceasing of older ones, have continued to occur at Craters of the Moon thermal area. These changes began in the early 1950's, when the pre-exploitation heat output was relatively stable at about 40 MW. Qualitative assessment of the changes since the last comprehensive survey in 1978 suggest that the total heat output has not significantly changed from value of 220 ±40 MW. An historically significant change occurred in February 1987 when the famous Karapiti Blowhole suddenly ceased activity. The simultaneous appearance of a weakly steaming hole -30 m away suggests that roof collapse into an underlying cavern probably shut off steam flow to the Karapiti Blowhole. Subsurface collapse of abraded feed zones to fumaroles may be a relatively common cause of fumarole changes and new steam eruptions.

INTRODUCTION

Craters of the Moon thermal area, formerly known as Karapiti thermal area, is an approximately circular 0.3 km area in which steam-dominated activity is widely distributed, with intense activity occurring at about half a dozen locations (Figure 1). The area is situated near the southern resistivity boundary of the Wairakei geothermal field, about 8 km north of Taupo town. It is a major geothermal tourist attraction associated with the Wairakei field.

Craters of the Moon is a prime example for illustrating the changes in surface thermal activity which may be induced by large scale geothermal exploitation for electricity generation. Prior to 1952, this region of the Wairakei field was relatively unimpressive, being a predominantly warm clay area, with thermal activity consisting of small zones of mudpools, hot ground and the relatively powerful fumarole, Karapiti Blowhole (Allis, 1979).

In 1950, exploration drilling commenced in the Waiora Valley, about 3 km north of Craters of the Moon. Large-scale testing of wells began in 1952, and the Wairakei Power Station was commissioned in 1958. Major changes in the natural surface activity at Wairakei (and the associated Tauhara geothermal field) resulted. New fumaroles began to appear at Craters of the Moon in the mid-1950's and large increases in heat flow from steaming ground and fumaroles occurred. Concommitantly, heat and mass output decreased dramatically at Geyser Valley, the former major tourist attraction. Here, the numerous geysers and hot pools died away to be replaced by weaker steam heated features.

Heat output from the Craters of the Moon area was monitored intermittently between 1950 and 1978. During this period heat output increased from the pre-exploitation 1950 value of -40 ±20 MW (Allis, 1979), to -90 MW in 1958 (Dawson and Dickinson, 1970; Fisher, 1964), to a maximum of -400 MW in 1964 (ibid). The heat output then began to decrease, reaching -220 ±40 MW in 1978 (Allis, 1979), a value at which it appears to have stabilised. About one third of the total natural heat output of Wairakei field presently flows from Craters of the Moon thermal area.

With the exception of the investigation of the April 1983 steam eruption (Allis, 1984), only periodic visual monitoring, accompanied by occasional temperature measurements, has been conducted at Craters of the Moon since 1978. The major changes in surface activity that occurred prior to this time have been documented and described in Allis (1979, 1981, 1984) and in the references cited therein. Consequently, only the major changes which have been identified since 1978, and in some cases, a bit of their, history are discussed below.

CHANGES IN SURFACE ACTIVITY SINCE 1978

There is no evidence to indicate that the heat flow in the Craters of the Moon thermal area has changed significantly during the past 10 years. However, it is clear that many of the "older" features have changed character, that new features have appeared (and are continuing to do so) and that the surface activity has generally been shifting southwards. The most prominent of these changes are described below, with feature areas, identified by the letters A-H which correspond to their locations on Figure 1. This lettering nomenclature has been kept consistent with that in Allis (1979), thus allowing easy comparison. Individual features within each area are numbered.

Feature Area A: The fumarole, Karapiti Blowhole (1), was the oldest known (described by Hochstetter (1864) in 1858) active thermal feature existent at Craters of the Moon until its demise in February 1987. The heat output from this feature increased from -12 MW in 1950, to a very impressive maximum of -38 MW in the mid 1960's, then decreased to -7 MW by 1978. The temperature of the Blowhole decreased from 119°C to 115°C in mid-1960 at the time of the eruption of the Rogue Bore (204) almost 2 km NW of the Blowhole (Dickinson, 1961; Allis, 1979). However, in view of the changes in thermal activity that occurred at Craters of the Moon between 1959 and 1961, this drop in temperature could also have been caused by a more local change in subsurface steam flow. From 1978 to early 1987 the heat output of Karapiti probably remained in the range 5-7 MW, until its sudden death in February 1987.

In March 1987, a weakly steaming hole (2) was noticed about 30 m up the hill, to the north of the Karapiti Blowhole site. Later investigation showed that beneath this -3 m diameter hole there existed a huge collapse cavern, >25 m deep (Figure 2). This discovery suggests that perhaps it was the associated underground cavern collapse which blocked off the steam flow to Karapiti Blowhole, resulting in its cessation.

Feature Area B: This area includes thermal features occurring in an area extending from the base, to about three-quarters the way up the hillside located at the northern edge of Craters of the Moon. In 1964, much of this area was found to

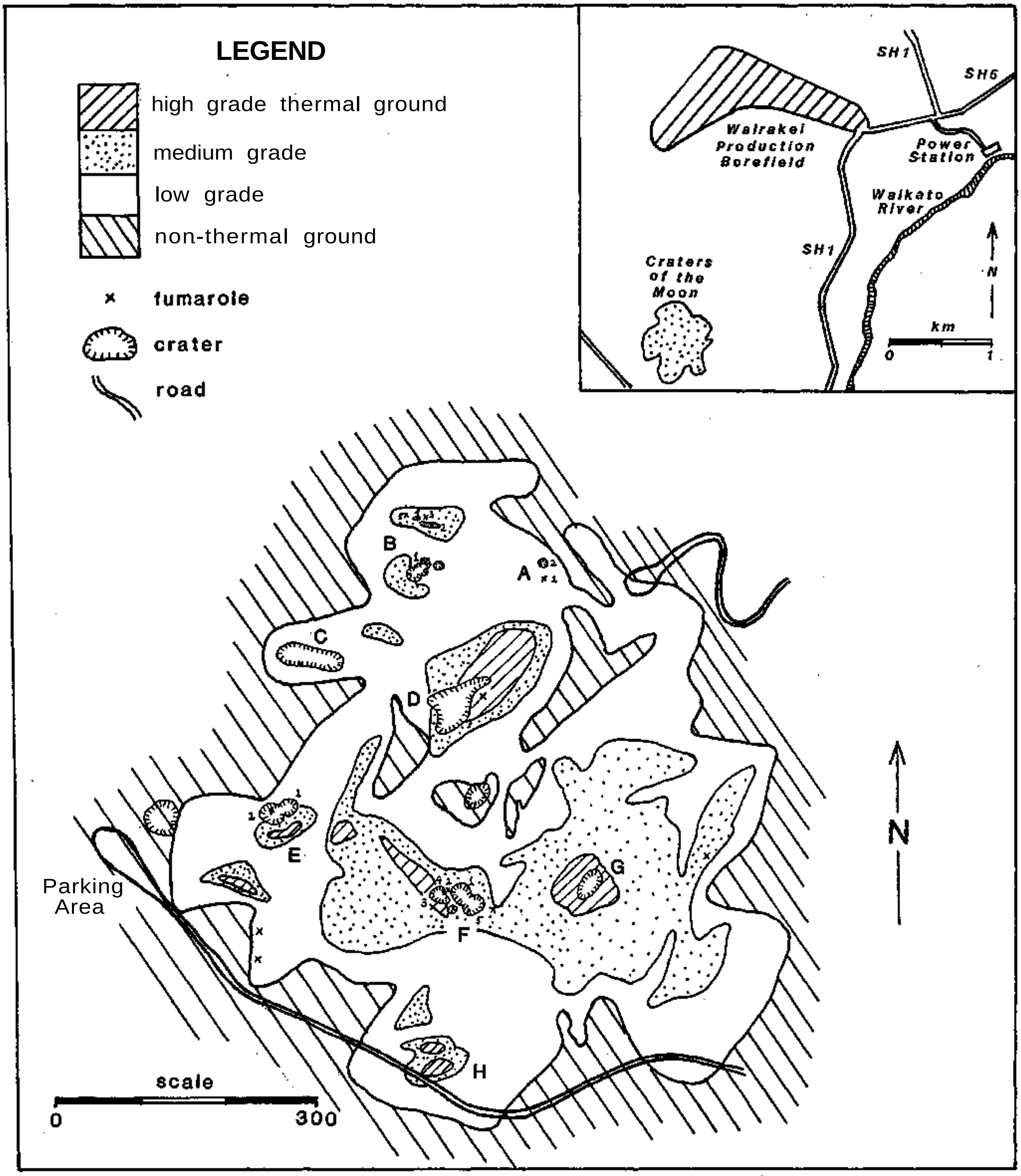

Figure 1: Schematic map of the thermal features at Craters of the Moon, Wairakei geothermal field. The labeled features are discussed in the text. The grades of thermal ground are mapped as they were in 1978 (Allis, 1979), though they are likely to have changed since then. The corresponding average heat flows are: high grade ~5 kW/m^2; medium grade ~0.5 kW/m_2 and low grade ~0.05 kW/m^2. The inset shows the location of Craters of the Moon with respect to the Wairakei production borefield.

have 15 cm temperatures of -16-52°C; with one -10 m x 15 m region, located about two-thirds the way up the hill, having 52-80°C at 15 cm. In December 1967, a powerful blowout (feature (1), Figure 1) occurred at the base of the hillside, about 160 m WNW of Karapiti Blowhole (Dickinson, 1968). This feature became the most powerful fumarole (-116 MW) at Craters of the Moon, and caused reduced heat output in the four features located within -300 m of it. Though the heat output from this fumarole declined to -6 MW by 1978 (Allis, 1979), activity in this area, particularly higher up the hillside, has increased markedly since. There have been at least two other blowouts nearby feature (1) since 1967, resulting in the present day triple-crater area at the base of. the hillside. A small fumarole presently issues from the northern wall of the central crater.

Activity further up the hillside from feature (1) has increased dramatically since mid-1970. The 1978 aerial photos show the presence of two fumaroles -30 m up the hillside, in the area which was identified as having 15 cm temperatures of 52-80°C (see above). Activity in this particular area has increased in intensity and grown in size (mainly westwards). At present there is a large, -20 m x 3 m, steaming muddy pool (2) at a temperature of -40°C, which lies in a similarly elongate crater formed during a blowout in -1986.

Other features which have formed on the upper hillside since the mid-1980's occur directly above and west of feature (2) and include: one relatively strong fumarole (3), to the west of which is a quite active, -2 m diameter mudpool (4), which periodically ejects mud and has built up a "crater type" wall around itself. Approximately 5 m west of feature (4) is a powerful fumarole (5) which probably appeared about mid-1988. In July 1988, this fumarole was discharging steam parallel to the hillside from a vent -0.3 m in diameter and its flow had scoured out an uphill gouge -2.5 m long. The steam temperature measured at the vent was -106.5°C.

Activity on this northern hillside area has increased dramatically during the last 10 years and appears to be continuing unabated.

Feature E: This feature (located beside the boardwalk) was described in 1978 as two coalesced craters having depths of -5 m and -10 m, a combined area of -1200 m and containing mudpools and fumaroles (Allis, 1979). Since this time, the crater areas have grown due to collapse of their steep, highly altered, soft walls and the effects of intermittant nearby steam eruptions. The two craters are presently aligned in an approximately NE/SW direction.

Since 1978, the activity associated with the north easternmost crater (1) has slowly decreased in intensity to its present dried-out state. It does still contain a few small mudpools along the southern edge of its base. A new fumarole appeared on the northwest rim of this crater on -18 September 1986. Four days later, this feature was dead, after having erupted, creating a -3 m diameter crater and covering a -10 m radius area with wet ejected mud.

The south westernmost, deeper crater (2) is still very active, though its character changed in early 1982 from being an extremely ebullient muddy pool emitting large quantities of steam, to its present dried-out condition containing a vigorous fumarole near the base of its western wall. This feature underwent a sizeable eruption in February 1987, when it ejected a thick layer of very fine clayey mud over a distance of -100 m, also covering the nearby tall (-20 m) pine trees to their tops. For the remainder of 1987, this feature remained in a state of very intense activity, with the high steam flow into its viscous mudpool base intermittantly ejecting mud up to -10 m beyond its rim. This behaviour almost resulted in the closure of the area to the public for safety reasons. Since the beginning of 1988, this feature has remained dried-out, despite the heavy winter rains.

It appears that the present dried-out conditions of both craters is a permanent one.

Feature Area F: This general area is located -100 m south of the centre of Craters of the Moon thermal area. In 1964, this region was -70 m in diameter, and contained very hot ground with steam vents and mudpools (Dickinson, 1964). In January 1966, two fumaroles formed in individual craters having -4 m diameters and separated by -10 m (Dickinson, 1968). The area was also described as being extremely active with many smaller collapse pits and mudpools. These two fumaroles appear to have remained unchanged up to 1968 (ibid.). By 1978, these craters had coalesced to form one -600 m^2 crater (1), -10 m deep, containing two fumaroles, one of which was then the most powerful feature (-40 MW) at Craters of the Moon (Allis, 1979).

The activity in this vicinity has continued to be very intense through to the present day, generally growing south and west towards the nearby gully. The area has experienced further eruptions and the formation of collapse craters and fumaroles since 1978. About late August 1986, a new fumarole (2) appeared west of feature (1) and just north of the head of the gully. It was one of the most powerful features in the Craters of the Moon thermal area at that time. It issued from a vent -1 m in diameter, at an angle of -45° towards the NE. In early September 1986, it was ejecting centimetre-sized material to heights of -0.5-2.5 m. It is believed that the activity of this feature continued until at least early 1987.

In late October 1986, the vegetation (mostly very stunted manuka) between feature (2) and the bottom of the nearby gully (a distance of -5 m) appeared to be dying. Sometime prior to 26 April 1988, this area underwent a collapse, creating a large crater containing a very active, boiling mud pool (3) at the head of the gully, just SW of feature (2). This crater, which is presently -3.5 m x 8 m in size, has grown down the gully floor towards the SE and up the gully wall NE until it has engulfed the site of fumarole (2) which no longer exists. The large amount of steam presently issuing from this feature prevents accurate description and makes safe approach impossible.

In early May 1988, cracks with associated steam emission appeared along the southern edge of the gully, concentric about the crater (3). By 2 September 1988, these steaming cracks were several centimetres wide and had grown in number and extended along the southern top of, then back down into, the gully, concentric about the crater. Some subsidence, towards the crater, has also occurred along these cracks. Steaming ground and small mudpots have also formed in the bottom of the gully, -5 m SE of the crater (3). Activity in the region just west and north of feature (3) has also intensified between May and September 1988, with very hot ground and small steam vents present (4).

In mid-April 1988 a new feature (5) appeared -5 m east of extinct crater (1). It was reported to be a boiling, spurting water feature, -1 m across, on 23 April. By 25 April, a large blowout had occurred, creating a crater containing a powerful fumarole, which slowly grew to merge with feature (1). The crater is estimated to be -10-15 m across and -10 m deep, about 5 m deeper than the extinct crater (1) it merged with. Ejecta from the eruption consisted of mostly fine, light-grey coloured mud, and around the crater's rim it varied in thickness from <1 m on the NE side to -0.3 m thick along the SW rim. The eruption appears to have been directed in a NNE direction, with ejecta covering a sector excluding east -50 m and north -60 m. The largest ejecta, which fell within a distance of <5 m from the crater rim, was -0.2-0.3 m in size. It is estimated that about 500-750 m^3 of material was blown out. By 27 May 1988, the fumarole had died, leaving the new feature, a steaming crater with a mudpool in its bottom.

Investigation of the blowout feature (5) on 27 July 1988, also revealed a change in the characteristics of two nearby fumaroles located -5 m east of the new crater. One had become extinct and the other had decreased dramatically in output to a weakly steaming hole.

Feature Area H: Tly's region consists of a reasonably large (>few 10^2 m^2) area comprising hot, steaming altered ground and mud, with some zones having crusty surfaces and some areas covered with clumpy moss and lycopodeum ferns. Hissing steam and boiling water can often be heard. The state of activity in some of the areas varies from being a boiling mudpot (especially after a heavy rain) to a dried, crusty surface with steam small vents. The actual hot thermal ground and associated steam vents have extended south of the nearby wooden fence and road in recent years, and has also grown westwards along the north edge of the road. The intensity of activity in this area also appears to have increased, though not dramatically. The presence of steam vents on both sides of the road, as well as in the road itself, is now a cause for concern because of the tourist traffic to the main carpark.

Features C, D and G: Features C and D do not appear to have changed greatly from their descriptions in 1978, and in the case of G, after the 1983 eruption described in Allis (1984).

DISCUSSION

The dramatic changes in thermal activity at the Craters of the Moon thermal area which began during the early 1950's are continuing to occur today (1988). Hydrothermal eruptions still occur, with a frequency of about one every one to two years. Over the last 10 years these eruptions have been close to existing craters which were generated by earlier eruptions. This has often resulted in the craters becoming larger and deeper with time. The craters near the centre (F) and near the eastern edge (G) of the thermal area are now at least 10 m deep. The steep sides of the crater walls makes them quite unstable, so slumping and the resulting blockage of contained fumaroles appears to contribute to changes in thermal activity.

Although the total heat output of Craters of the Moon has not been surveyed since 1978, qualitative observations suggest that the total heat output has not changed significantly. The uncertainty in the 1978 value of 220 MW was estimated to be at least 20% so the heat output may still be in this range. The steam at Craters of the Moon is originating from a low pressure steam zone in the rhyolite lavas at less than 100 m depth. Steam pressures in wells north of the thermal area have been gradually declining with time (e.g. Grant, 1982), hence so the total heat output at Craters of the Moon may also be slowly declining. The vegetation changes, however, indicate that the area of thermal ground is still increasing. This is particularly obvious around the southeast and southern boundaries, and possibly also

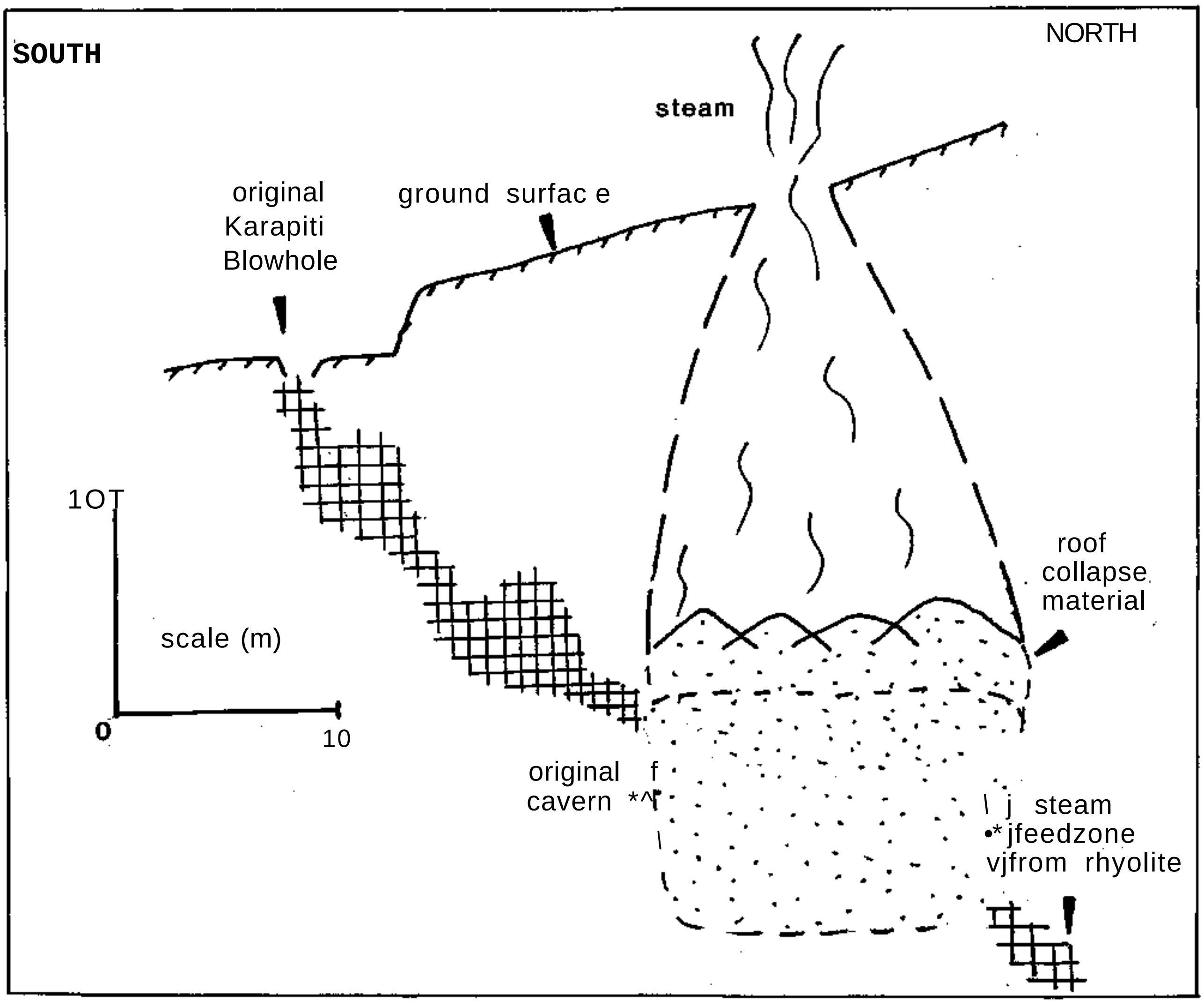

Figure 2: Schematic cross-section of the hillside area "behind" the Karapiti Blowhole after its cessation in February 1987. Roof collapse of a subsurface cavern is believed to have caused Karapiti's final demise.

around the northern boundary. Deducing the heat output changes by the vegetation changes evident in aerial photography has been made more difficult during the 1980's by at least two tree-felling operations by N.Z. Forest Service (which included trees in the middle of the thermal area), and more recently by the Department of Conservation.

The steady increase in the total area of thermal activity at Craters of the Moon probably reflects gradual heating of the surrounding ground, which clearly must precede the lateral spread of steam. There are no groundwater monitor wells near the thermal area to provide data on changes in groundwater temperatures or levels. The deepening and drying out of the crater beside the boardwalk (E) may mean that groundwater levels in the thermal area have dropped with time, if indeed, there is a groundwater aquifer overlying the steam zone. It may be more accurate to consider a near surface zone of partial saturation which is completely saturated locally, particularly after periods of wet weather.

Allis (1983) speculated that the timing of hydrothermal eruptions may be influenced by the weather. It was suggested that a few days of heavy rainfall after a long dry period may decrease the permeability to steam in the floor of a crater, thereby causing a small increase in steam pressure at depth which is sufficient to exceed the weight of near-surface pumice and start the eruption. The April 1988 eruption was not obviously related to rainfall immediately prior to the event, so this mechanism may not be widely applicable. There was a month of relatively dry weather beforehand however, so the dryout, and therefore the decrease in shallow overburden pressure could still have been a contributing factor. As already mentioned, slumping of crater walls causing fumarole blockages is another mechanism. The blockage of one fumarole could be sufficient to cause a sudden increase in the underlying steam zone pressure, resulting in a new blowout nearby. The high pressure fumaroles at Craters of the Moon appear to steadily abrade their vent walls with vent diameters increasing with time, and fine pumice dust sometimes being mixed with the steam. Abrasion may also occur in the deeper steam channels feeding the vents, so sudden collapse and blockage could occur at depth, and there would be no obvious evidence for the stoppage of one fumarole and the eruption of a new crater and fumarole nearby. The collapse of the roof of the massive cavern feeding steam to the Karapiti Blowhole may be an extreme example of this process.

The powerful superheated steam flows from the Craters of the Moon thermal area mean the low density, pumiceous ground is inherently unstable, and further dramatic changes can be expected. Existing fumaroles may become blocked, new eruptions can be expected, with the formation of new craters, mudpools, and fumaroles.

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