Annual Conference of the Geoscience Society of New Zealand

Field Trip 2
Monday 26th November2018
White Island

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Cover image: Aerial view of White Island from NE 25 July 2018 during a routine GeoNet gas flight.

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INTRODUCTION

White Island has been a prominent part of the view from the Bay of Plenty coast since the early 1880's, steaming away on the horizon. In recent years, White Island's landscape has been reconstructed by a large and fatal landslide in 1914, explosive eruptions and crater formation post 1975, gully erosion and post 2003 the formation and destruction of crater lakes. This field excursion will highlight the products and processes of White Island's recent history. The island is privately owned, by the Buttle family. GeoNet has an active volcano monitoring system on the island, and the island also supports many research projects and tourism. Currently it is one of New Zealand's most active volcanoes.

HEALTH & SAFETY

The fact is we are visiting an active volcano that may erupt at any time. There is an open water boat trip for about 80 minutes each way, so be prepared for sea-sickness. At the island, participants will be transferred from the main boat into an inflatable dinghy. There is a short ladder at the jetty, then a short boulder hop onto the island proper. White Island Tours will provide gas masks and hard hats for walking around on the island.

Covered shoes are required to provide some protection from hot ground and hot acidic water – no jandels or open-toed sandals are allowed. The ground on the tracks is generally dry and dusty, though in places it might be rough and uneven or damp with slippery clays at shallow depth. White Island Tours will give the group a safety briefing before we depart, informing us of hazards on the boat trip and at the volcano.

GEOLOGY AND 1976–2000 ERUPTIONS OF WHITE ISLAND

White Island is the summit of a largely undersea volcano situated 48 km from Whakatane in the Bay of Plenty. The portion of the volcano above sea level forms a steep-sided and highly eroded edifice, which is visible from the mainland. About 70% of the volcano is below the sea (Fig. 1). White Island has seen near continuous volcanic activity for 150,000 years and is currently New Zealand's most frequently active volcano. Intermittent volcanic activity was apparent since the first observations in 1826, mostly in the form of small steam and ash eruptions, that generated many small craters, especially in the western portion of the crater floor (Fig. 2). After 1975 the character of the eruptive activity changed significantly as magma started to reach the surface (Houghton and Nairn, 1991).

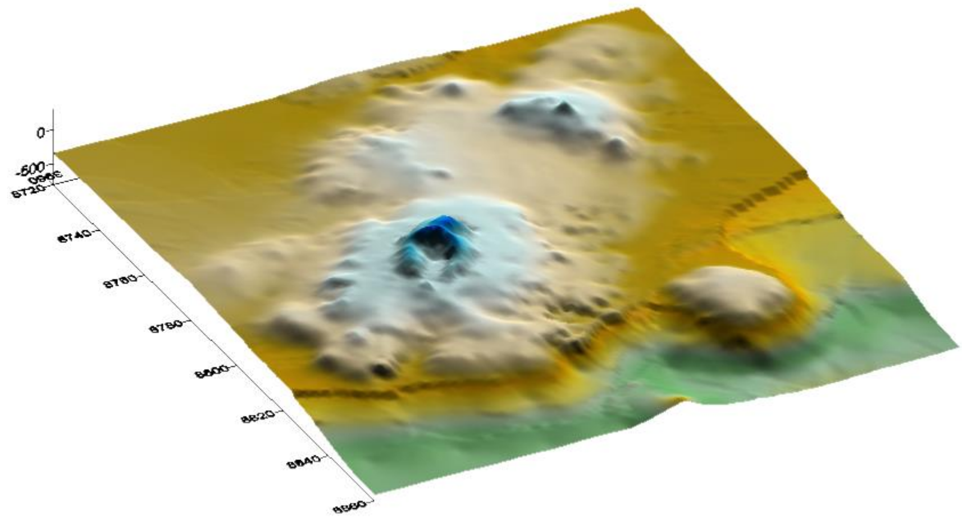

Figure 1: White Island area viewed from the northeast.

White Island is constructed of predominantly andesite–dacite lava flows and pyroclastics, which subsequently have been hydrothermally altered (Clark and Cole 1986; Cole et al., 2000; e.g. Hedenquist, et al. 1993). Three sub-craters are recognised on the Main Crater floor (Fig. 2) and all historic activity has been confined to the Western sub-crater. Historic volcanic activity on White Island was dominated by phreatic activity, creating short lived eruptions and small craters from the 1830's until 1975 (Fig. 3). After 1975 more magma became involved, the tempo of eruptive activity increased, larger craters where formed, phreatomagmatic and magmatic eruptions followed through to 2000 (Houghton and Nairn, 1991). Volcanic unrest restarted in 2011 and further phreatic eruptive activity occurred in 2012, 2013, 2014 and 2016. Unrest is now declining. Hydrothermal activity currently comprises continuous and intermittent hot spring activity and gas–steam release from numerous fumaroles, and heat flow into the crater lake (Christenson et al. 2017). The temperature of the lake is currently about 56 °C (Fig. 16; Sept 2018).

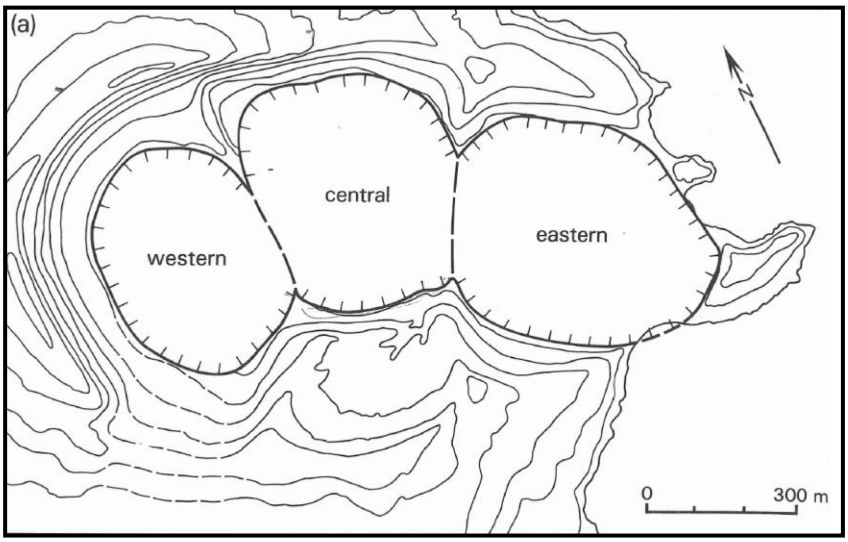

Figure 2: Location of postulated sub-craters within the Main Crater of White Island (after Houghton and Nairn, 1989).

The largest and longest historically recorded eruption sequence began in December 1976 and continued semi-continuously through to July 2000. This eruption sequence included numerous small to moderate sized volcanic eruptions (Houghton et al., 1989), and formed large collapse craters. Effects on White Island vegetation show that this has been the most damaging eruption sequence for the last 200 years (Clarkson and Clarkson, 1994; Houghton and Nairn, 1991).

Magma rose to shallow levels in 1976, when ground surface deformation (inflation) peaked and the largest individual eruptions occurred in 1977–78 and 2000, with incandescent eruption columns observed from the coast. The largest explosive eruptions threw bombs and blocks over the entire Main Crater floor, with a major pyroclastic flow (surge) in August 1977. At times, voluminous ash clouds covered the entire island. About 10^7 m^3 of mixed lithic (old rock) and juvenile (new lava) ejecta, mostly ash sized, has been erupted in alternating wet steam explosions and dry strombolian (lava fountaining) phases (Houghton and Nairn, 1991).

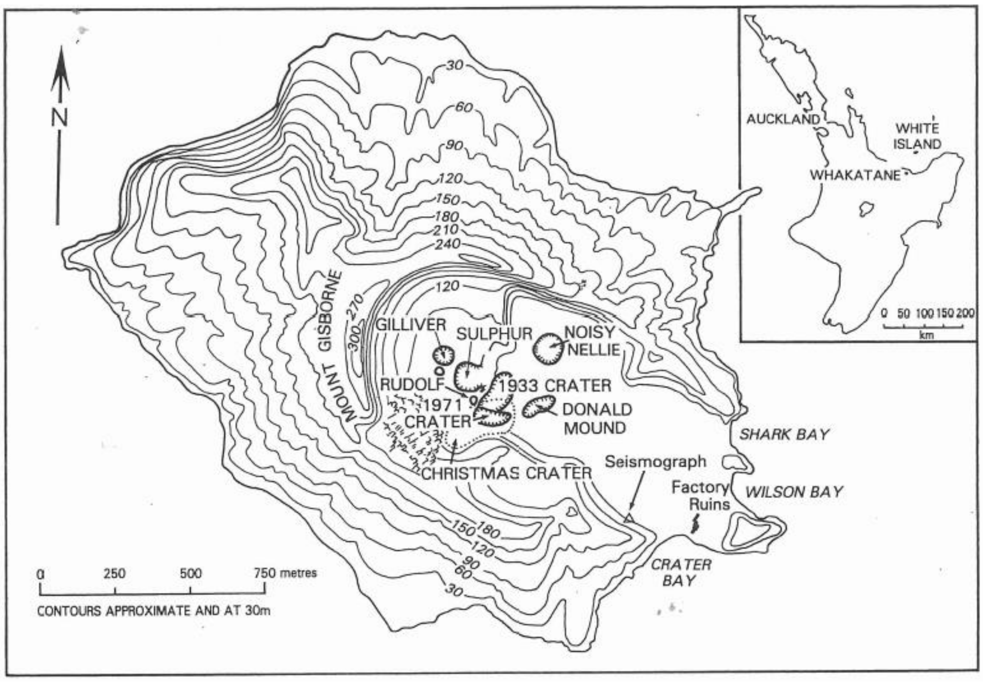

Figure 3: Location of the vents and active craters on the Main Crater floor before 1976.

The lithic ejecta is derived from the partial re-excavation of the sediment infilled Western subcrater (Fig. 2), initially forming "Christmas" and "Gibrus" craters. These craters later coalesced into the "1978 Crater Complex" (Fig.3). Eruptions occurred less frequently in 1979–80 as the magma retreated. At times the floor of the vent was more than 200 m below sea level. During the 1980s and 1990s small scale eruptions continued, accompanied by the formation of numerous small craters within what became the “1978/90 Crater Complex” (Fig. 4). In July 2000, an explosive strombolian eruption occurred, covering much of the Main Crater floor in scoriacious lava bombs. Conditions in the 1978/90 Crater Complex then cooled, and lakes could develop.

The eruptions and collapses since 1975 have excavated a significant depression that has extended below sea level in the Western sub-crater, and built a low-angle tuff cone around the margins of the 1978/90 Crater Complex. This tuff cone is about 100–150 m wide and a maximum of 10–15 m thick and is composed of unconsolidated pyroclastic fall deposits. The Crater Lake in the 1978/90 Crater Complex is impounded by the tuff cone.

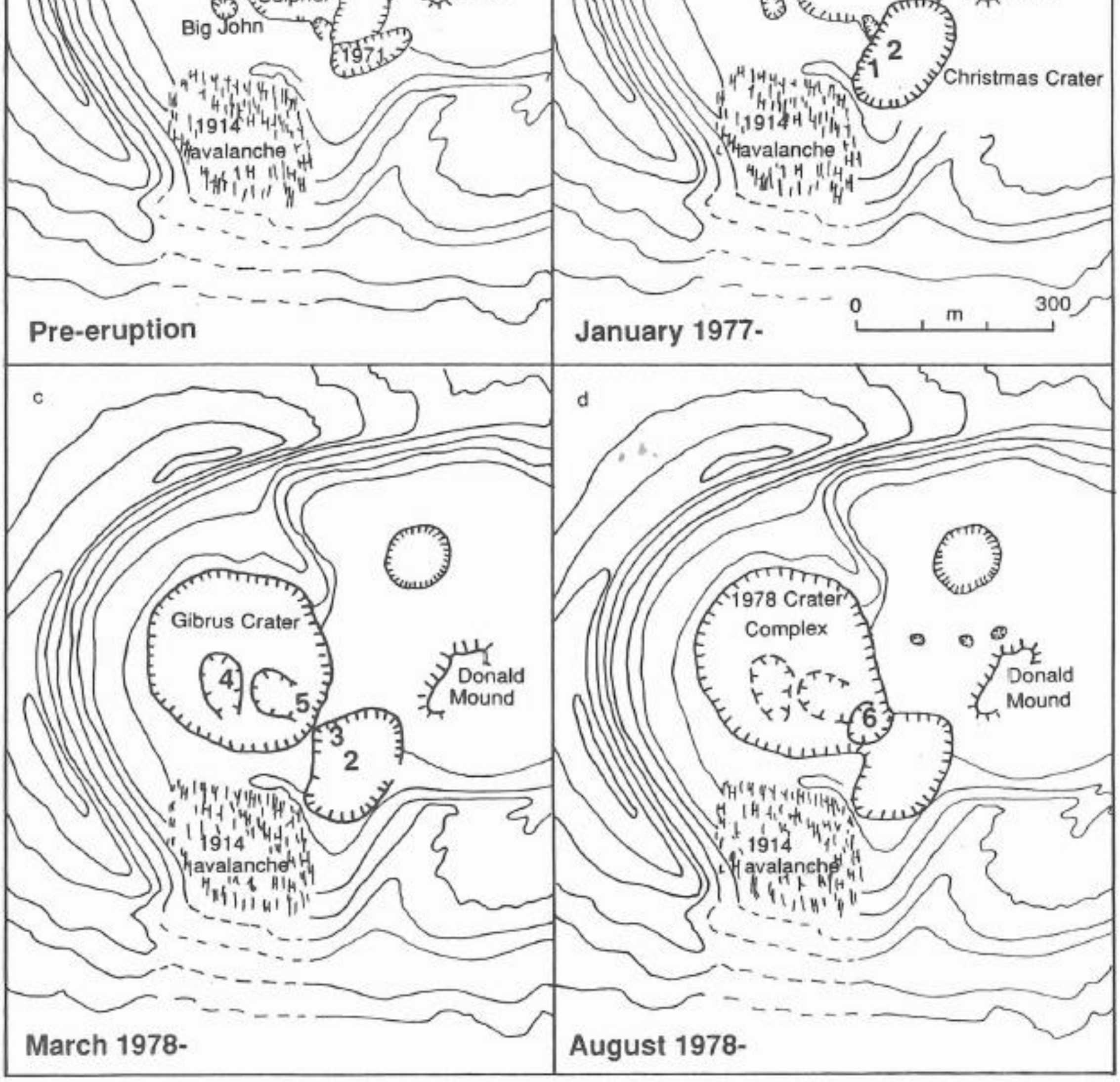

Figure 4: Summary of the collapse crater and vent geometry during the 1976–1990 eruption of White Island. Vent locations are numbered: 1 Dec 1976–March 1977; 2 March 1977–Nov 1977; 3 Nov 1977–March 1978; 4 Feb 1978–March 1978; 5 late March 1978; 6 Dec 1978–1990.

THE 1999–2000 ERUPTION EPISODE

For the first time in more than 20 years, a small batch of fresh magma reached the surface in 1999 and 2000, generating two small explosive eruptions from beneath the 1978/90 Crater Complex (Fig. 5).

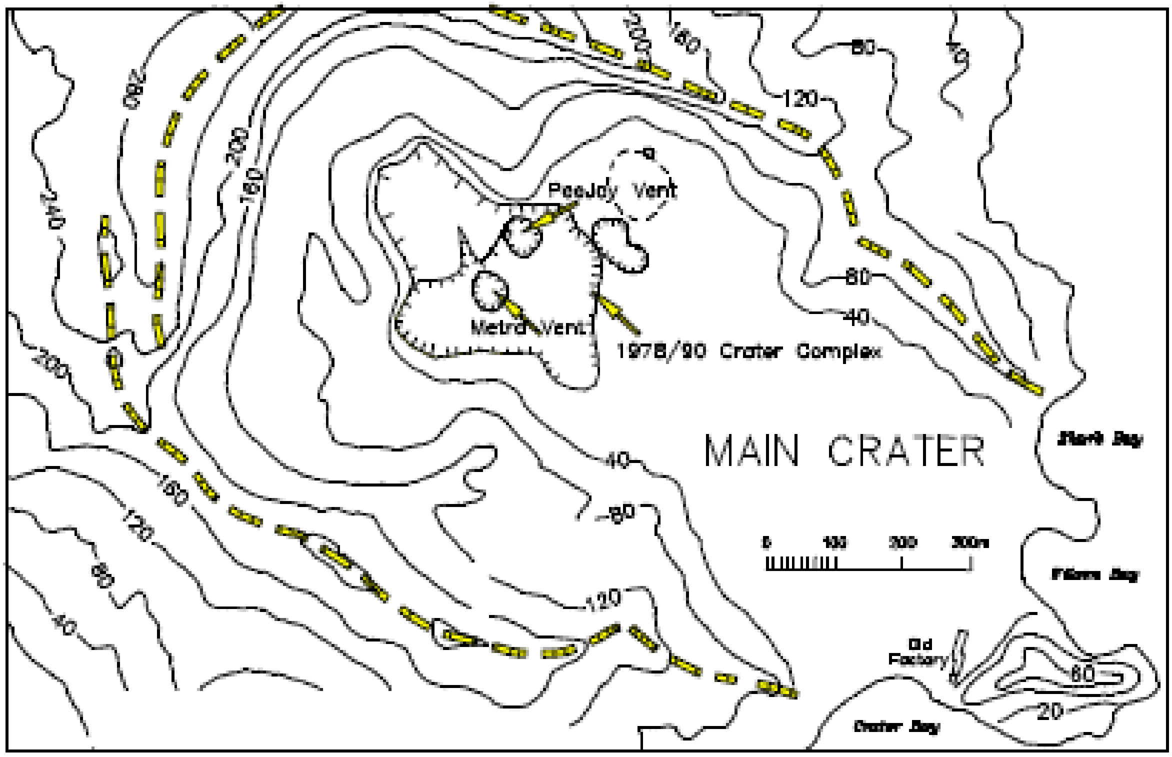

Figure 5: Sketch map of Main crater at White Island showing locations of PeeJay and Metra craters formed in 1999 within the 1978/90 Crater Complex.

April 1999

In January 1999, a surveillance trip to White Island revealed a relatively low level of eruptive activity, but found that a new vent, about 50 m diameter, had formed in 1978/90 Crater located approximately at the site of a crater (Wade Crater) that was very active in the 1980s. Frequent hydrothermal eruptions of black muddy water were occurring in the new “Metra” vent and ash-poor steam-rich plumes to 600 m were being emitted. There had been a prior increase in seismic activity which, combined with the low level of eruptive activity, suggested that magma was being intruded beneath the surface. In the next several weeks, minor ash and steam emission was sustained and sub-craters of the 1978/90 complex were occupied by a lurid lime-green lake, which by April 1999 had declined to a few small puddles of yellow-green coloured brine.

On Sunday 18Th April 1999, White Island erupted and the whole of the island was thinly blanketed with light grey coloured ash. At least 10 cm of fresh ash fell within a 200 m radius of the Metra source vent. Blocks and bombs (maximum 2 m x 2 m) were ejected towards the S and SW to approximately 450 m and abundant centimetre size fragments impacted new ash radially to at least 600 m, though distribution thinned towards the NE. Most of the large bombs were juvenile, black highly-vesicular andesite, sometimes with internal crystal (plagioclase) rich and crystal-poor banding (Fig. 6). There was no evidence of plastic deformation and the largest blocks had shattered on impact. Most bombs had an outer rim of red “baked” ash. Ballistic blocks were generally smaller (< 300 – 500 mm) but relatively more abundant than the lava bombs. Poorly sorted muddy sandstone blocks (crater-fill) were the most common variety, being either “fresh” dark grey soft sandstone or harder red/yellow/pale grey (hydrothermally cemented altered) material. Hydrothermally altered andesite lava blocks were less common.

Figure 6: Left: 12 January 1999 oblique aerial view of Metra crater area with weak ash-poor eruption typical of PeeJay vent. Right: 18 April 1999 impact-fractured juvenile andesite lava bomb.

July 2000

By August of 1999, White Island activity had declined to background levels and another small shallow brine lake had formed. In March 2000, weak ash emission recommenced from a vent (“MH” vent) on the ridge southwest of the location of PeeJay vent which was active in 1999. COSPEC measurement of SO_2 in the plume was, at the time, the highest then recorded and was interpreted as a precursor of further eruptions. During April to June, volcanic tremor increased and steam and ash plumes were commonly seen. By mid-July, seismicity was at almost background levels but MH vent was producing a strong yellowish brown coloured gas and ash plume to 1500 m altitude, visible c.20 kilometres from the island. Several millimetres to several centimetres of yellowish brown coloured fresh ash covered the island and the sea-water beneath the plume was visibly discoloured by ash fall. Between 5 pm and 10 pm on Thursday 27th July 2000, moderate-sized explosive Strombolian style eruptions occurred from the floor of the 1978/90 crater complex. A thick deposit of ash and scoria was spread east of the crater, extending at least as far as the sea, 700 metres away.

The eruption, signalled by a short period of strong seismicity, occurred during poor weather and a strong westerly wind, and the ash deposits were restricted to the eastern sector of the island. The new 120–150 m diameter explosion crater occupied the site of a shallow, warm-water lake that had filled most of the floor of the 1978/90 crater complex for more than a year. The lake completely disappeared and low-pressure steam, gas and ash were being emitted from the new crater and MH vent. MH vent, active since April, was widened to c. 50 m size and was also emitting steam, gas and ash. The eruption was of similar style and scale to the magmatic eruptions of March–April 1977. It generated a thick deposit (up to 30 cm) of ash, rock debris and fresh mafic pumice blocks that covered much of the main crater floor, extending at least as far as the sea, 700 metres away (Fig. 7). Pumice blocks up to 1.5m diameter were observed. The shapes of these blocks indicate that they impacted the ground in a semi-molten state.

The focus of activity since that time (until 2003) was strong (though gradually declining) steam and gas emission from the active MH Vent. In 2000, the volcano was at Alert Level 2 for 154 days.

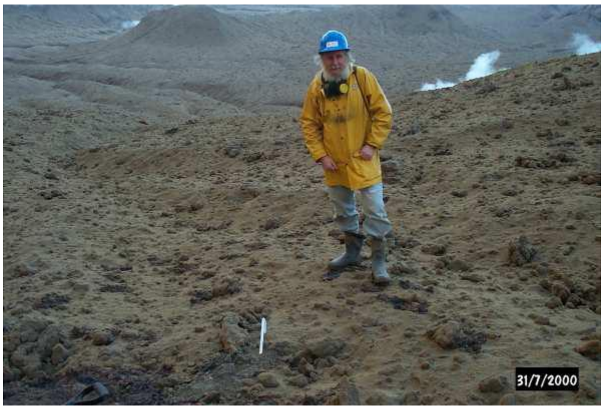

Figure 7: Left: 27 July 2000, Strombolian tephra deposit (red brown colour in main crater) was clearly visible in early August 2000. Right: Fresh magmatic bombs, lapilli and ash blanketed most of the crater floor.

2011–2018 Activity

In 2011 signs of volcanic unrest again started to be seen at White Island. This was particularly noticeable in the seismic energy and SO_2 gas flux (Fig. 8). The background SO_2 gas flux (monthly average) increased from around 50–60 tons per day to around 400 tons per day. This was indicative of new magma reaching shallow levels in the volcano. This increase in gas flux was also accompanied by an increase in the seismic energy, measured as the daily average ground velocity (nm/s).

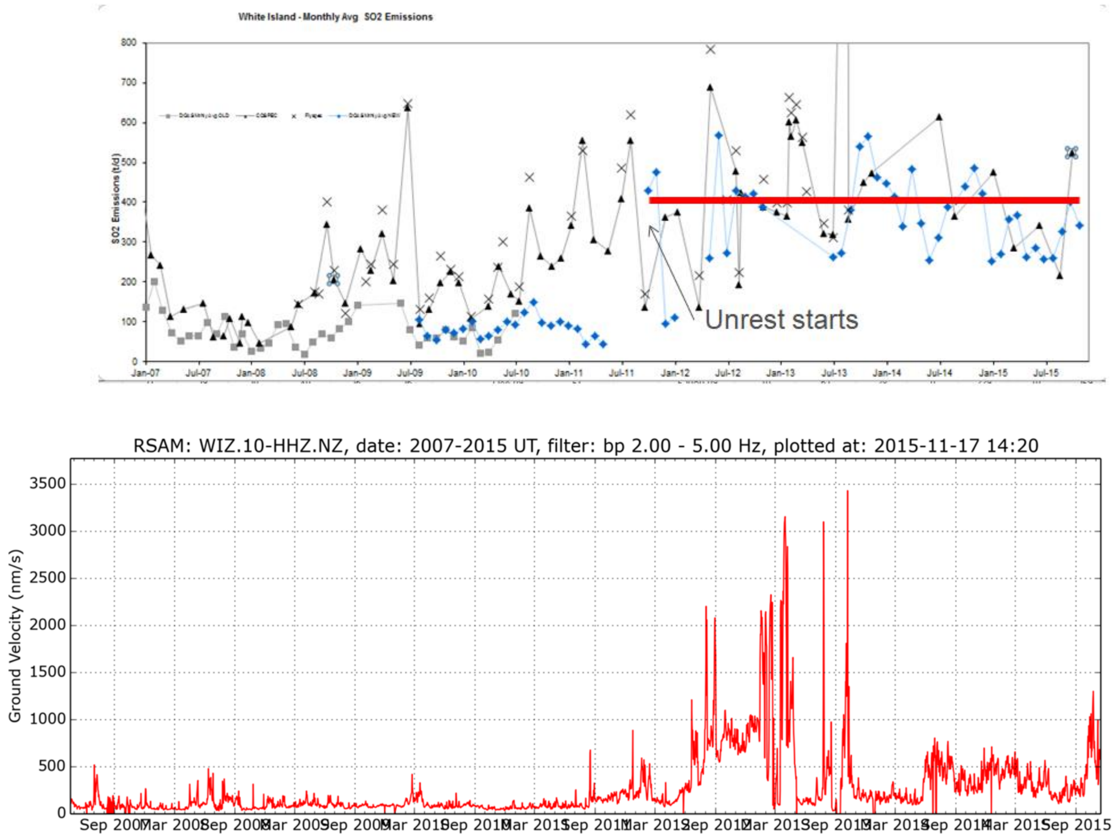

Figure 8: Time series plots for the gas flux and seismic energy (WIZ) before and during the 2011 unrest as recorded by the GeoNet project.

This increase in volcanic unrest lead to a series of eruptions over the next 4 years. The first significant change was in July 2012, when the lake level rose about 2–3 m between 27 and 28 July. The level continued to rise through to August 3 with explosive eruptions on August 4, followed by ash eruptions through to the 17^{th} (Fig. 9).

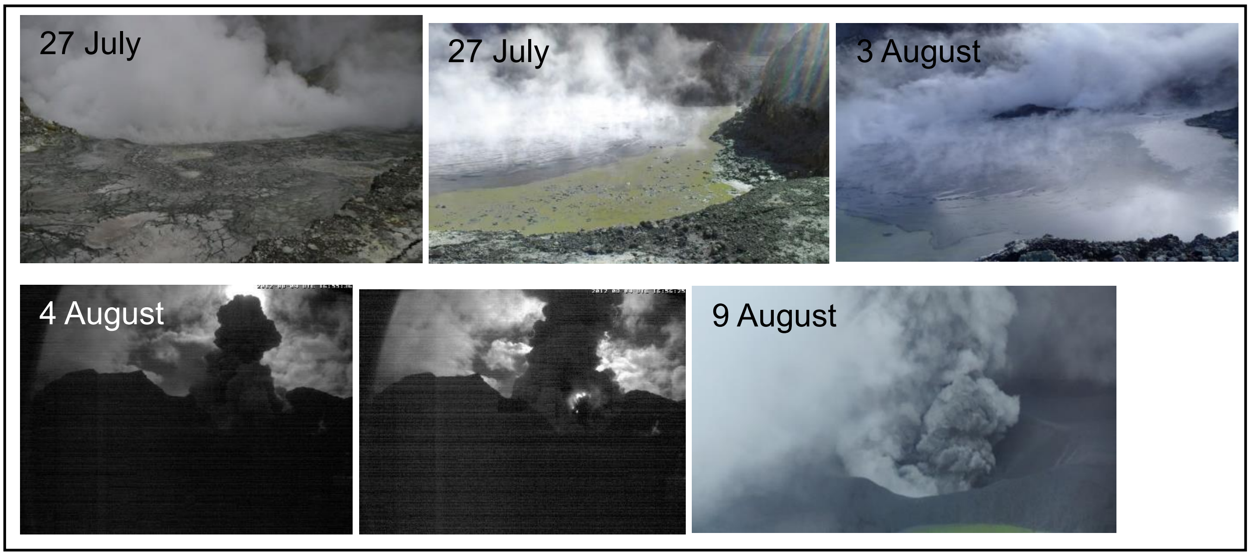

Figure 9: Views of the crater lake showing rapid water level chnages before the 4 August 2012 explosions and ash emissions that followed.

During the period September to November 2012 the volcanic unrest was dominated by high gas flux, often obscuring views, and vigorous wave action in the lake. When views improved in December a small lava extrusion was visible in the active vent area. The lake was gone and water was only present in two small craterlets much reduced in size (Fig. 10).

Figure 10: View of the 1978/90 Carter Complex, showing the two small ponds and the lava dome in December 2012.

The February though to March 2013 period was dominated by spectacular phreatic activity, every few seconds molten sulphur and hot muds were 'geysering' from one of the active vents. Bursts of steam, sulphur and mud reaching 70–100 m high (Fig. 11). In the April through June period water started to pond on the floor of 1978/90 crater complex and drowned the active vent area. The level of recorded seismic activity declined at that time (Fig.8). Phreatic activity restarted in the larger pond during July and extended into August 2013.

Figure 11: Views of the phreatic activity in the active vent (February–March 2013).

On 20 August 2013 a series of explosive eruptions followed from the active vent. Spared headed slugs of ejecta exploded to several hundred metres height and tall steam plumes formed above the island (Fig. 12). Fortunately, no tourist was ashore at the time of the explosions. The island was visited later in the day. The impacts of these explosions were restricted to the 1978/90 Crater Complex. Further sequences of stronger explosive eruptions occurred on 4, 8 and 11 October. About 30% the Main Crater floor was impacted by ejecta and surges (Fig. 13).

Figure 12: Views from the crater rim web camera on 20 August 2013, showing the explosive eruptions from the active vent and a view of the steam plume from a tour boat.

Figure 13: Before and after views showing the area impacted by explosive jetting and surges on Oct 8. Note the dark grey ash coating in the crater floor.

Following the October eruptions activity declined and a crater lake started to reform on the floor of the 1978/90 crater complex in November 2013. The lake continued to grow through 2014 and 2015, drowning steam vents as the water level rose (Fig. 16). Landslide activity also occurred in to the reforming crater lake (Fig. 14).

Figure 14: Views from the West Rim web camera in June 2015 (left) and November 2015 (right), showing the impacts of landslide activity into the lake.

On 27 April 2016 strong and potentially fatal explosive eruptions occurred from the floor of the 1978/90 Crater Complex. These explosions produced extensive surges across the Main Crater floor sheering off survey pegs, removing the Crater Lake and about 13 m of the lake floor and generating collapse of the crater margins (Fig. 15). Minor ash emissions also occurred in September 2016, but were not sustained for every long.

Figure 15: Top left, view showing the extent of the surge deposit (white line); Top right, damaged survey peg, broken by passing surge; Bottom left–right, views from crater rim showing the lake before and after the eruption. Note the excavation of the crater floor.

CRATER LAKE: 2003–2018

In February 2003 a large pool of water started to collect on the floor of the 1978/90 Crater Complex, drowning the vent that was active during the July 2000 eruptions. By late March the water level had risen enough to create a breach into the then active MH Vent and started to flood it. By August the water level had risen to such a height it was clear that the pool of water was growing into a semi-permanent lake within the crater. The rising water also offered easier access to the lake and a monitoring programme including water level and temperature. During 2004–2005 the lake filled to almost reach overflow level. The lake started to heat in 2005 and by 2006 was starting to evaporate as it heated. The lake had retreated to below sea level by mid-2007 (Fig. 16). A smaller lake then reformed in 2007–08 but only rose to within 6–7 m of the overflow level and was sustained until the unrest mentioned above started in 2011, which again decreased the size of the lake. There was not lake present by December 2012 (Fig. 10). Following the August and October 2013 eruptions a lake started to reform (Fig. 14,16). This lake did not fill as high as previous lakes. In April 2016 it was removed along with about 13 m of the lake floor (Fig. 15, 16). Since early 2018 a new lake has started to form.

Detailed topography is available of the 1978/90 Crater Complex so it is possible to calculate lake surface areas and volumes. When full, the lake would have an area of 74850 m^2, whereas when low it only covers about 24800 m^2. When (if?) the lake reaches overflow level the volume of the water in the crater will be about 1.8 million m^3. The volume in the top 5 m, which is the estimated volume of water that may drain when the lake overflows and cuts down to establish an outlet is about 35150 m^3. The lake fills at about 1900 m^3 per day (22 litres/sec). The primary source of water filling the lake was, and in future is likely to be, condensing steam and gas from fumaroles now beneath the lake and runoff from the surrounding crater walls.

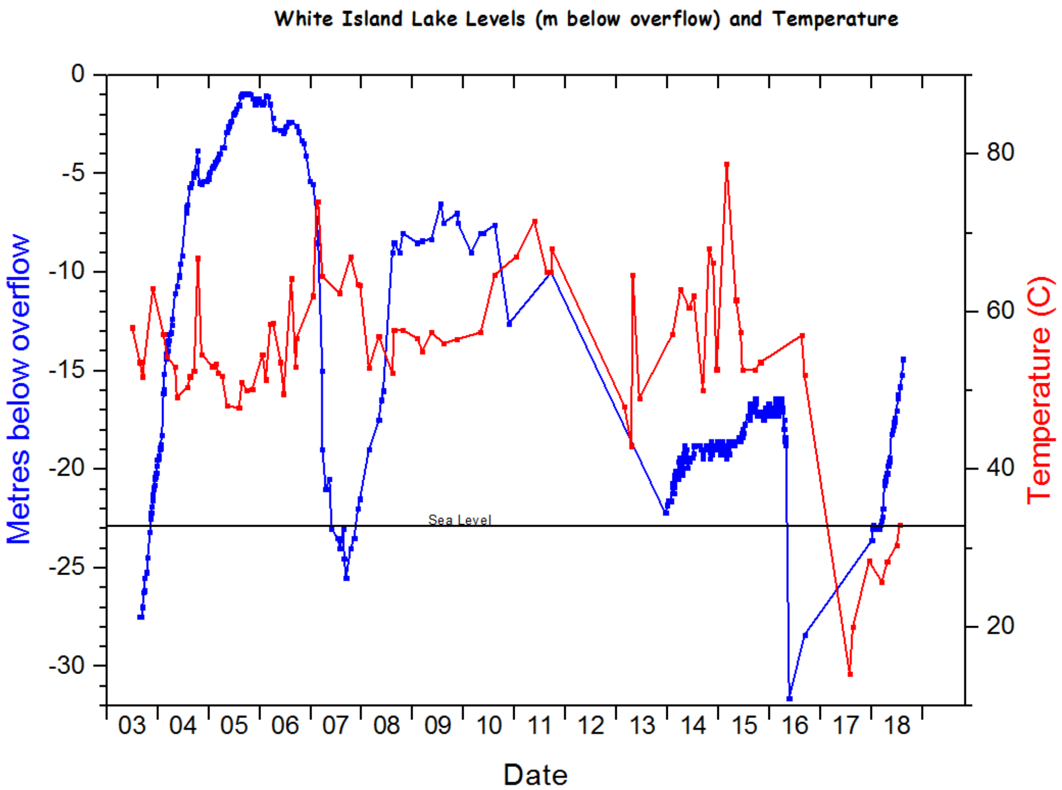

Figure 16: Time series plot of water level and temperature in the Crater Lake (2003–9 October 2018).

The establishment of a semi-permanent Crater Lake at White Island has changed the range and likely impacts of the hazards to visitors on the island (Scott, et al. 2004). The Crater Lake(s) on White Island now present visitors and users of the island with a range of previously undocumented hazards. In 2005, the lake filled to within 1m of overtopping, through Donald Duck Crater on its northern side. If in the future the lake reaches overflow level, hot acid lake water will flow east-southeast down an existing valley system on the northern side of the Main Crater floor; reaching the sea at Crater Bay. Flow may also reach Wilson Bay if the released flow is large enough to flood over the July 2004 landslide debris onto the flat surface to the east. Based on the outbreak flood scenario modelled (see Scott, et al. 2004) a hazard map is presented in Figure 17 which indicates areas where there may be a risk of flooding.

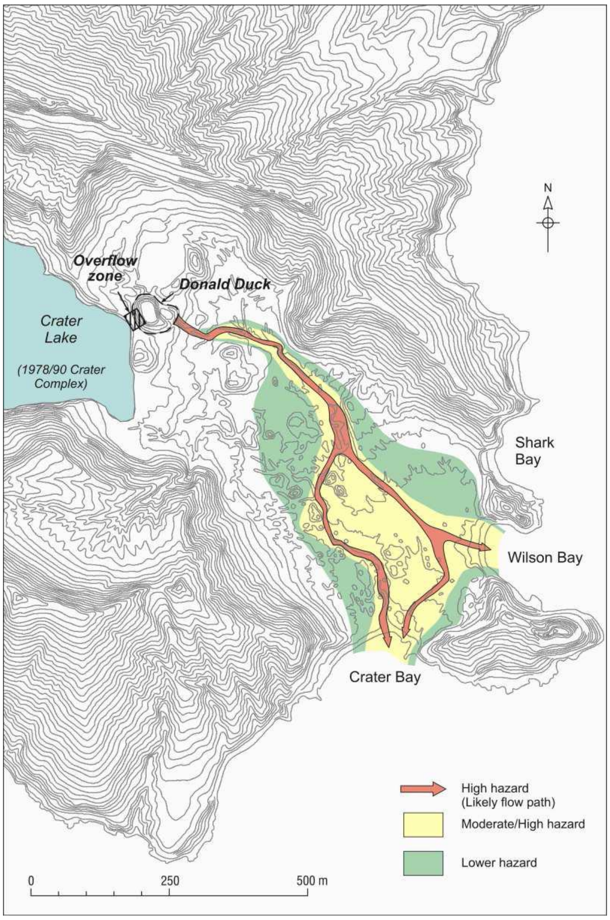

Figure 17: Hazard Map for Crater Lake Dam break scenario or an overflow from a small landslide or eruption.

MONITORING

Detailed monitoring started in 1967 with a programme coordinated by Victoria University of Wellington, including University staff and staff from DSIR NZ Geological Survey and Chemistry Division. Monitoring included ground temperatures, spring and fumarole chemistry, ground deformation and magnetic measurements. In 1975 a seismograph was added, with radio telemetry back to Whakatane.

The first success for the monitoring system came with the 1971 eruption, when a clear deformation signal was seen in the months before the eruption (Clark, 1973). A similar signal was also seen before the 1975 activity started (Clark and Otway 1989). The eruptions starting in 1975 were to continue through to 2000 and saw large changes on the island, along with the destruction of some monitoring sites (e.g. levelling pegs, solar panels). Today the monitoring is conducted by the GeoNet project (www.geonet.org.nz) and includes seismicity, ground deformation, soil gas flux, fumarole chemistry, spring and lake water chemistry, land and airborne gas flux measurements (miniDOAS) and near real-time web cams.

The seismic data from a broad band sensor installed in 2007 is telemetered to Whakatane, and on to the GeoNet data centres (Avalon and Wairakei), along with data from a micro barograph that can measure the airwaves from explosions. A variety of volcano seismic signals are recorded, including high and low frequency volcanic earthquakes, very low frequency (VLP) signals, volcanic tremor and complex volcanic/explosion earthquakes. The GeoNet system includes tremor detection and alarm to detect changes in the level of volcanic tremor and alert staff on duty.

The ground deformation surveying continues, based on the levelling network established in 1967. Several of the original sites were lost when 1978/90 Crater formed; hence no data is now collected from close to the active vents. The network of pegs has been modified as necessary, with time–space overlap with the old sites. The larger scale activity trends are well depicted by the levelling data (Figure 18); for example, with inflation of the crater floor showing before the 1971 and 1976 outbreaks, subsidence during the 1975–1990 eruptions, and uplift before the July 2000 eruption. The network was significantly damaged in 2016.

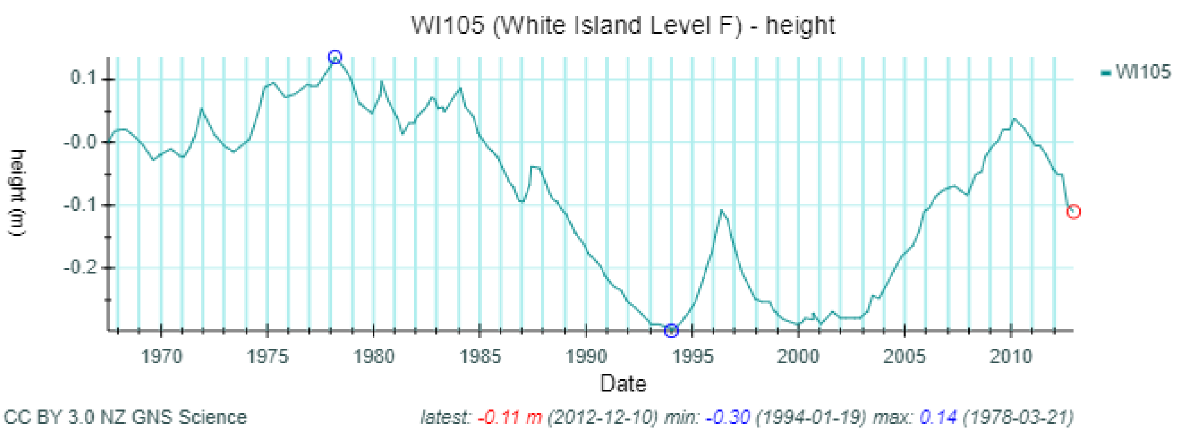

Figure 18: Time series plot showing height changes at Peg F, Main Crater floor.

Regular soil gas surveys are conducted to quantify the amount of CO_2 gas escaping through the Main Crater floor. Measurements are made at 56 sites and the data integrated to obtain the gas flux. As new magma intrudes the volcano, an increased flux to the surface is expected ahead of the ascending melt. The soil gas surveys are complimented by airborne measurements to quantify CO_2, SO_2 and H_2S, using COSPEC, Lycor and InterScan equipment. Currently the average gas fluxes are ~20 kg/s of CO_2; ~3 kg/s of SO_2 and ~ 0.08 kg/s H_2S. The miniDOAS scanning spectrometer system that is installed outside the Main Crater measures SO_2 gas flux during daylight hours and allows data collection when conditions are unsuitable for airborne measurements (Fig. 19).

Chemical studies focus on selected high temperature fumaroles, springs and the Crater Lake. The fumarole gases include magmatic gases and their temperatures range from "background" ~110° C to over 500 °C. When the Crater Lake started to form in 2003 many new springs appeared on the Main Crater floor and the flow of acid water into the sea at Crater Bay increased significantly (Christenson et al. 2017). Despite the island setting, there is only a minor sea water signature in the spring chemistry. The White Island waters are very acid (Table 1).

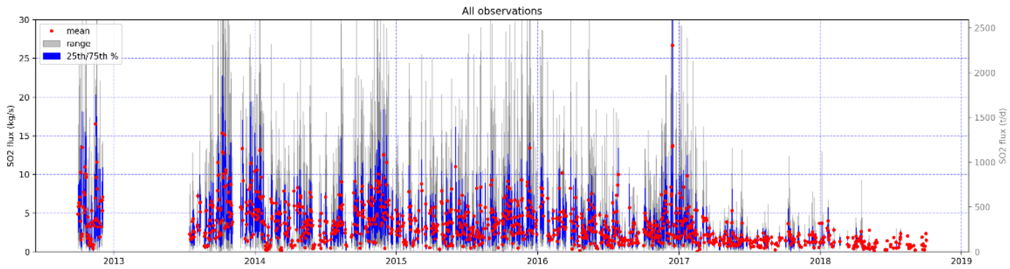

Figure 19: Data from the mini DOAS system in White Island.

Table 1: A representative Crater Lake analysis.

pH	Li	Na	K	Ca	Mg	Cl	SO_4
−0.2	11.6	8281	1337	3525	3529	71190	22884

To allow rapid, near real time checks on activity on the island, (and for public interest) three remote cameras have been established as part of the GeoNet network on the island. One camera is also located at Whakatane. Images from the island are available from the GeoNet web page (https://www.geonet.org.nz/volcano/monitoring/whiteisland).

ACKNOWLEDGEMENTS

Our knowledge of the White Island volcano-hydrothermal system has been enhanced by the access provided by the Buttle family. Their support of activities on the island that increase knowledge and public safety are greatly acknowledged. The data collected through the GeoNet Project, supplemented by valuable observations provided by tour operators has improved our understanding of process's. The GeoNet Project is sponsored by the New Zealand Earthquake Commission (EQC).

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