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Field Trip 1

21st to 23rd November 2013

Jim Cole Field Symposium: Taupo Volcanic Zone

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Cover photo: The 1886AD fissure through Wahanga dome and looking towards Whale Island and White Island (which is background centre left, and barely visible in the photograph).

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Jim Cole Symposium Taupo Volcanic Zone Trip

Ben Kennedy, Rose Turnbull, Paul Ashwell, Darren Gravley, Sam Hampton and Jim Cole

We also acknowledge a significant contribution on information from the 1886 Tarawera eruption from B.F. Houghton, C.J.N. Wilson and R.J. Carey

This trip celebrates Professor Jim Cole's 50 year contribution to volcanology in New Zealand. We aim to visit a range of volcanological field sites that span some of Jim's research and to use these sites to promote scientific discussion and the telling of volcanlogical yarns that celebrate Jim's career.

Day 1: Tarawera Summit and surroundings- Jim's PhD field area.

Day 2: Taupo caldera and surroundings

Taupo Volcanic Zone

The volcanic landscapes of Tarawera and Lake Taupo each represent a sequence of volcanic events important to New Zealand's geological history. The rhyolitic dome complex and basaltic fissure of Mt. Tarawera, represent 22 kyrs of intra-caldera activity following the last caldera forming eruption either 45 or 61 ka (the age remains contentious) from Okataina caldera complex (OCC). The Taupo region contains several large ignimbrite forming eruptions as well as a series of lava domes and scoria cones spanning 350 kyrs (Figure 1) (including the Taupo and Oruanui ignimbrites, the Ben Lomond and Tauhara lava dome complexes, and the Punatekahi scoria cone that we plan to visit on the trip).

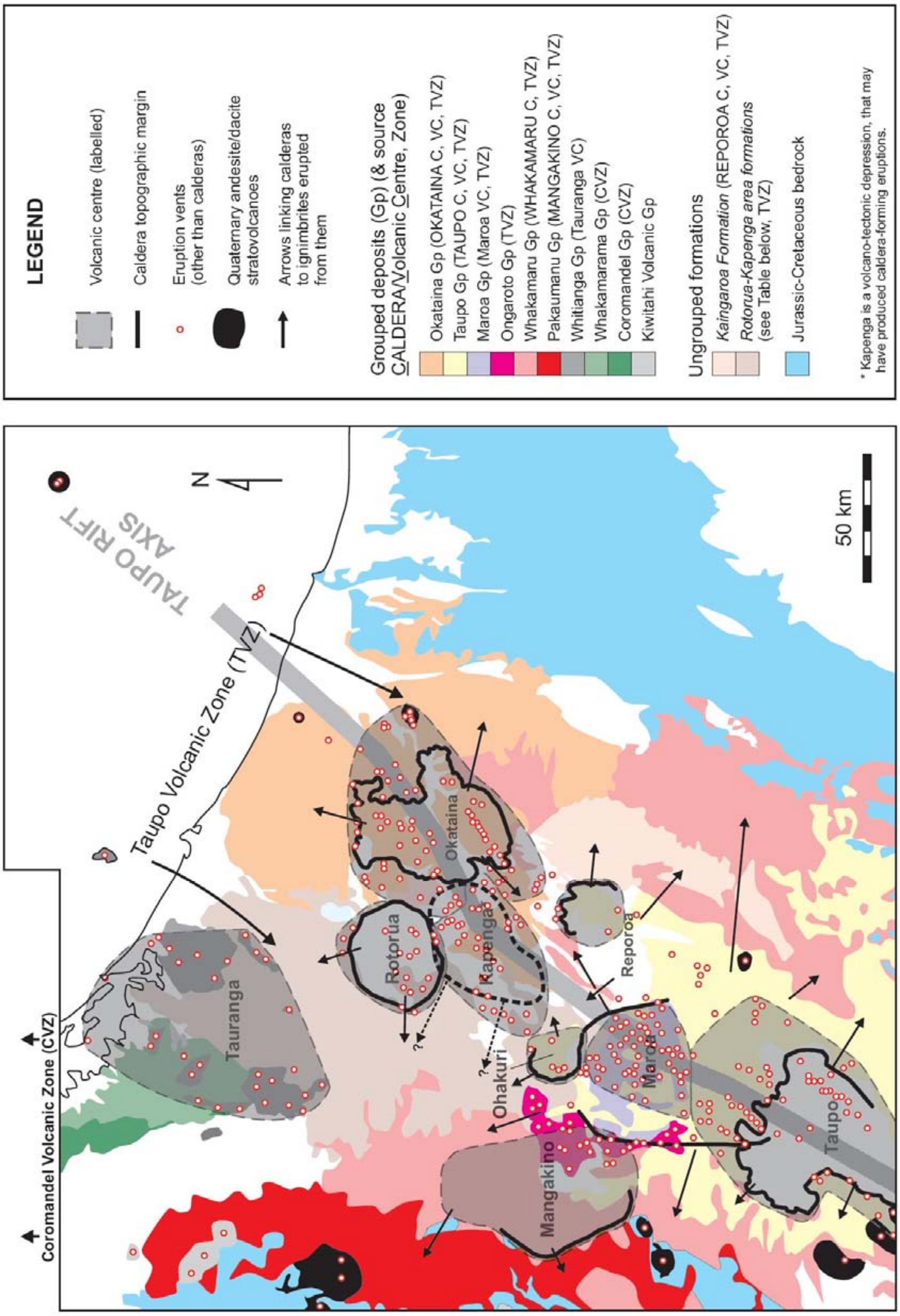

Figure 1: *Distribution and relationships among volcanic centres, calderas (structural margins), non-caldera vents, grouped deposits and ungrouped deposits, for Miocene to Holocene volcanism in the map area. From Leonard et al., 2010. Most vent 'dots' have been filled with rhyolite lava domes.*

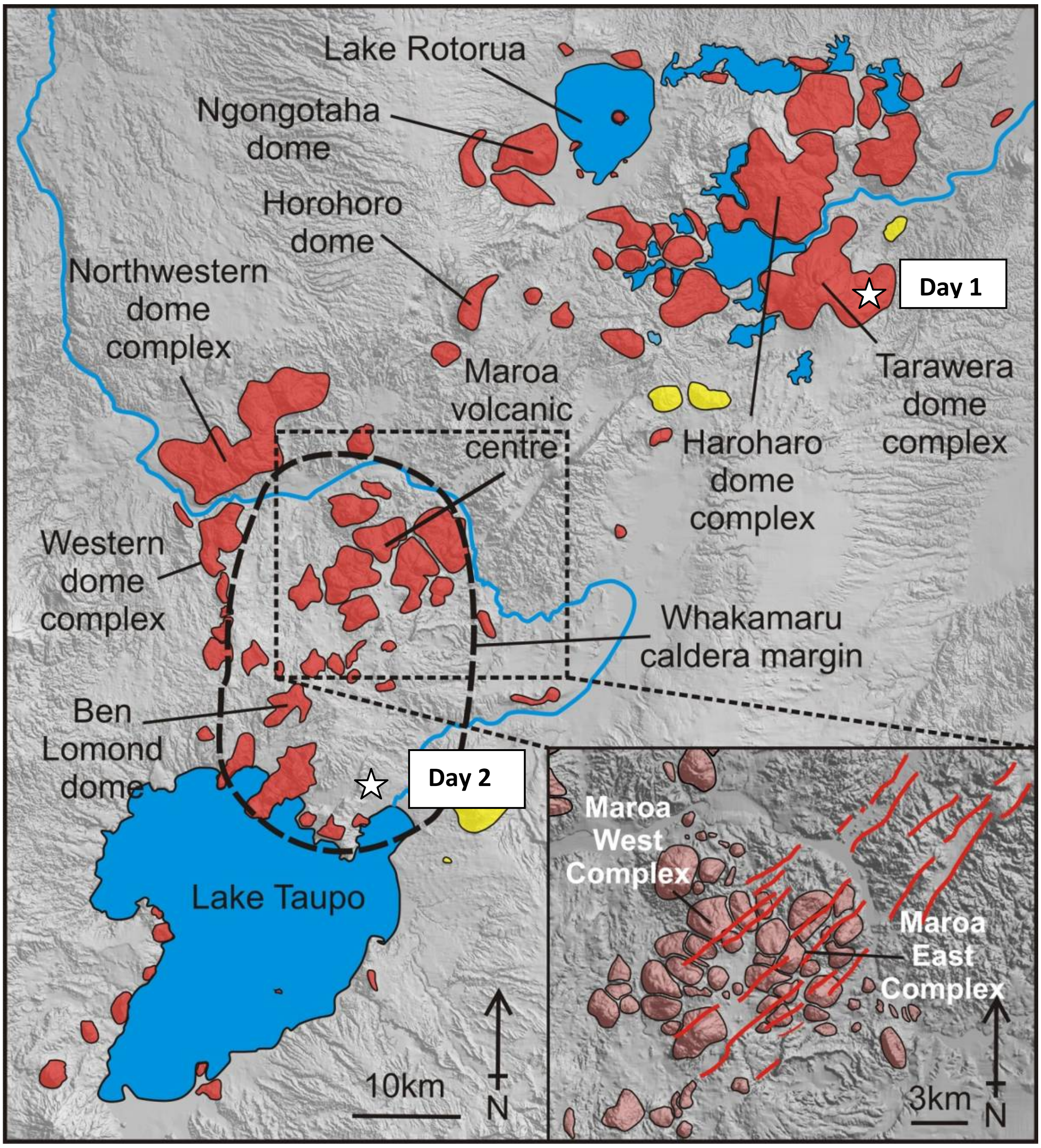

Figure 2: *Locations of rhyolitic (red) and dacitic (yellow) lava domes in the TVZ. Inset: Detail of Maroa volcanic centre with relationship of lava domes (pink) to regional structures (red lines) (from Leonard 2003). Stars mark the focus of field days 1 and 2.*

Tarawera dome complex

The Tarawera dome complex, in the south of the OCC, consists of a series of overlapping lava domes built up in five separate eruptions in the last ~22 ka (Leonard et al. 2010) (Figure 2). The oldest domes are the 21.8 +/- 0.5 ka Hawea and Ridge lavas on the eastern edge of the dome complex and the 17.6 +/- 0.4 ka Te Puha, Western, Southern and Rotomahana domes of the Rerewhakaaitu eruption, which underlie the youngest domes on the western and south-western flanks (Nairn 2002; Shane et al. 2007; Leonard et al. 2010) (Figure 3).

Dome eruptions during the 13.6 +/- 0.2 ka Waiohau eruption formed domes on the northern and western areas, extruding onto the older Hawea and Ridge lavas, and onto which the youngest domes have extruded (Speed et al. 2002; Leonard et al. 2010) (Figure 3). The Waiohau lavas are known to have formed large block and ash flows to the NE and S from dome collapse which contain large, pristine clasts of obsidian (Speed et al. 2002) (Figure 3).

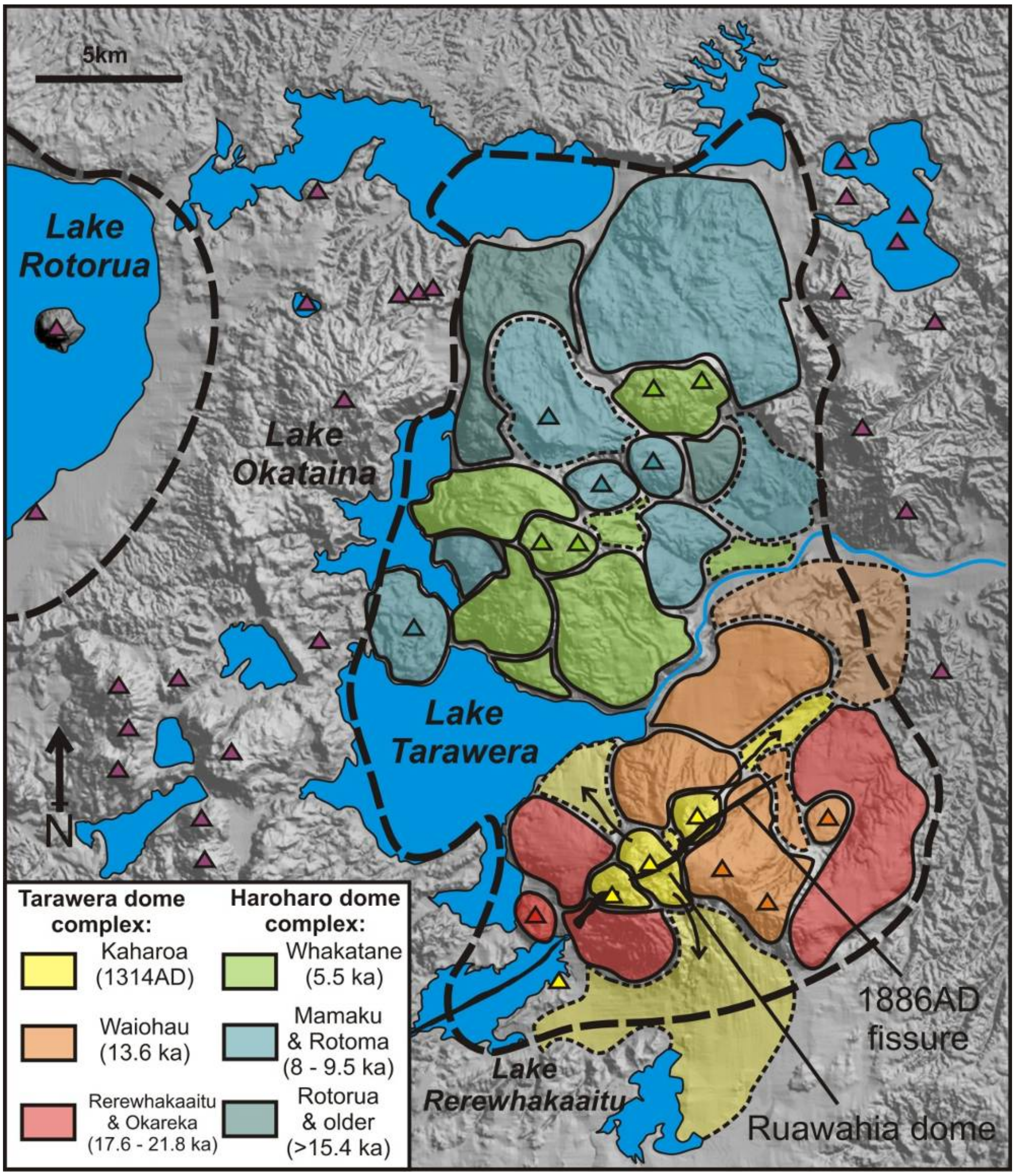

Figure 3: *Shaded D.E.M. of Okataina caldera complex (OCC). Thick black dashed line indicates the deformation margin of the OCC. Blues/greens indicate the domes and flows Haroharo dome complex, while red/ yellows are Tarawera dome complex, see ages in lower left box. Areas with dashed borders are pyroclastic deposits; arrows from the Kaharoa domes indicate dome collapse directions. The 1886AD rift is shown in black across Tarawera. Triangles indicate vent locations of Haroharo (blue/greens) and Tarawera domes (red/ yellows) and other non-OCC vents (purple) from Nairn (2002), Smith et al. (2006) and Cole et al. (2010).*

The youngest dome forming eruption of the OCC includes the domes of Wahanga, Tarawera, Crater and Ruawahia, extruded during the later stages of the 1314AD Kaharoa eruption (Cole 1970a; Cole 1970b; Nairn et al. 2001; Leonard et al. 2002). The Kaharoa eruption also formed a large pyroclastic cone underneath, and to the east of, Ruawahia dome, from the initial explosive Plinian phase, as well as large block and ash flow deposits on top of the previously deposited block and ash flows from the Waiohau eruption (Nairn et al. 2001; Nairn 2002) (Figure 3). The domes extruded towards the end of the Kaharoa eruption (Cole 1970b), and were controlled by the palaeotopography of the underlying lava domes and pyroclastic cone. As with the Haroharo domes, the Kaharoa domes are aligned NE – SW, reflecting the underlying structural trend across the OCC (Cole 1970b; Nairn et al. 2001; Smith et al. 2006; Rowland & Sibson 2001). The summit of Mt.

Tarawera lies on Ruawahia dome, and is comprised of two large flow lobes in a NW and SE direction, bisected by the 1886AD fissure. A large pyroclastic apron has been shed from the NW flow lobe, while widespread block and ash flow deposits on the southern margin of the dome complex have been sourced to the SE flow lobe (Nairn et al. 2001) (Figure 2). Ruawahia is bounded to the west by the contemporaneous Tarawera dome and to the east by the Ruawahia tuff cone, deposited during the initial Plinian eruptive phase.

The last major eruption from the OCC was the 10th June 1886AD Tarawera eruption, a large basaltic Plinian eruption that claimed at least 108 deaths (Keam 1988). A basaltic dyke intruded through the dome complex, resulting in a violent eruption due to sealing of the conduit (Kennedy et al. 2010) and interaction with hydrothermal and lake water (Houghton et al. 2004; Sable et al. 2006). This formed a fissure, which has exposed the cores of the Kaharoa domes (Figure 3), and destroyed the then world famous Pink and White Terraces. Several Maori villages from the Ngāti Rangitihi iwi on the shores of Lake Tarawera were completely buried by ash, lapilli and mud from the eruption, and still remain buried to this day.

There is strong archaeological evidence to support that the first human settlers arrived before the 1314AD Kaharoa eruption (Lowe et al. 2000). The Ngāti Rangitihi iwi have the mana whenua (power and authority to use the land to support themselves) of Mt. Tarawera and the catchment of the Tarawera river, and are the kaitiaki (guardians) of the maunga (mountain). Oral histories inherited from the early settlers survive to this day. The Ngāti Rangitihi relate that the domes of the Kaharoa eruption were formed when Ngātoroirangi, who arrived on one of the canoes of the Great Migration, was called upon to battle a taniwha (spirit/ guardian), who preyed upon weary travellers on the shores of Lake Tarawera. Ngātoroirangi engaged the taniwha, slowing it with prayers, and was able to overcome come it, and forced the taniwha into the ground on top of Mt. Tarawera. He commanded the mountain to rise up and bury the taniwha, analogous to the eruption of the Kaharoa domes. 'Ruawahia' can be translated into 'pit' (rua-) and 'tearing' (-wahia), and suggests that the pre-1886AD eruption shape of the dome was one with a cleft or rift in the centre. Maori oral traditions also suggest that the 1886AD eruption was a result of the taniwha escaping the mountain to punish those who had abandoned their duties as kaitiaki of the mountain.

The 1886AD fissure, as well as the domes in the Haroharo and Tarawera dome complexes share a NE – SW trend; an orientation which is also shown in numerous faults across and to the south-west of the OCC (Rowland & Sibson 2001; Acocella et al. 2003; Seebeck et al. 2010). This regional structure is a primary control on many of the lava domes and calderas in the TVZ.

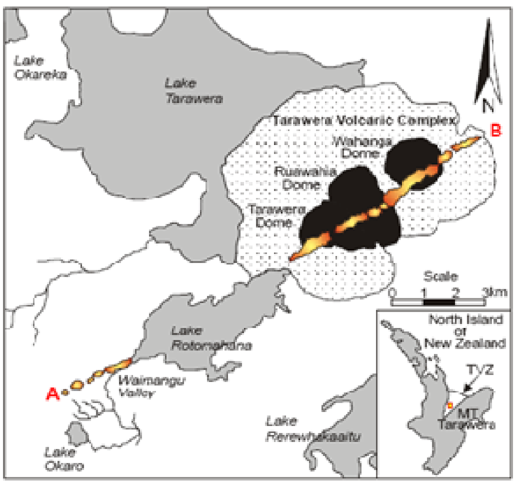

Figure 4: *Location map. 1886 eruption fissure (AB) extends 17 km from the Waimangu geothermal field to Mt Tarawera. Modern Lake Rotomahana occupies at least 5 coalesced craters from the 1886 eruption. 1314 Kaharoa lava domes are shown in black. Older domes are stippled.*

The 1886 eruption (The following section was provided by Houghton, Wilson and Carey)

The 1886 eruption of Tarawera volcano in the TVZ is New Zealand's largest and most destructive historical eruption (Walker et al. 1984). This event was unusual in several ways. First, although the eruption involved exclusively basaltic magma, its main phase included intense sustained activity that is rarely associated with basalt, resulting in a >10,000 km^2 plinian fall deposit (Thomas 1888; Walker et al. 1984). Second, the eruptive source was a 17-km-long fissure (Figure 3) formed by >50 vents in thirteen major craters across Mt. Tarawera itself (Figure 4) in addition to as an uncertain number of vents to the southwest at Rotomahana (Nairn 1979; Nairn and Cole 1981; Houghton et al. 2004a). Third, in addition to the plinian sheet of scoria fall, the eruption produced strongly over-thickened proximal deposits on Mt Tarawera that form a series of half-cones on both sides of the fissure, visible in excellent exposures at sites extremely close (90 – 300 m) to vent (Houghton and Wilson 1998). The geometry of the 1886 proximal deposits is extremely complex and has consequent implications for the diversity of transport and deposition processes not only for the Tarawera eruption itself but also for plinian plumes in general. Tarawera 1886 provides a valuable opportunity to study links between fall deposition close to vent and deposition in the far field. About 0.8 km^3 of basaltic magma (DRE) was erupted in only five and a half hours (Walker et al. 1984). This eruption deposited scoria distances of up to 150 km, and ash up to 230 km downwind, to the northeast (Thomas 1888).

The SW portion (Rotomahana-Waimangu) of the 1886 eruptive fissure was the source for the fine-ash-rich deposits with common accretionary lapilli collectively called the Rotomahana Mud (Nairn 1979). The SW deposits include localized pyroclastic density current deposits and a widespread fine-ash fall with a northerly dispersal that forms a significant component within the upper levels of the otherwise scoria-dominated 1886 fall deposits.

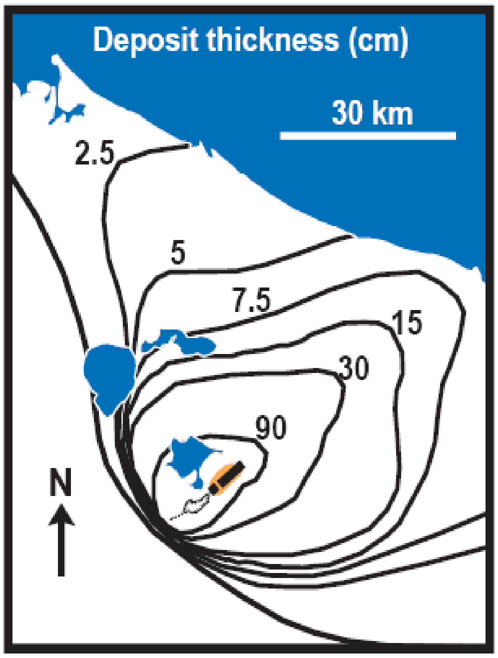

Figure 5: *Isopach map of widespread scoria fall from the Tarawera 1886 eruption, after Walker et al. (1984).*

The NE vents produced both sheet-forming and cone-building deposits of basaltic scoriaceous lapilli (Walker et al. 1984). The widespread scoria sheet covers an area of 6000 km^2 within the 2.5 cm isopach (Figure 5), and an estimated total area of 10,000 km^2, with a dispersal axis toward the northeast (Thomas 1888; Walker et al. 1984). The large extent and low rate of thinning (bt = 4.3 km after Pyle 1989) qualify the deposit as Plinian, with an estimated column height of ~28 km (Walker et al. 1984). Median grain size of the widespread scoria fall decreases systematically with increasing distance, changing from -3.3Φ (1 cm) at 1 km to 2.3Φ (0.2 mm) at 40 km from vent; however, these values include up to 15% of the fine-grained Rotomahana Mud (Walker et al. 1984).

Proximal deposits

The cone-forming proximal deposits surround the 7 km long Mt. Tarawera portion of the rift and are confined to an area within 400 m of it. The north-eastern proximal 1886 deposits consist of a series of truncated, partially overlapping scoria cones, or more accurately half-cones (Figure 6). The deposits are well exposed and consist of a series of moderately to well-sorted lapilli-and-bomb beds with a total thickness between 35 and 75 m along the fissure. Most of the beds dip outwards away from the fissure and show rapid changes in thickness both parallel and perpendicular to the 1886 fissure (Sable et al. 2006).

Houghton and Wilson (1998) presented field evidence that the widespread Plinian fall deposits largely accumulated simultaneously with the proximal second unit, rather than representing only the later stages of the latter's accumulation (cf. Walker et al. 1984). However, along the fissure, the sequence of beds making up unit 2/3 varies greatly at different locations; in ways that are not immediately compatible with deposition from a classical Plinian plume (Sable et al. 2006). These lateral changes are primarily expressed in: (1) dispersal characteristics, with high variations of thinning rates of beds in crater walls parallel to the fissure; (2) variations in juvenile clast properties, i.e. grain size, vesicularity/density and morphology; and (3) content of wall-rock lithic clasts. A complication in interpreting proximal transport and deposition of pyroclasts is that all beds must also contain a mixture of clasts erupted from different point sources along the ca. 8 km long segment of the NE fissure (Sable et al. 2006).

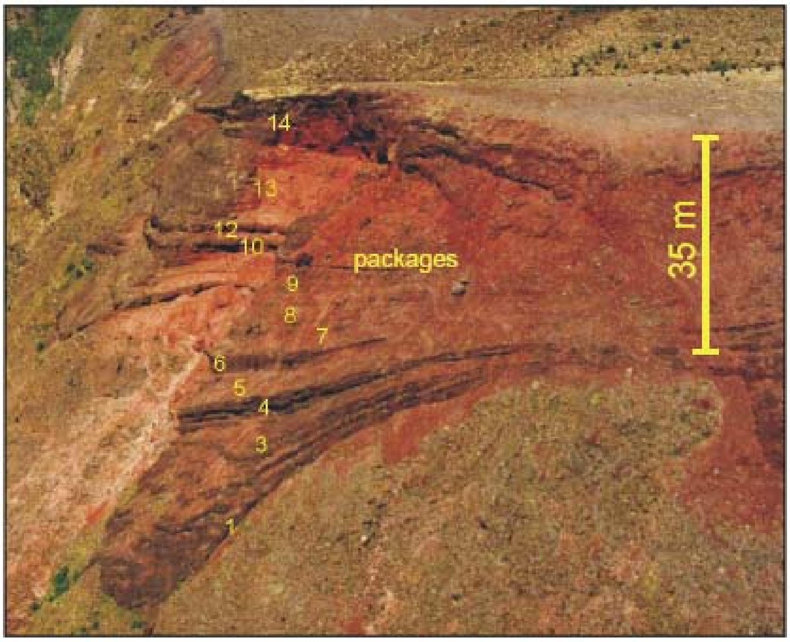

Figure 6: *Photograph showing the local distribution of packages. Note the contrasting dispersal of adjacent groups of packages.*

How did the Tarawera 1886 magma achieve Plinian intensity?

The rarity of basaltic Plinian eruptions implies that they require an unusual set of conditions before and during fragmentation. Therefore the 1886 melt must have undergone some event atypical of basaltic systems, probably causing prolonged closed system vesiculation, leading to the acceleration necessary for Plinian eruption (Wilson et al., 1980; Woods, 1988; Papale et al., 1998).

Tarawera's bubble number densities span a limited range of relatively high values (1.5 – 2.5 × 10^6 cm^{-3}), and all the clasts have similar ranges of bubble sizes, bubble shapes, and groundmass crystallinities. This relative homogeneity indicates that all the 1886 magma shared a common early ascent history. The microlite crystallinities of the 1886 clasts are unusually high for basaltic products. The high number densities of microlites and bubbles in the 1886 clasts support an interpretation that this shared early history was characterized by rates of ascent and decompression atypically high for basaltic magmas. The bubble number densities for the Tarawera 1886 clasts are 1 – 2 orders of magnitude higher than those observed in Strombolian and Hawaiian scoria and 1 – 3 orders of magnitude lower than those encountered in silicic explosive eruptions. It is therefore suggested that relatively high rates of ascent and decompression led to a rate of bubble nucleation that was higher than the rates in most Strombolian and Hawaiian eruptions but slightly lower than the rate in the Etna 122 BC basaltic Plinian eruption (Sable et al., 2006a).

Melt inclusions are not available in the Tarawera clasts due to the scarcity of cognate phenocrysts, but the H_2O content of the 1886 magma is roughly constrained by the whole rock compositions adjusted for the presence of xenocrysts, phenocryst assemblage (plagioclase + clinopyroxene + olivine), and clinopyroxene compositions (A. Freundt, unpublished data). The normative compositions indicate an initial dissolved water content of 3 – 5 wt% (Moore et al., 1995). It has been considered an additional possibility that a high CO_2 content could have played a critical role by driving some vesiculation early in ascent, and speculated that the early exsolution of significant CO_2 at depth could have given an early start to the upward acceleration of the magma. There is also evidence that the rising dyke remelted the rhyolite around it affectively self sealing as the basaltic magma rose decreasing degassing during magma rise (Kennedy et al., 2010).

Lake Taupo

The volcanic rocks in the Taupo area include ignimbrite and lava domes from 350 - 1.78 kyrs including eruptions related to both the Whakamaru and Taupo calderas.

The Whakamaru Caldera formed during the largest caldera-forming rhyolitic ignimbrite eruption in TVZ history at ~340 ka. Several episodes of collapse occurred at Whakamaru Caldera, with dome emplacement between collapse events (Brown et al. 1998b). The proposed Whakamaru Caldera is defined to the west by the Western Dome Belt (WDB), a 32 km long curvilinear chain of simple and compound silicic domes inferred from field evidence to post-date the Whakamaru ignimbrite eruptions (Wilson et al. 1986; Brown et al. 1998b), a result of post-collapse volcanism localized along the western caldera margin. The Maroa dome complex in the northern half of the Whakamaru caldera is comprised of an accumulation of simple and composite silicic lava domes (Leonard, 2003). Domes are strongly aligned along NNE trends and extensively faulted along the same lineation, indicating the same regional structure is responsible for controlling vent locations and subsequent deformation. Field stratigraphic evidence and new age data on rhyolite domes and basalts (B.F.Houghton et al., unpubl. data) imply that Maroa entirely postdates the Whakamaru caldera centre and actually infilled the large 2 to 3 km deep caldera in 25 kyrs. Field data imply that activity at Maroa diminished from 60 – 30 ka as activity at Taupo increased in volume and intensity (Wilson, 1993).

Tauhara and Ben Lomond domes are some of the oldest members of the Taupo group dated at 65 ka and 100 ka respectively. Taupo Caldera has been frequently active in the past c. 65 ka (Wilson et al. 1986; Houghton et al. 1995), while its poorly constrained early eruptive history indicates activity over c. 300 ka (Wilson et al. 1986; Cole et al. 1998). The Taupo Caldera Complex has a large trapezoidal shaped negative Bouguer gravity anomaly. The most intense negative gravity anomaly in TVZ (Davy & Caldwell 1998), is documented over the northern part of Lake Taupo consistent with a caldera collapse structure elongate NW – SE. The gravity data cannot distinguish individual collapse structures, and Davy & Caldwell (1998) consider the caldera structures are nested, with the Taupo eruption producing additional subsidence in the NE part of the modern lake. The early history (>65 ka) of volcanism in the vicinity of modern Lake Taupo is represented mainly by domes and limited pyroclastics scattered around the lake (Sutton et al. 1995).

The caldera-forming Oruanui eruption at 26.5 ka (calibrated; Wilson 1993) generated a 430 km^3 fall deposit, a 320 km^3 bulk volume non-welded density current deposit (mostly ignimbrite) and 420 km^3 of caldera-fill material erupted, equivalent to 530 km^3 of magma (Wilson 2001). The

Oruanui event is thus largely responsible for the modern caldera morphology. Wilson (1993) has identified 28 separate eruptions since the Oruanui eruption; the most recent and largest of these, the caldera modifying 35 km^3 Taupo ignimbrite eruption, occurred about 1800 years ago from vents near the Horomatangi Reefs in the eastern part of the lake (Wilson & Walker 1985; Smith & Houghton 1995).

Tarawera field day – Friday 22nd November 2013

We drive North from Taupo through the central TVZ to the OCC. We will meet up with Tarawera Tours at the foot of the volcano where we will have an overview of the volcano. Bring gaiters for a scree run if you have them and swimming gear for hot pools

Stop 1:

Tarawera overview (Figure 7): Looking NNE towards the volcano, we look at the skyline of the 1314AD Kaharoa lava domes; Tarawera, Ruawahia, and Wahanga (hidden from view) sitting on top of older (17 – 14 ka) Rerewhakaaitu, Okareka and Waiohau lava domes.

Figure 7: *Locations of stops on Day 2 around Tarawera*

As we drive up the mountain, we will be passing through regenerating native forest that has recovered after the 1886AD eruption destroyed most of the vegetation on the volcano. We will also be traversing old, buried domes of the Waiohau eruption before emerging from the forest on the plateau of the top of the Waiohau domes (where the disused airfield is).

Stop 2:

This view looks across the 1886AD explosion crater towards the exposed face of Ruawahia dome. White pyroclastic beds trace the crater of the Ruawahia tuff cone, formed during the Plinian eruption phase of the 1314AD Kaharoa eruption.

These beds grade into the basal breccia of Ruawahia Dome, visible at the base of the exposed cliff. This breccia then grades into the massive dome core of Ruawahia. Visible in the centre of the exposed cliff, and above the black scoria scree slope, is the location of one of the 1886AD dyke segments that has intruded through the Kaharoa domes. Mantling the top of the domes and tuff cone is the thick, proximal scoria beds from the 1886AD eruption, in places ponding and welding to produce pseudo-lava flows. To the NE is Wahanga dome, with its exposed dome core showing large spine-like extrusions.


Figure 8: *Left: View towards Ruawahia dome and the summit of Mt. Tarawera, with location of dyke intrusion in centre of photo. Right: Basaltic dyke intruding through Ruawahia dome.*

Stop 3:

A short way on from Stop 2, to the left of the track is a large ballistic bomb and impact crater formed during the 1886AD eruption. The block consists of rhyolite, likely from the Kaharoa dome lava, although blocks of significantly different flow banded rhyolite can be found at the bottom of the large crater to your right, sourced from the older, buried domes.

As we continue up to the summit of Mt. Tarawera, we will cross a saddle formed from the en echelon nature of the 1886AD basaltic dyke (Figure 8). The dome outcrops to the NE and ahead of you are often vesicular and breadcrusted, and in places shows shear indicators during brittle deformation and hydrothermal alteration from the 1886AD eruption. In places deep in the fissure, steam still rises close to the remains of the dyke.

Figure 9: *Tarawera 1886 fissure viewed from the SW. The portion of fissure in the middle distance is the proposed site of one of the Plinian vents during the eruption. Note the white pyroclastic density current and fall deposits of the Kaharoa eruption underlying the 1886 fall units.*

Stop 4:

At the summit, the 1886AD fissure can be traced from beyond Tarawera dome (starting at Waiotapu to the SW), through Crater dome (to the SW of the summit – white pyroclastic beds can be seen beneath the 1886AD scoria, but above the rhyolite dome) and Ruawahia dome (where you are standing) (Figure 10), then out towards the edge of Wahanga dome (to the NE). Beyond Wahanga dome is Edgecumbe/ Putuaki volcano and beyond that is Whale Island (near shore) and White Island (far distance – only visible on clear days). Ruapehu and Tongariro can also be viewed far to the south.

From this viewpoint, the outline of the OCC can be traced along Lakes Rotomahana, Tarawera and Okataina, and then beyond the Haroharo dome complex (to the north). Beyond the OCC, Lake Rotorua (with Mokoia Island) can be seen to the northwest.

The undulating surface of one of the flow lobes of Ruawahia can be seen to the northwest. Most of the surface of Ruawahia has been covered in 1886AD scoria and spatter, which creates a false topography of the underlying dome close to the fissure. In the distance and on the flanks of the domes, small outcrops of dome lava penetrate through the scoria covering and have been studied to distinguish lava dome facies and flow directions. The two craters of the fissure immediately south and southwest of the summit exposes the core of Ruawahia dome. Flow banding and internal breccia zones here also provide evidence to the formation of Ruawahia dome.

Figure 10: *Panarama of the main exposed interior of Ruawahia dome, opposite to the summit of Mt. Tarawera.*

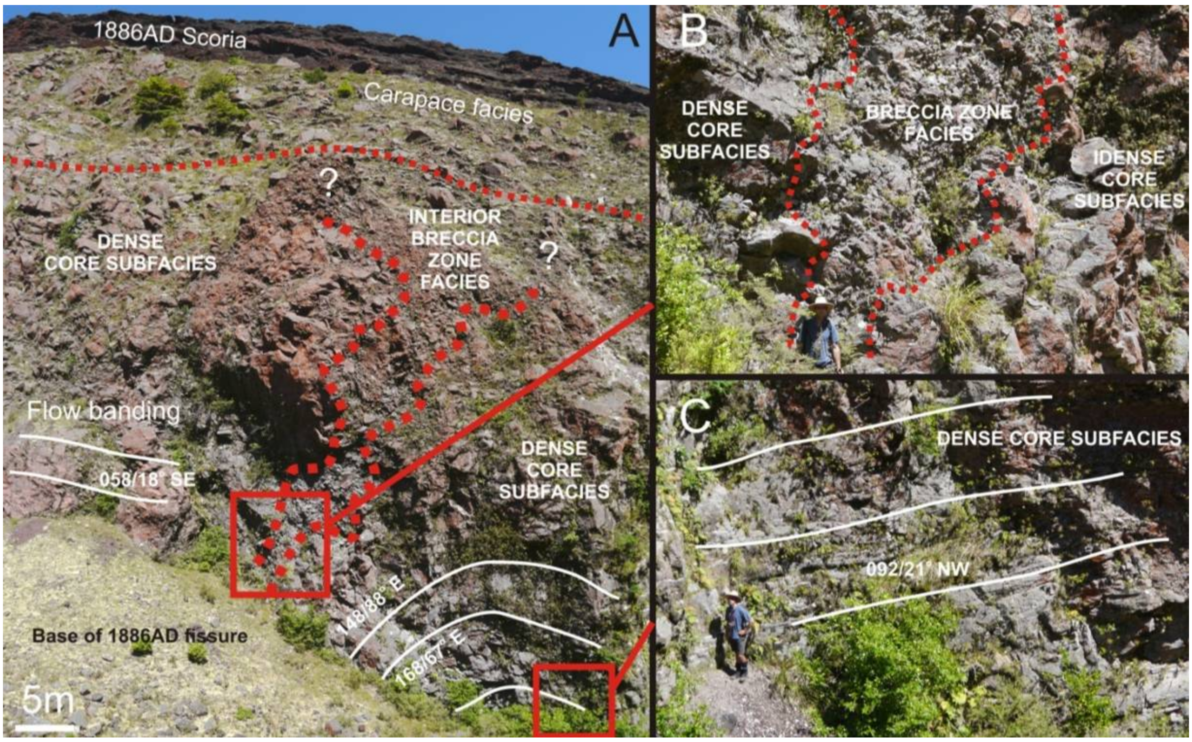

Figure 11: *Internal breccia zone in dome core at Ruawahia.*

Ashwell, (2013) has suggested that Ruawahia formed as a series of small flow lobes and spiny lobes that collectively make up the dome. Evidence from flow banding, breccia zones (Figure 11), devitrification and palaeotopography supports this theory. In the region of the summit and fissure, spiny lobes were constrained by the crater of the Ruawahia Tuff cone, forming complex, often near vertical flow bands and breccia zones (Figure 12) that indicate vertical, confined movement of lava.

Flow lobes of the northwestern dome were able to flow down the flanks of the tuff cone, forming ramp structures (ridges visible at the very far end of Ruawahia dome) with gently dipping flow bands (Figure 13). Failure of the toe of the flows formed the large block and ash flow deposits on the shore of Lake Tarawera.

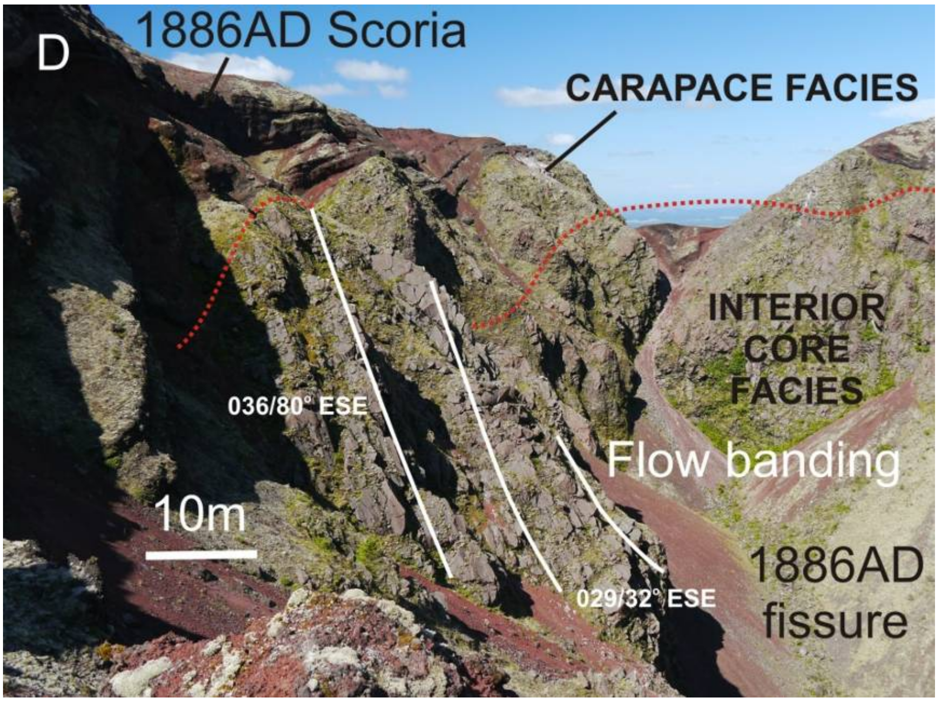

Figure 12: *Steeply dipping flow bands in fissure. Summit area is on top right.*

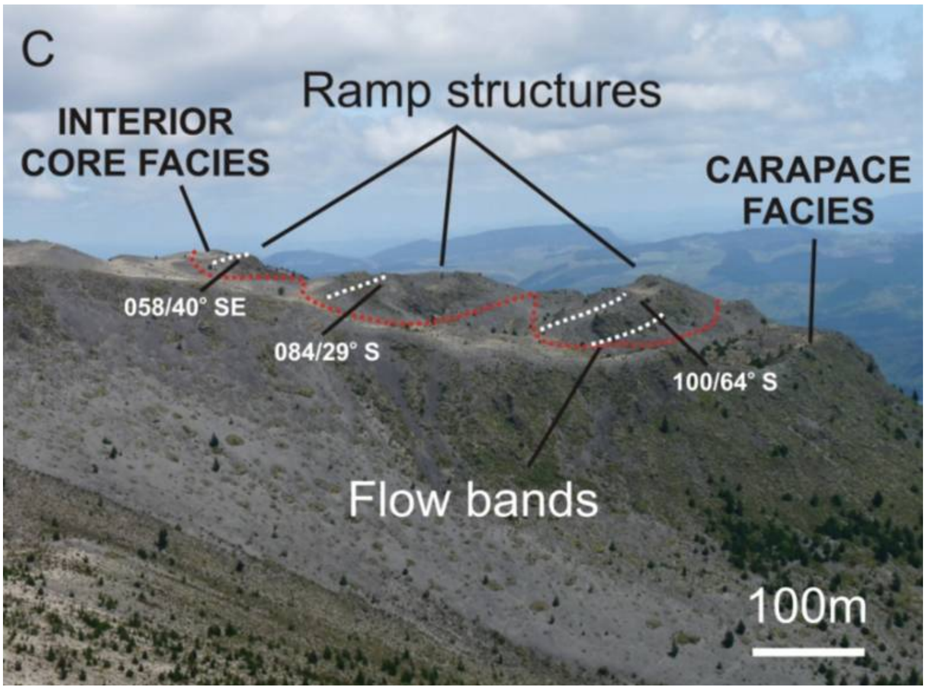

Figure 13: *Ramp structures on northern tip of Ruawahia flow lobes.*

The outer edge of the flow lobes also contains areas of extremely vesicular carapace lava with spherical bubbles (in contrast to the elongated bubble shape of the rest of the dome). These outcrops are suggested to be the collapse scars from failure events, that subsequently inflated when exposed to atmospheric pressure levels.

Stop 5:

Looking back into the fissure through Ruawahia dome, high dipping flow bands in the region of the conduit are visible in the core of the lava dome (Figure 12). These are interpreted as formed through near vertical movement of confined lava.

The lava extruded against previously erupted lave lobes as well as the rim of the crater of the pyroclastic tuff cone formed through earlier explosive activity. The flow bands, in addition to the internal breccia zones and outcrops on the edge of the dome, suggest that the dome was produced as a series of flow lobes (unconfined) and spiny lobes (confined) controlled by palaeotopography and viscosity (Figures 14 and 15).

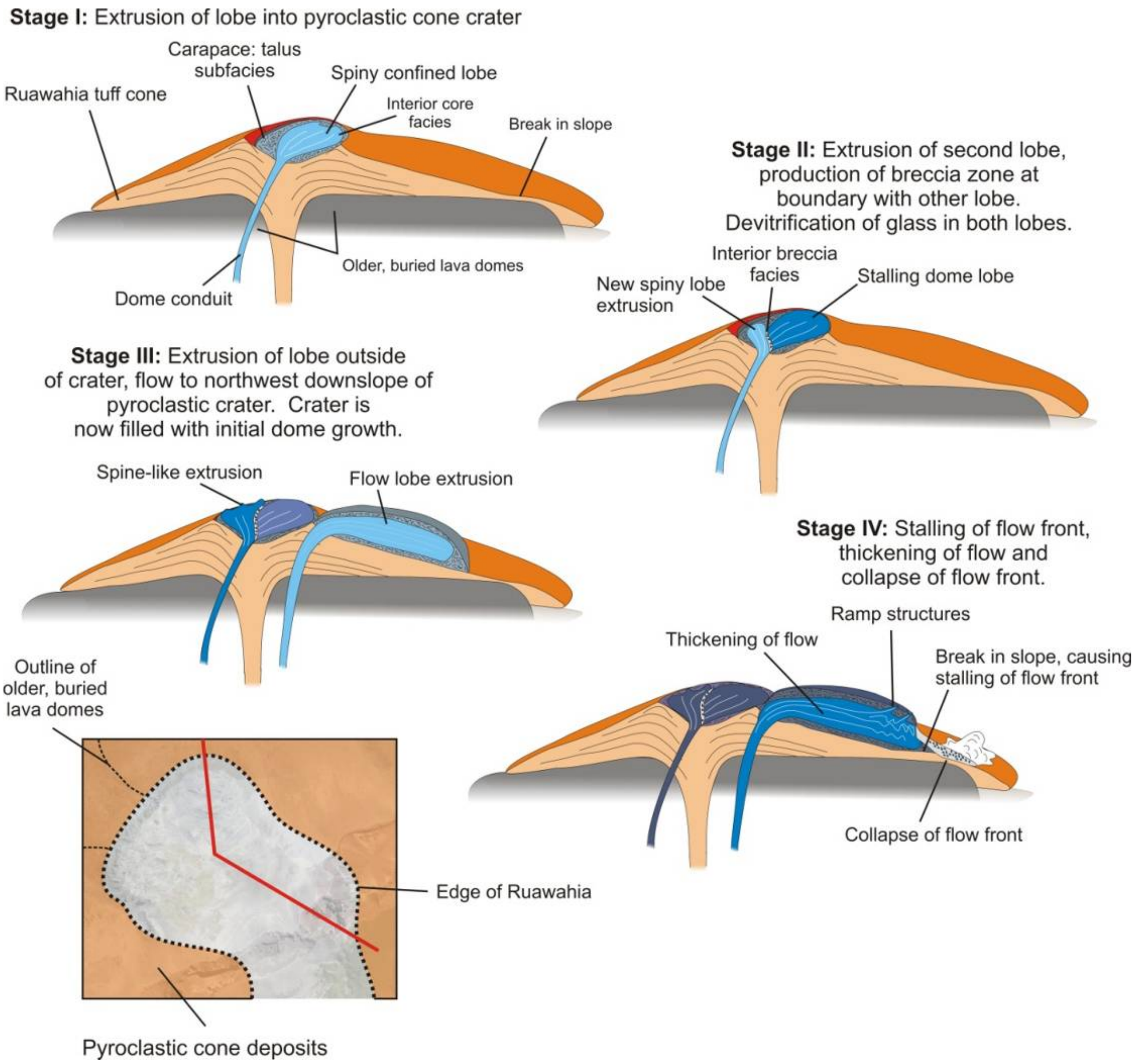

Figure 14: *Cross section of flow and spiny lobe formation at Ruawahia.*

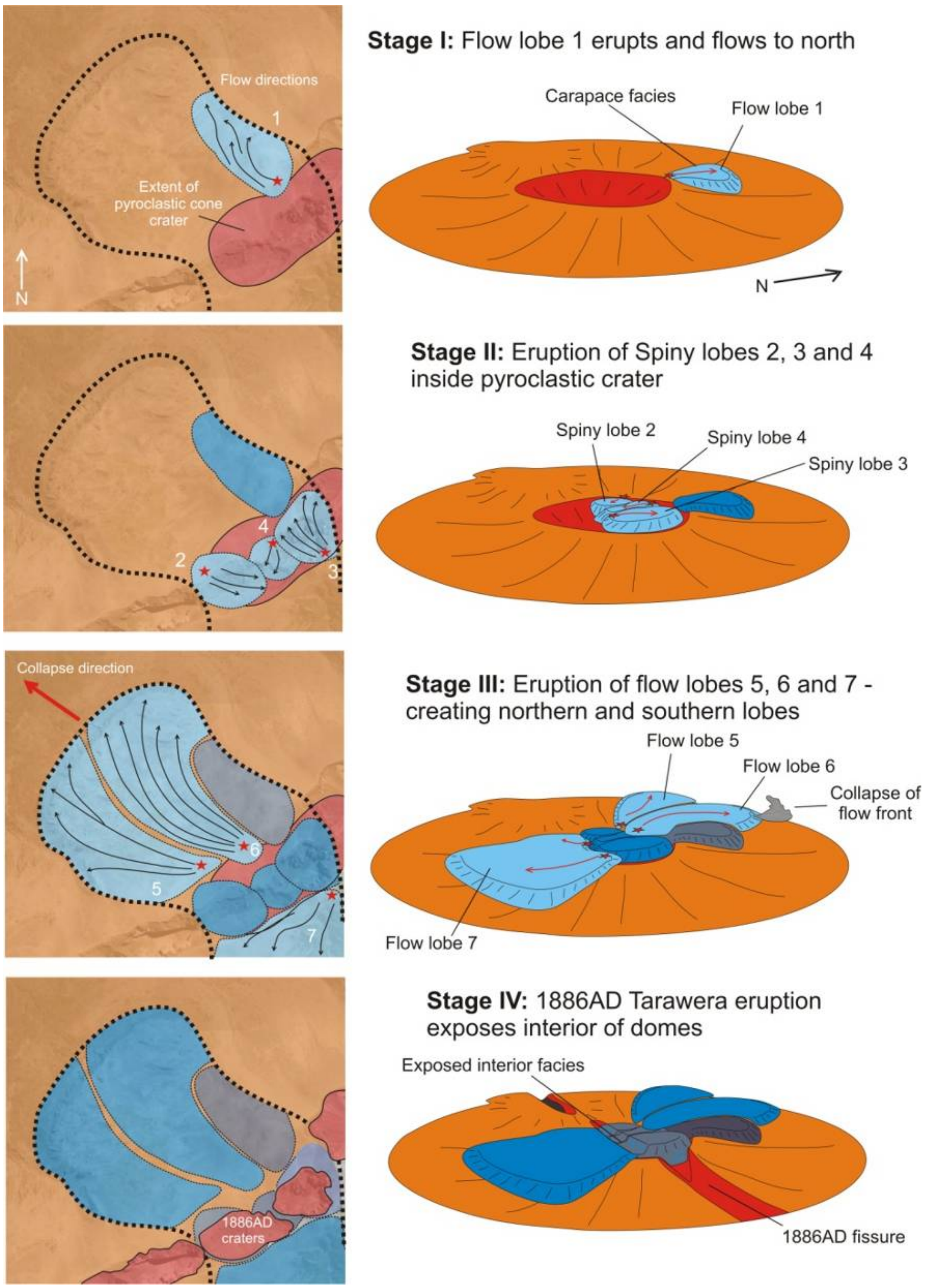

Figure 15: *Locations of individual flow and spiny lobes at Ruawahia dome.*

Stop 6: 1886 eruption units within the widespread proximal products of 1886 eruption at the top of the scree run.

As we descend into the crater, there is an opportunity to see the contrasting 1886 eruption packages (Figure 16). This vent erupted with high intensities starting very early in the eruption, and maintained its high intensities through the full duration of the main phase. However, the evidence that the eruption lasted only 5 hours with no significant time breaks, coupled with the observation that most craters contain two or more packages at any given stratigraphic level, led Houghton, Wilson and Carey to conclude that vents spaced as little as 30 m apart were erupting simultaneously. It follows that deposition at any one location or moment in time probably involved clasts from more than one vent and therefore that every deposit package is a mixture of clasts with different dispersals. The mixed nature of the deposits must be considered in any interpretation of their geometry. All the packages have localized dispersals. Many beds within the packages are welded to various degrees, ranging from weak tack welding to moderately strong welding where clasts adhere firmly to each other but still have distinct boundaries. Clasts of glassy, coarsely re-vesiculated rhyolite are commonly found encased in basalt. Basalt clasts generally have a red oxidized colour. The grain size is coarse and sorting is typically moderate to poor. Basalt clast morphologies are typically fluidal, slaggy, and ragged, with minor knobbly clasts. The wall-rock lithic content is typically 5-15% and rarely up to 40%, ranging from ash to 20-30 cm, and rarely 1 m, blocks.

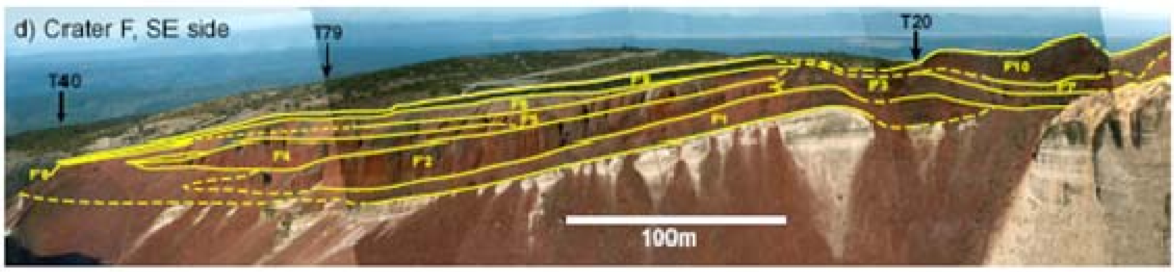

Figure 16: *View of eruption packages associated with crater F (where you are located), note it is very difficult to trace these packages from one side of the crater to the other.*

Stop 7: Crater Road Quarry

This quarry exposes many of the pyroclastic units associated wih the Kaharoa eruption and is overlain by the 1886AD basaltic scoria. Block and ash flows overlie pumiceous pyroclastic flow units and airfall. Figure 17 shows one of the block and ash flows largely composed of blocks of lava from Ruawahia dome. A charateristic feature of the block and ash flows are breadcrusted clasts that have inflated during flow and deposition Figure 17 shows the pumiceous pyroclastic flow units underlaying the block and ash flows. Charcoal is common in these units and banded pumices can be found, indicating a mafic mingling event may have been related to triggering this eruption (Leonard et al., 2002). It is likley these flows resulted from column collapse of large Vulcanian/Sub-Plinian columns towards the end of the Kaharoa airfall sequence. Some of these units may have been remobilsed as lahars and streamflow.

Figure 17: *Block and ash flows and pyroclastic flows of the Kaharoa.*

Stop 8: Kaharoa airfall

The 5 km^3, 1314AD Kaharoa eruption was a prolonged eruption (~5 years) involving at least 7 source vents located along an 8 km fissure on a pre-existing dome complex. Following vent-opening weak explosions, seven early powerful pyroclastic fall phases formed tephra lobes to the SE with minor pyroclastic density currents (Figure 18). Each sub-Plinian – Plinian pumice fall unit is separated by partings rich in fine ash, interpreted to represent short, quiescence intervals between eruptive phases. Three large summit domes then grew, accompanied by major block-and-ash flows.

Individual fall units show contrasting patterns with some characterized by abrupt and some by gradual shifts in maximum grain size, which is a proxy for eruption intensity. The large number of Plinian – sub-Plinian explosive phases, together with the patterns indicating fluctuations in eruption intensity over periods of just minutes (assuming Plinian accumulation rates and estimated phase durations), are unique among Plinian eruptions. The fall deposits are distributed in two elongate isopachs to the SE reaching Hawkes Bay, and to the N reaching Northland (Newnham et al., 1998)

Figure 18: *Left: Jim in his natural habitatexplaining the Kaharoa airfall units (as seen on right).*

Stop 9: Hot pools – Hot and cold springs near Waiotapu and mud pots

Here we stop for a photo/tourist look at the Waiotapu mudpools and we will walk down to the hot and cold pools in the river.

Taupo field day – Saturday November 23rd 2013 (Figure 19)

In order to minimise the time spent in the bus and maximise the time spent in the hot pools, most of this field day will be spent close to Taupo township, although we will loop through the Whakamaru caldera and western dome complex (remember to bring swimming gear for hot pools at the end of the day).

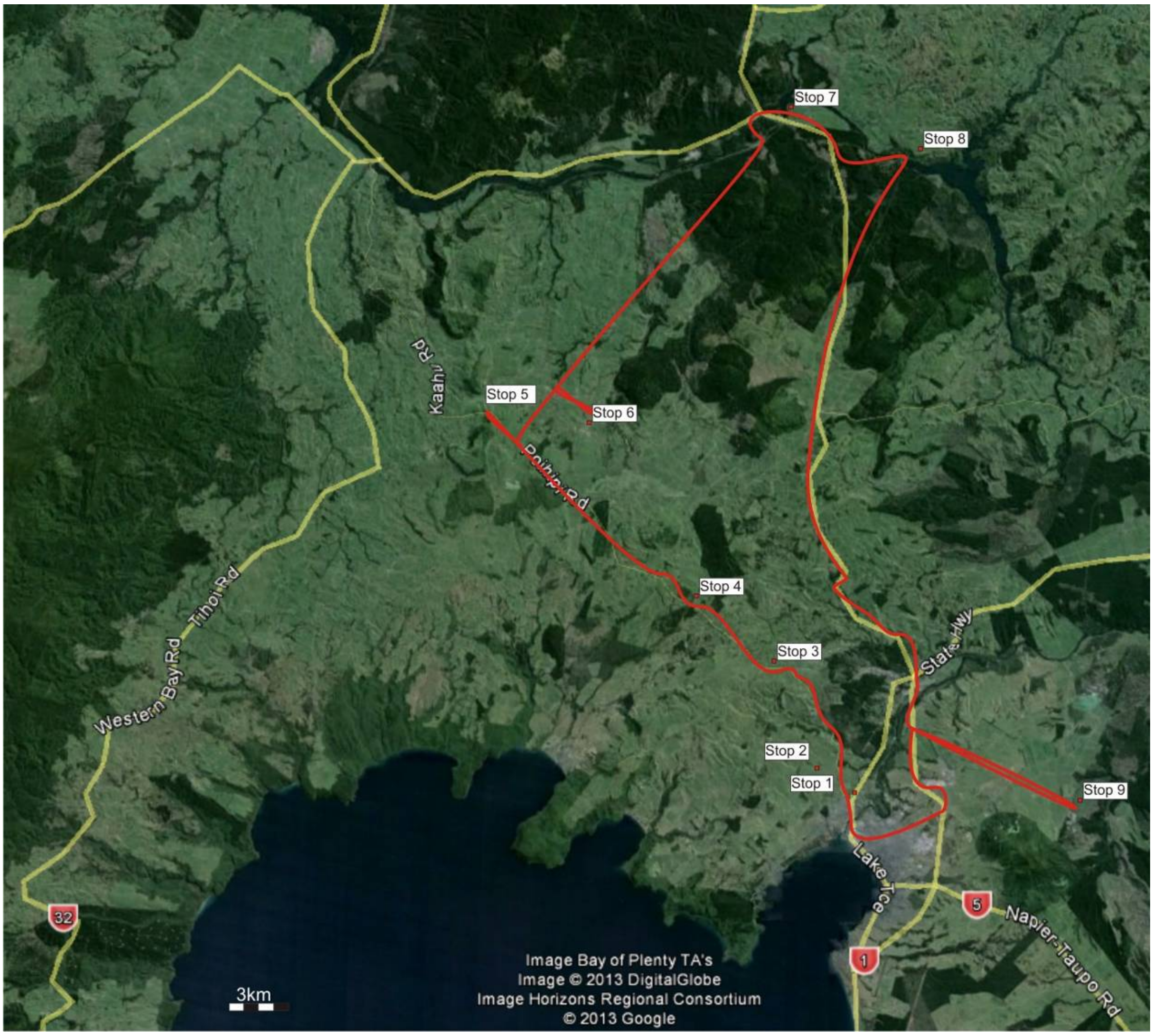

Figure 19: *Approximate locations of stops on Day 2 around Taupo*

Stop 1. Taupo overlook (from town)

Looking south down the lake, Pihanga, Tongariro, Ngauruhoe and Ruapehu may be visible on the skyline (Figure 20). To the east is the cone of Tauhara volcanic dome complex and the Wairakei geothermal field. Pre- and post-Taupo caldera collapse lava domes outcrop on the lake side and the distinctive ignimbrite plateau can be seen either side of the lake.

Figure 20: *Lake Taupo from a similar perspective to the Taupo overlook, with Ruapehu and Tongariro (including Ngauruhoe) in the distance. Photo D. Townsend, GNS Science.*

Stop 2. Scoria cone Punatekahi

This working quarry contains multiple cross sections through basaltic scoria cones. Depending on the quarry levels both outer flanks and inner crater facies may be exposed. Facies range from proximal spatter grading into welded spatter flows (Figure 21), to poorly sorted scoria containing rarer ribbon bombs and spatter.


Figure 21: *Left) Overview of the quarry, is this a cross section of the crater. Right: Spatter grading downwards into welded spatter flows*

Stop 3: Taupo caldera pyroclastic deposit on Pohipi road

Oruanui and Taupo ignimbrite deposits show a classic valley fill geomorphology. Here (Figure 22) we can see roadside exposures of erosional contacts between the Oruanui 26.5 Ka and Taupo 1.8Ka ignimbrites. This locality is ideal for comparing these contrasting ignimbrites and the influence of lake water on the style of fragmentation

Figure 22: *The complex erosional relationships between the Taupo and Oruanui ignimbrites.*

Stop 4: Ben Lomond dome

Despite being a spectacularly unimpressive exposure, if you root around in the bush on the roadside you can find a very impressive range of obsidian textures ranging from dense obsidian to pumice over a few centimetres (Figure 23). The relationships in these rocks provide vital clues to the debate on whether obsidian erupts as foamy magma and collapses to form obsidian, or erupts as obsidian and locally foams to form pumice.

Figure 23: *Obsidian bands within road cutting through predominantly pumiceous zone of Ben Lomond Dome.*

Stop 5: Whakamaru caldera overlook

Here we are standing on the dome belt that erupted along the western margin of the Whakamaru caldera for about 100 k.yrs afterwards, with highly varied chemistry. Looking to the NE (180 degree view to Figure 24) we can see across the caldera containing the Maroa dome complex and the Mokai geothermal field. The Whakamaru caldera is the largest caldera in the TVZ erupting more than 2000km^3 of magma. The western dome belt and the Maroa domes, along with voluminous buried pyroclastics and sediments infilled the caldera to nearly todays' land surface within as little as 50 k.yrs; neither of these groups of domes share the same geochemical affinity as the caldera forming ignimbrites.

Figure 24: *Looking southeast over the Mokai area. Maroa Volcanic Centre is at left, the Western Dome Belt is at the right (Stop 5, marking the west edge of the Whakamaru Caldera), with the green fields around Mokai in the centre of the image. Most of the central photo coverage is within Whakamaru Caldera, which extends from a northern edge near the Waikato River in the foreground, to a southern edge part way across Lake Taupo in the distance. Photo D. Townsend, GNS Science.*

Stop 6: Mokai geothermal field

Mokai geothermal field is one of the few geothermal fields in the western TVZ and sits within the Whakamaru caldera in contrast to Rotokawa, Natamariki and Orakei Korako which sit on the eastern caldera margin. Mokai produces >100 Megawatts of electricity (Figure 25) and is a joint venture between Mighty River Power and the local Maori Iwi. It is a very progressive development where not only is the steam used for generating electricity but it is also used for a milk drying plant and a large green house facility for growing export grade vegetables.

Figure 25: *Mokai geothermal field and Whakamaru caldera viewed from the air. The greenhouse complexes can be seen adjacent to some of the post caldera forming lava domes to the top of the photo.*

Stop 7: Atiamuri boulder field from the catastrophic dam breach of Lake Taupo

Here we can stand on a garage sized boulder carried in a debris flow/lahar that formed following the 26 ka Oruanui eruption. Following the eruption the ignimbrite dammed the lake and this catastrophically failed as the lake refilled. Boulders (Figures 26 and 27) were transported 6km downstream from our next stop at the Ohakuri dam site sending a devastating torrent down the Waikato River. This is one of several significant events that ultimately changed the path of the Waikato River from the east coast to the west coast.

Figure 26: *Pohaturoa lava dome with boulder field in foreground, near an early bridge across the Waikato River. Barraud, Charles Decimus, 1822-1897. [Rock. 1860s or early 1870s?]. Ref: A-029-063. Alexander Turnbull Library, Wellington, New Zealand. http://natlib.govt.nz/records/23111531*

Figure 27: *Looking southeast at Pohaturoa dome in foreground, Maroa domes to the left behind that, Mokai to the right with the Western Dome Belt cutting the green pasture. Ruapehu in the distance over Lake Taupo. The boulder field is within the pine forest between Pohaturoa and the road in the foreground. Photo D. Townsend, GNS Science.*

Stop 8: The fossil hydrothermal system at the Ohakuri Dam (Figure 28)

Here the 240 ka Ohakuri ignimbrite is barely recognisable due to hydrothermal alteration and silica cementation. The ignimbrite is highly veined and brecciated, preserving a record of shallow hydrothermal circulation and dominantly silica precipitation. This area has also been explored via drill holes as a potential epithermal gold mine site but was not deemed economic.

Figure 28: *Ohakuri dam site on the Waikato River, forming Lake Ohakuri; with Maroa Volcanic Centre domes to the right and lumpy eroded partially hydrothermally altered Ohakuri Formation ignimbrite in the foreground. Photo L. Homer, GNS Science*

Stop 9: Tauhara dacite quarry

Tauhara cone and dome complex (Figure 29) is heavily vegetated; however, the dacite is quarried for road aggregate. The dacite is an unusual mixed composition and makes a great hand specimen with beautiful textural evidence for mingling (Worthington, MSc thesis).

Figure 29: *TOP - Tauhara dacite within the quarry.*
BOTTOM - Tauhara from the southwest, photo D. Townsend, GNS Science.

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