Triassic to Neogene tectono-magmatic events within Lorne Basin evolution, coastal New South Wales, eastern Australia

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Supplementary papers

Appendix 1. Detailed field relationships

Milligans Road Formation, down-thrown blocks

The youngest part of the Triassic Lorne Basin sequence, defined by Pratt (2010), is preserved in fault blocks that contain the oldest dated Triassic volcanic units (*ca* 231 Ma, Graham *et al.*, 2006). Pratt described air fall tuff beds in the type section quarry exposure (Byabarra ML; 733, 114, 90 m). A study in 2001 by the present authors at the type section, however, interpreted the lower thicker units as parts of a descending feldspar-phyric pyroclastic flow overlying an exposed window in carbonaceous mudstones. A thinner rhyolite flow (733, 114, 80 m) differs in petrology to the lower feldspar-phyric volcanic units. It overlies laminated shales and sandstones indurated by the flow base. This flow extends back through sporadic exposures to a columnar-jointed rhyolite flow in the Bago Vineyard entrance road, 1.8 km to the west, dated at 160 Ma (714, 114, 55 m; Graham *et al.,* 2006). This flow is clearly younger than the feldspar-phyric pyroclastic exposures, which extend back to Milligans Road quarries, 3 km to the WSW (704, 122, 70 m), where they were dated at *ca* 231 Ma (Graham *et al.*, 2006). Here a feldspar-phyric unit 9 m thick was exposed (Pratt, 2010; Sutherland, Graham, Henley, & England, 2017). Underlying basal units included tuffaceous horizons with accretionary lapilli, which overlie carbonaceous mudstones with thin coaly beds. Quarried sides expose altered, pale leached and brown ferruginous zones and typical Liesegang ring development, with only limited cores of fresher rock. Steep dyke-like feldspar-phyric bodies ~ 1–2 m wide on the quarry margins lie along a WNW–ESE trend and suggest a local feeder source for the feldspar-phyric unit (702–703, 115–117, 60–70 m). An extension of the unit was drilled 1.5 km SE of the quarry (CTK Constructions Pty Ltd, 1991), and reached a 34 m depth of solid rock west of Herons Creek (050, 043, 65 m).

The Bago Vineyard rhyolite develops columnar jointing in places and expands westwards as a large subsurface rhyolite resource along Lookout Road under surficial deposits which average ~ 1 m in depth (De Groot & Benson Pty Ltd, Geoff Smyth Consulting and Keiley-Hunter Town Planning, 2015; Joint Regional Planning Panels, JRRP No.2016NTH002, Council Assessment Report, 2017). The hidden rhyolite area represents an estimated resource of 1,700,000 m^3 and 4 million tonnes of hard rock. The source of such a significant rhyolite mass needs consideration.

An elongate Mesozoic intrusion mapped by Pratt (2010) on the Lorne Basin margin, 2–3 km NW of the Lookout Road rhyolite resource was investigated. A massive vertical SSE-trending rhyolite dyke, some 15 m wide, ascends into Carboniferous basement at ~ 200 m asl to rise through a cliff of lower Lorne Basin Triassic beds to intrude Coopernook Conglomerate (707–709, 146, 312–357 m). Fine-grained pinkish rhyolite shows steep marginal flow-banding and columnar jointing in places. The dyke interior, in a road-cut (708, 145, 315 m) shows coarser mosaic grained texture and remnant outcrops descend SSW (709, 137, 252 m). The rock resembles the Bago Vineyards rhyolite flow, suggesting a source for that flow and the intervening Lookout Road rhyolite resource, which infills a broad SSE valley descending from ~ 190 to 55 m asl.

A tongue of similar flow-banded rhyolite also descends SSW, skirting older feldspar-phyric volcanics along Milligans Road where it overlies Triassic carbonaceous siltstones (701–700, 123–121, 70–50 m). Intersected by Herons Creek drainage, the rhyolite re-appears S of the Milligans Road–Rollover Road junction (695, 117, 80 m), before a major cross fault down throws the Milligans Road Formation against Paleozoic basement. To the west, rhyolite of similar petrology caps a ridge trail for a km SSW of Herons Creek Road (684–688, 108–114, 70–105 m). The lower part was mapped as an intrusion (Pratt, 2010), but the higher outcrops show sub-horizontal flow banding suggesting a flow capping.

Western Lorne Basin includes the largest down-thrown segment of Milligans Road Formation, isolated by Dellward, Waitui and Black Creek uplift faulting (Figure 1). Several volcanic horizons were designated as air fall tuffs (Pratt, 2009, 2010). A re-worked exposure at Isaacs Road quarry (Lorne MK; 955, 546, 300–330 m) revealed a substantial wall of sub-vertical, hexagonal columns of whitish rhyolite in 2018, before being dismantled by quarrying. N–S-trending dyke-like bodies in the quarry floor suggested a local source for the 30 m thick rhyolite around the quarry walls. The flow-banded rhyolite includes sporadic euhedral crystals phenocrysts altered to greenish ‘illite’ (XRD analysis), as pseudomorphs of alkali feldspar (as seen in thin-section). Exposures of ‘air fall tuffs’ (Pratt, 2010) further NW along Isaacs Road show blocky jointing and buff to brown colour (571, 957, 260 m). These rocks, however, retain the distinctive flow banding and green ‘illite’ pseudomorphs seen in the Isaacs quarry rhyolite. These 'air fall tuffs' more likely represent pyroclastic flows. Unmapped flow-banded rhyolites on Isaacs Road west of the quarry (561, 957, 300 m) and along Waitui Road near Waitui Falls (552, 969, 195 m), lack the distinctive green 'illite' pseudomorphs found at Isaacs quarry. Waitui Falls flows over resistant felsic sills emplaced laterally within Camden Haven Claystone (Pratt, 2009).

Massive flow banded rhyolite forms cliffs at least 60 m high that expose large cooling columns in outcrops that overlie Milligans Road Formation beds on the down-thrown southeastern side of Dellward Fault (537, 978, 102 m). The columns and basal sheet jointing incline 5–10º NW towards the fault. It is unclear whether the rhyolite represent post-eruptive tilting along the fault or post-faulting eruption into a paleo-channel of the Camden Haven River, which now diverts around and erodes through the rhyolitic mass.

Rhyolitic flows are exposed along Hannam Vale Road in an eastern down-thrown block. One flow showed a fine-grained phase mingled with massive micro-feldspar phyric-rich rhyolite (602, 934–935, 100–110 m). The now disused quarry is much altered, although the flow retains residual columnar jointing within a 15 m thick keel. Another, zircon-rich rhyolite was located farther north (605, 947, 170 m) and well north beyond Hannan Vale–Lorne Road junction rhyolite flows appear in Lorne Road embankments, both east and west of Citizens Bridge, (620, 978, 35 m; 625, 977, 40 m). These rhyolites appear to be fault bounded and the sources are obscure. East of Lorne Road –Stewarts River Road junction, two micro feldspar-phyric rhyolite flows enclose dark carbonaceous siltstone in a sequence that dips SW at 15–20º. The dips may represent tilting related to the major Waitui Fault, which downthrows the sequence half a km to the east.

The granitoid plutons

The eastern topographically prominent granitoid plutons, North, Middle and South Brother Mountains, differ in size and unlike the more subdued Black Creek and Holey Flat plutons lack bounding ring fault uplifts. The plutons have been irregularly studied by previous workers. This study although sampling the plutons also focuses on their subordinate post-pluton structures. North Brother, a relatively massive and homogenous pluton, intrudes the lower Triassic beds to rise from ~ 20 to ~ 490 m asl. It is largely composed of plagioclase-phyric micro-granites (Laurieton MK; 787–791, 985–973, 350–490 m).

The largest pluton, Middle Brother, has the most diverse petrological components. The SE side, in major quarrying, has exposed finer to coarser diorites, monzodiorites, granites and porphyritic alkali feldspar granites (Lorne MK; 716, 909, 20 m – 716, 912, 50 m). Pacific Highway upgrades on the NE flank exposed detailed transitions between mafic dioritic and felsic granitic rocks, which were recorded and sampled by the New South Wales Road Traffic Authority (2005). Several dioritic variants included overprinting alterations (753–754, 950–961, 15–20 m) and other sections exposed fresh micro-granodiorite. The petrography of these rocks is illustrated in Appendix 3.

The pluton summit is uniform textured granodiorite at the transmission towers (694, 924, 558 m), while a composite phase of altered granodiorite outcrops at the radio mast, 0.8 km SW (691, 922, 525 m).

The northern pluton margin reveals prominent outcrops of noticeably flow-banded, red to pink and grey micro-porphyritic granitoids. On Stoney Creek Road a finer grained margin, with inclined westerly flow banding, passes up into coarser, massive, blocky to sub columnar-jointed outcrops with steep flow banding (713–714, 947–945, 185–200 m). West along Grey Gum Road, higher outcrops show shallow flow banding dipping north at ~ 20º in places (710, 948, 240 m) and pass into finer-grained, greyish more mafic lithology that includes composite contacts with coarser pinkish variants. They are intruded by a 5 m wide ~ N–S-trending rhyolite dyke with steep flow banding (708, 947, 260 m).

The NW plutonic margin is poorly-exposed and masked by faulted intervals of Camden Haven Claystone and Carboniferous basement (Pratt, 2010). Rounded monzogranodiorite masses on roads along Batar Creek valley sides (711, 983, 50 m; 684, 968, 95 m), have a breccia-like nature and may mark fault or slip zone material. South of Batar Creek, pink orthoclase-phyric micro-granites and granular-textured micro-granodiorites and micro-monzodiorites fringe the pluton margin along Big Gum Road (676–678, 944–949, 177–247 m). A quarry on Mudfords Road worked hornfelsed Camden

Haven Claystone (682, 938, 360 m), which may indicate thermal metamorphism from an adjacent intrusion.

The SW margin exposes lower-level massive, jointed, micro-phyric felsic lithologies. Jerrys Creek crossing on Mudfords Road, has eroded into jointed, slabby sheets of reddish, shallow flow-banded rhyolitic rock (665, 918, 90 m). Similar, but greyish finer grained, strongly banded units border Jerusalem Road, south of Mudfords Road junction (651, 916, 130 m). These dip ~ 45º SW and may represent truncated, tilted segments along the southern side of adjacent Holey Flat uplift ring faults. Micro-granitic outcrops extend east along Jerrys Creek into The Falls Retreat area. Here, they show regular blocky intersecting joints, with one set striking at 290º, dipping ~ 60º SSW, the other at 037º, dipping ~88º ESE. Alkali feldspar-rich granites form the falls on Jerrys Creek (678, 918, 30 m) and quartz-phyric types and aplites outcrop in Jerrys Creek near The Falls Retreat entrance (682, 913, 20 m). At higher levels, along Cliff Trail, massive diorite lies east of quartzose metasediments. The metasediments are intruded by a porphyritic rhyolite dyke (682, 918, 125 m). The dyke contacts trend from 225º (N end) and 230º (S end) and are intersected by two sets of joints, spaced at intervals of 2–10 cm (one set strikes at 290º and dips 60º SWS, the other strikes at 037º and dips 88º ESE). The red phenocrystic alkali feldspar and flow-banded matrix in this dyke resemble features in rhyolitic dykes that intrude South Brother pluton, 3 km to the south, where they yield a Cretaceous age (Graham *et al.*, 2006).

South Brother, the smallest pluton, intrudes Triassic Camden Haven Claystone, slivers of Coopernook Conglomerate and Carboniferous basement uplifted by adjacent Holey Flat ring faulting. Basal micro-granites (Knutson, 1975) appear to merge into micro-monzonitic rocks. Petrographic variation in the pluton was a focus in this study. A western chilled margin of mafic alkaline rock suggests emplacement post-dated and obscured the adjacent ring faults (678, 884, 100 m). Monzonitic samples (Lorne MK; 687, 885, 270 m; Coopernook MK; 678, 868, 100m) gave an early Cretaceous zircon FT age of 126 Ma (Graham *et al.*, 2006). The micro-monzonitic rocks host E– W-trending red alkali feldspar-phyric, steeply flow-banded rhyolitic dykes on the north flank (Lorne MK; 688, 890–885, 40–200 m). The dykes gave a slightly younger Cretaceous age of *ca* 120 Ma (Graham *et al.*, 2006). These rocks form many of the prominent knolls and ridges that lead up to the summit (western shoulder, 683–685, 876, 230–490 m; southern side, 688, 877, 410 m; east flank, 695, 875, 340 m; summit area, 686, 877, 460–495 m).

Western plutons

Black Creek and Holey Flat plutons lie within ring-faulted uplifted Carboniferous basement. Black Creek pluton petrology (Knutson, 1975) includes diorites at the NE margin and granodiorite at the SW margin. The central part sampled in this study, includes outcrops of micro granites (684–685, 027–045, 20–40 m) and red orthoclase-rich granites that extend westward through the Kew Trig–Perrots Road region (Byabarra ML; 685–705, 025–050, 30–243 m). A dioritic intrusion and its off-shoots on the NW side of the pluton were studied along a 0.8 km exposure SSW along Blackbutt Road from Fork Creek ford (666, 064, 50 m). Coarser grained, plagioclase-rich rocks outcrop in Fork Creek and show steep flow banding. Finer grained, micro-porphyritic diorite on the margins shows inclined flow banding suggesting an upward flaring intrusion. In the SSW road sections finely-laminated siliceous beds abut micro-porphyritic diorite and show moderate dips and near-vertical jointing (666–664, 063–058, 90–125 m; 663–658, 057–056, 160–180 m). They may represent siliceous sedimentary host beds contact metamorphosed by adjacent diorite intrusion prior to later jointing. Small satellite bodies, up to one km across and SW of the main pluton include even-textured micro-granodiorite (648, 039, 225 m).

The Holy Flat pluton truncated on its west side by ring faulting, suggests it was a prior emplacement. Samples from NW margin (Knutson,1975) were granodiorite, while a central sample was a monzogranite with a texture suggesting unmixing of feldspar phases during cooling (Richardson, 2013). The NE margin was examined here along Northern Access Road, where massive pink micro-granite outcrops (Lorne MK; 664, 880, 60 m – 638, 888, 180 m).

Farther west, an eroded micromonzonite body on the margin is obscured by a high-level deep red-brown soils and weathered fine-grained, flow-banded trachyte (619–616, 890–892, 250–300 m). The faulted SW margin of the pluton includes coarse granite (Coopernook MK; 620, 870, 230 m). The S margin intrudes folded Paleozoic basement beds, well-exposed in Hallidays quarry on Juhles

Mountain Road. A blocky-jointed, dyke-like body at the quarry entrance trends at ~ 140° magnetic, shows interior cores of pink felsic medium-grained rock (626, 854, 60 m) and may mark a satellite intrusion from the flanking pluton.

Four intrusive bodies and associated rhyolites lie within NE–SW-trending fault blocks of uplifted Triassic Camden Head Claystone and Coopernook Conglomerate in western Lorne Basin (Pratt, 2010). They are dissected by headwaters of Upsalls and McLeods creeks and partly intrude along bounding faults, which suggests a post-faulting emplacement. The bodies range from 2 to 5 km across. Massive, blocky jointed microgranites, in places form vertical columns up to 3 m high (Lorne ML; 592, 984, 105–130 m; 566, 989, 190–195 m). These pink to red rocks contain sporadic micro-phenocrystic alkali feldspar and small aligned feldspar laths and opaque oxides in an intergranular groundmass. White altered rhyolite with distinctive green 'illite' replacements of sporadic alkali feldspar micro-phenocrysts appears at higher levels (552, 002, 359 m). The most complete sequence lies westwards along Lorne–Comboyne Road. Here, bedded sediments underlie blocky micro-granite invaded by coarse veins and patches of granophyric granite, which is capped by 'illite'-bearing altered rhyolite (542–539, 015–997, 360–433 m).

The 'illite' altered rhyolite resembles the remnants associated with Isaacs Road quarry vent some 3 km southeast and suggests a potential correlation. The higher levels in the western outlying sequences (~ 30–130 m) can be accounted for by later down-throw faulting of the Milligans Road Formation block. This matches rhyolite faulted against Carboniferous basement beds demonstrated in Isaacs Road quarry (Pratt, 2009).

Mount Lorne volcanic complex

A major extrusive centre within Lorne Basin, the Mount Lorne rhyolite plug, (length1.5 km N–S, and width 1.2 km E–W), is a dominant structure that ascended through and partly conceals the double ring fault system of the Black Creek uplift. This suggests a post-faulting age. The base at 30 m asl, rises to a northern peak at 244 m asl, which is fringed by cliffs left by mass wastage on its SE side. A limited central lower plateau with darker soil includes float of a chilled fine-grained, partly fluidal textured rhyolite (675, 986, 150 m). The overall topography may represent a composite plug structure. A lobe-like segment on its NW flank exhibits noticeable, multiple vertical flow bands within the rhyolite (674, 988, 90 m). The summit shows steep flow banded rhyolite that carries reddish alkali feldspar composites. The rocks exhibit areas of significant deuteric alterations and developments of quartz lined vughs towards the top. This indicates late-stage fluid activity. Poorly-exposed brecciated materials along the SW base of the plug include fragments of flow-banded rhyolite, reddish strongly oxidised rhyolite and jig-saw fit fragments in an argillitic matrix (668–690, 990–982, ~ 20 m asl). This supports suggestions of late-stage volatile venting in the plug.

Mount Lorne's conduit forms a potential source for peripheral flow-banded rhyolites found at lower levels around its eroded core. Flows lie to the NW in Upsalls Creek valley, to the N in Black Creek valley and to the NE–E in Camden Haven River valley. In the NW, weathered rhyolite along North Branch Road is intersected by a NE–SW-trending micro-porphyritic rhyolite dyke, where steep flow-banding dips ~ 60° SW and a hornfels contact was worked in an old quarry on its east side (Lorne ML; 654–657, 034–035, 30–35 m). To the N, micro-porphyritic rhyolite descends westerly along Cross Creek Road (Byabarra ML; 690–684, 025–027, 160–60 m). Flow banding dips W from ~ 20° to ~ 70° W within a steeper fall in the paleo-drainage channel before the flow bottoms on micro-granite (40 m asl). Downstream, the rhyolite reappears along the west bank of Black Creek (680–687, 014–024, 15–25 m). The flow finally intersects blocky-jointed massive basement rocks, where feldspar in the rhyolite shows alteration to greenish 'illite' (685–686, 014–015, 15–30 m).

NE of Mount Lorne, low level rhyolites extend to Lorne Road near Kendall and Kew (709–712, 011–012, 30 m). To the E, flows of micro-phyric rhyolite fringe the sides of Batar Creek outlet (Lorne MK; 711, 981, 45 m) and to the SE–S form headwater ridges along Batar Creek on Old Coach Road (683–685, 739–741, 90–100 m; 673, 967, 125 m). The easterly flow remnants probably continued across Camden Haven River where similar rhyolite with shallow flow banding lies east of Sunnyvale Road (731–737, 973–999, 20–50m), south of Stage Coach Road–Glen Ross Road (730–748, 967–970, 10–30 m), and possibly as far south as Charles Yard Road (752, 951, 25 m). This suggests flow paths of 6–8 km in length.

Small satellite intrusions around Mount Lorne plug probably mark further sources for surrounding flow remnants. A rhyolite plug, quarried on Kendall Forest Road, 2 km WSW of Kendall, is ovoid, 80 m long, 40 m wide and trends NNE. Alkali feldspar micro-phyric rhyolite showed steep flow banding near its margin, against fine-grained, dense contact rocks (699, 993, 165 m). Dykes of pink alkali feldspar-phyric rhyolite, ~ 0.5 m wide, in Batar Creek Road embankments, 3 km S of Mount Lorne plug (672, 952, 150 m), trend ~ E–W, show steep flow banding and poorly-exposed sleeves of brecciated material.

A southern satellite feeder and its flow remnants lie 6 km SW of the Mount Lorne summit. A dyke, 3m wide and 10 m long, trends at ~ 150° magnetic in a quarry wall at Stewarts River Road–Jerusalem Road junction (636, 938, 110 m). The micro feldspar-phyric rhyolite, with near-vertical flow banding, has baked Camden Haven Claystone. An adjacent rhyolite flow, with a vesicular base, continues along Stewarts River Road as paleo-valley fill remnants that descend 2 km north to Savilles Creek (636, 938–934, 110–80 m; 637–635, 951–956; 45–35 m). There it becomes highly altered to clay and iron oxide products. Such alterations make former rhyolite flows difficult to discern in surrounding topography. An extreme example of alteration is seen in a clay quarry near Upsalls Creek–Black Creek road junction. Here a flow is almost entirely altered, although still retains the original ghosts of vertical columnar jointing within the keel of the flow (634, 015, 30 m).

The ages of the Mount Lorne plug, its satellite intrusions and surrounding rhyolitic flow remnants are undetermined. However, the reddish-pink alkali feldspar-phyric rhyolites closely resemble such dykes dated as early Cretaceous features within South Brother pluton.

Batar quarry rhyolitic centre and major flow

A rhyolite plug and dyke in the Batar quarry, on Stoney Creek Road, was visited and sampled in January 2001 (708, 962, 130 m). The rhyolite intruded Camden Haven Claystone to form hard contact hornfels, the target of quarrying which left the rhyolite structures in place. A NNW–SSE-trending elongated plug, ~80 m long, 15 m in girth and 3 m high, showed irregular blocky to hackly joints and close vertical jointing. A basal dyke ~ one m wide and 150 m in length protruded into hornfels, trending SE and dipping ~ 35° SW. Prominent flow banding parallelled the contacts. Zircons sampled from the plug gave a Jurassic FT date at 184 Ma (Graham *et al.*, 2006). When revisited in November 2017, quarrying had levelled the rhyolite structures, but had exposed further dykes that extended N and NNE into the northern hill side. The hill is an eroded, substantial northerly elongated rhyolite plug, ~ 450 m long and 300 m wide. An aphanitic, steeply flow-banded margin (708, 963, 140 m) encloses a slightly coarser rhyolite core that extends to a summit at 190m asl. A similar, more subdued plug ~ 0.5 km SE extends along Charles Yard Road (712–714, 961–962, 120–140 m). The Batar quarry plugs and dykes mark the source of a major massive rhyolite flow that caps an east-trending ridge, where its base intersects Charles Yard Road (716, 957, 170 m).

Blocky-jointed, near-horizontal flow-banded, aphanitic rhyolite reaches thicknesses of up to 80 m along Charles Yard Road (717–718, 955–956), where an offshoot descends south along Green Dump Road (723, 948, 120 m). Outcrops on the divide descend from a summit height of 269 m asl above the road junction to 218 m asl on its eastern end above Charles Yard Road (738, 954). The rhyolite-filled valley profile is exposed in a road curve at 240 m asl (726, 956) and its base overlies silicified quartz-rich gravels at 225 m asl (728, 955). This probably marks a former alluvial lead. A nose of massive, layered rhyolite above the road at 230 m dips at ~ 20 ° N and suggests the rhyolite partly spilled into a northerly tributary channel (730, 956). The rhyolite base reaches its lowest level where silicified quartz-rich grits and gravels mark its former alluvial lead, cut into shallow E-dipping beds of laminated Camden Haven Claystone (747, 954, 70 m).

These flow remnants trace a voluminous outflow from the Batar quarry feeders that travelled through a narrow Jurassic drainage course for at least 3 km, and now remains as prominent ‘inverted’ ridge of tough rhyolite.

Rim rhyolites

Rhyolitic bodies are prevalent on the outer margins of the Lorne Basin. A relatively old, large and well-preserved volcanic centre on the east rim forms a 217 Ma structure at Diamond Head (Knutson, 1975;

Higgins, 2007; Richardson, 2013). A massive rhyolite flow is intruded by late-stage dykes and sills of rhyolite, dacite, diorite and trachyandesite. In the northern section, a basal diorite sill intrudes into Camden Haven Claystone and overlying rhyolite (Laurieton MK; 812, 003, 0–100 m). In places, hydrothermal alteration in the rhyolites form muscovite-rich felsite (812, 899, 100 m). Mafic samples with cm-sized plagioclase crystals in the southern complex (812, 893, 58 m) were analysed in Knutson (1975) and this study.

Elsewhere, a flow-banded rhyolitic dyke intersects diorite in the Pacific Motorway extension on eastern Middle Brother (Lorne MK; 754, 961, 15 m). Other flow-banded rhyolites in the highway cuts contain conspicuous glomero-feldspar and quartz inclusions or altered feldspar phenocrysts and extend as far north as Herons Creek (Byabarra ML; 744, 058, 5 m; Appendix 3).

A string of rhyolitic bodies across northwestern Lorne Basin lie in eroded Carboniferous basement. An inner dyke/plug with steep flow-banded micro feldspar-phyric rhyolite intrudes olivine-bearing (?) mafic rock on Blackbutt Road (Byabarra ML; 675, 062, 135 m). From there, rhyolite with sub-horizontal flow banding descends WNW as a paleo-drainage infill for 0.8 km to overlie a diorite margin at Fork Creek crossing (674, 062, 55 m). Slabby, jointed rhyolite from that feeder also extends north along Blackbutt Road, dipping at ~ 25° N, until deflected NNE against massive micro-diorite (674, 066, 160m). The rhyolite reappears along Perotts Road, S of Blackbutt Road junction, infilling a SSE drainage cut within hornfels (674, 073, 210 m), then descends over micro-diorite (677, 066, 180 m) and terminates in a brecciated contact zone with fine grained diorite (679, 064, 180 m).

A lower rhyolite source is exposed in a plug, quarried at Upsalls Creek Road–Cold Nob Road junction (647, 019, 70 m). The exposed walls of alkali feldspar-phyric rhyolite are cut by dykes that trend at ~ 120° ESE and convert the underlying basement into hornfels. Nearby, massive rhyolite outcrops along Cold Nob Road (647, 020, 60 m), and 2 km farther N vertical jointed, blocky siliceous rhyolite grades up into finer grained rhyolite (649, 038, 180 m).

Rock Nob, a steep 50 m high plug, at Cold Nob Road–Rock Nob Road junction, has a base of blocky jointed, orange pink rhyolite (645, 063 330 m). Near-vertical flow banding and swirls of alkali feldspar-rich, glomerophyric rhyolite intermingle within non-phyric rhyolite. Similar rhyolite outcrops on Cold Nob Road, one km ESE (654, 058, 250 m). This satellite body, in contrast, shows shallow flow banding and may form a sill-like plateau rising to 280 m behind the road exposure. A potential feeder for this body is a wide dyke of steep flow-banded rhyolite, 0.4 km SE on Blackbutt Road, where it intrudes silicified inclined laminated sedimentary beds (656–658, 056–056, 240–220 m).

Cold Nob forms a NNW–SSE-trending rhyolitic ridge above Cold Nob Road, where it outcrops as massive blocky-jointed grey rhyolitic micro-breccia, showing shallow banding at its SE end, while similar rocks rise up to the ridge top (641–642, 065–067, 330–360 m). The basal medium-grained crystal-rich rocks contain small fragments of fine-grained rhyolite and may represent pyroclastic flow deposits. The NW side of Cold Nob ridge is skirted at road-level by sub-horizontally flow-banded fine-grained rhyolite (638–641, 068–072, 350–370 m).

Similar fragmentary rhyolitic bodies occur at Hyndmans Road–Cold Nob Road junction. In Hyndmans Road cut, massive, well jointed, fine-grained rhyolite assemblages, show near-vertical flow banding and small pull-apart lithic fragments aligned in an upward flow direction (617, 082, 330–370 m). This section may mark a proximal vent lithology, while stratigraphically higher samples of layered, crystal-lithic-micro-breccias, suggest pyroclastic flow deposits. Just west, a vitrophyre dyke forms a small elongated steep, slippage-disrupted, dyke, ~ 1–2 m wide and over 50 m length, that intrudes a granular, sandy feldspathic breccia, possibly a reworked pyroclastic deposit (615, 082, 370 m). This dark, glassy, flow-banded body carries sparse to common corroded feldspathic composites, disaggregated feldspar crystals, and developments of spherulites. A separate volcanic assemblage at SW Mount Tirrandubundeba, 750 m to the NE, is fine-grained, flow-banded, fragmentary rhyodacite, with dark finer grained lenses and whisks of opaque materials (609, 085, 300 m).

Unmapped rhyolitic outliers within the outer northwestern fringes include a massive flow banded cap, south side of Dividing Ridge Road (670,103, 214 m), a small flow remnant in Boundary Road between Corner and Tea Tree road junctions (630, 104, 250 m) and a massive ENE-trending blocky, flow-banded pink rhyolite dyke, south side, Blackbutt Road (636, 046, 237 m). Ducks Nob summit, Ducks

Ridge fire trail, is surmounted by large blocks of rhyolitic breccia, with greenish alteration phases (664, 110, 318 m). Textures suggest that it represents an eroded, brecciated, metasomatised plug.

Vitophyre dykes

Minor glassy bodies with partly resorbed cumulates and crystals in a glassy pitchstone to perlitic matrix, as described from W of Hyndmans Creek Road Junction, are found elsewhere in Carboniferous beds over much of Lorne Basin. At Kew gravel quarry, a 1.5 m thick, W-dipping sill had baked the enclosing Mingalettta Formation beds (Lorne ML; 743, 003, 30 m). This, and a similar body at West Moorland were described and analysed by Knutson (1975). Two conformable vitrophyres were reported in Mingaletta Formation beds in a rail cutting 0.5 km NE of Kendall (Roberts *et al.*, 1995). Native iron recovered from the Kew pitchstone, was a point of interest for a meteoritic impact model for the Lorne Basin (Tonkin, 1998). This site was destroyed during Pacific Motorway upgrades in October 2008). The vitrophyre intrusion, however, was documented, sampled and sectioned. Its petrography is described in Appendix 3.

All told, at least 12 vitrophyre sill/dyke sites were documented and mostly sampled during Lorne Basin mapping (Pratt, 2010) and subsequent visits (G. W. Pratt, pers comm., December 2018). A few sites are now lost to construction purposes, but all known finds were located in Carboniferous basement beds.

Northern ring fault rhyolites

The north rim of Black Creek pluton and its uplift boundary ring faults form sites for rhyolitic intrusions. Flow remnants from these intrusions extend from uplift boundary as former infills within Cedar Creek, Herons Creek and Camden Haven River drainages. A low plug of micro feldspar-phyric rhyolite, with steep flow banding and aligned elongated vesicles, lies on a trail to Kew Trig, adjacent to banded hornfels (Byabarra ML; 707, 044, ~ 230 m). Its flow remnants descend north to overlie granite outcrop (706, 049, ~ 220 m) and reappear on Perrots Road, surmounted by an arch of slabby-jointed aphanitic rhyolite, 1–2 m thick (704, 052, 140 m). The lower rhyolite descends along Perrot Road, then easterly along Tramline Road, until overlapped again by the upper aphanitic rhyolite flow (708, 056, 70 m). The flows show shallow ESE-dipping flow banding in their direction of descent and seem to re-appear in Corrigans Road quarry, 2 km to the ESE (728, 051, 45–50 m). The non-phyric rhyolite was the main quarried material and blocks of silicified gravels on the south side may mark a former paleochannel deposit. The distance from the rhyolite sources to Corrigans quarry gives a flow path of over 3.5 km and a drop of 200 m in paleo-thalweg.

An elongate plug intrudes the outer Black Creek uplift fault on Dividing Ridge Road (Pratt, 2010), where massive, jointed, micro feldspar-phyric rhyolite shows steep flow banding (687–689, 086–087, 140–150 m). The summit ridge above is capped by a closely jointed aphanitic rhyolite flow, up to 30 m thick, which shows shallow banding where its base descends west along Dry Ridge Road (687–685, 086–087, 200–190 m). Summit float includes a rhyolitic breccia, suggesting a nearby vent, while basal remnants of silicified quartz grit suggests a former paleo channel deposit. A lower rhyolite remnant lies at Dry Ridge Road–Dividing Ridge Road junction (685, 089–090, 140 m). Further rhyolitic plug and flow remnants extend NW along Dividing Ridge Road just beyond the uplift ring faults (685, 088, 170 m; 682, 098, 180 m; 679, 101, 220 m). A prominent NNW–SSW-trending porphyritic rhyolite dyke, and minor flanking minor vitrophyre dyke, lie just west of Link Road junction (682, 101, 200 m). An adjacent plug-like exposure at 220 m underlies float of vesicular basalt, with fresh aligned plagioclase laths in a dark oxidised iron-rich matrix (680, 102, 240 m). The source of this mafic lava is obscure. A northern centre forms a small dyke of micro feldspar-phyric rhyolite, with steep flow banding, on Link Road (689, 099, 105 m). It probably sourced similar rhyolite down the road, where a slabby flow base exhibits chalcedony- and agate-filled amygdales. The flow banding dips up to 25° east, before the base bottoms on Carboniferous basement at Link Road–Milligans Road junction (691–692, 099, 110–80 m).

Other rhyolitic bodies extend along the north eastern Black Creek ring fault zone. At Hi-Tech Bridge, at Blackbutt Road–Cedar Creek crossing, hard, siliceous alkali feldspar-phyric rhyolite shows sub-horizontal flow banding (704, 078, 20 m). Remnants of similar rhyolite extend SW along Cedar Creek and Blackbutt Road (701–694, 071–068, 30–35 m) as far as Bulls Ground Road (706–700, 064–061, 80–85 m). They seem unaffected by the Black Creek ring fault uplift. NW of Hi-Tech Bridge, a large quarry 0.2 km along Milligans Road has exposed a substantial hill of rhyolitic lithological units (703, 080, 25–35 m). Upper massive, blocky-jointed coarser material forms an arch-like structure dipping north and south over a central lens of aphanitic material. Faults break the continuity of the higher arch. Rare wavy bands up to a few cm long that break up into crinkled flow-like patterns appear in the higher units. A lower, flow-banded rhyolite extends SE along Milligans Road and the quarry entrance, where slabby, jointed, banded units dip SW (702–704, 082–080, 50–40 m). The quarry floor exposes a band of hornfels-like material and a rise of finely banded rhyolitic material containing fragments of silicified claystone. The complex nature, arching and fracturing of the quarry rocks make lithological interpretations difficult, but the top unit matches volcanolithic micro-breccias considered to represent pyroclastic flows elsewhere in Lorne Basin. Such units appear in Blackbutt Road cuts, 2.5 km to the ENE, at higher levels bounded by Black Creek uplift ring faults. Massive, blocky-jointed, fine-grained greyish rock surfaces dip NNE at ~ 30º, intersected by NNE–SSW-trending joints that dip ~70º SSE. The rocks show subdued, shallow flow banding, include dark aphanitic bands and extend west towards Blackbutt–Perotts Road junction (680–674, 073–074, 150–190 m). Whether the Hi Tech quarry and Blackbuttt Road sequences were connected prior to ring fault uplift is unclear due to substantial intervening erosion by Cedar Creek drainages.

One isolated intrusion is known along western Black Creek ring faulting. A micro-porphyritic rhyolite dyke is exposed in a disused quarry on Quarry Road intruding shattered Carboniferous basement beds on the inner side of inner ring fault (658, 088, 210 m). The ring faults surrounding the western plutons, clearly gave access for post–uplift felsic magmatism.

Western edge young rhyolites

Cenozoic rhyolitic plugs and tuff beds that form Big Nellie, Little Nellie and Flat Nellie lie within uplifted slivers of Carboniferous basement. Big Nellie, the largest plug, partly intrudes Camden Haven Claystone and stands 140 m above its base (Lorne MK; 542, 929, 420–560 m). These bodies are considered off-shoots of Comboyne central volcano, and a late Miocene correlation would suggest substantial removal of Triassic cover since their 16 Ma emplacement. To the southeast, a minor intrusion was mapped in the N–S aligned Koolah Creek Fault, that separates Carboniferous basement and Triassic Coopernook Conglomerate (Pratt, 2010). Petrographic analysis revealed a fine-grained assemblage of alkali feldspar, plagioclase and quartz (Coopernook MK, 585, 866, 150 m). The assigned Mesozoic age needs checking, as trachyte of Miocene age outcrops nearby at Juhle Mountain, 2.5 km NW.

Basaltic drapery

Evolved basalts related to Comboyne volcano form remnant infills of late Miocene drainages. The highest remnant occupies a narrow paleovalley cut in Coopernook Conglomerate, to thicknesses > 40 m (Byabarra ML; 601–620, 051–044, 360–300 m). This dense hawaiite includes feldspathic and mafic xenocrysts and composites. Similar rock, farther east, shows a poorly-exposed chilled margin against porphyritic micro-granite on Big Gum Road (Lorne MK; 677, 944, 247 m). North of Hannam Vale, basalts occupy a SE-trending ridge above Farm Road, infilling a former paleovalley up to 1.3 km long and 60 m deep (589–600, 947–941, 295–180 m). One flow with a vesicular base and more evolved nature carries feldspathic composites and overlies the Milligans Road Formation (592, 945, 220 m). Other basalts are largely fluidal-textured mugearites.

Basaltic remnants form the Juhle Mountain, a small peak 2.4 km S of Hannam Vale, which lies on a N–S fault within the Camden Haven Claystone. Three distinct rocks form its summit: a west-flanking hawaiite, with abundant xenocrysts and composites of mafic feldspathic mineralogy (598–600, 882–884, 230–260 m); a northern sub-horizontally banded felsic rock (600–603, 883, 220–270 m) and an east flanking mugearite that exhibits basal cooling columns and zeolite- and carbonate-filled amygdales (603–605, 883–885, 260–220 m). The summit felsic rock and mugearite gave Comboyne volcano ages (18–16 Ma; Sutherland *et al.*, 2012). Weathered rhyolite and sandstone exposed below the Juhle Mountain summit, probably mark older, Mesozoic units.

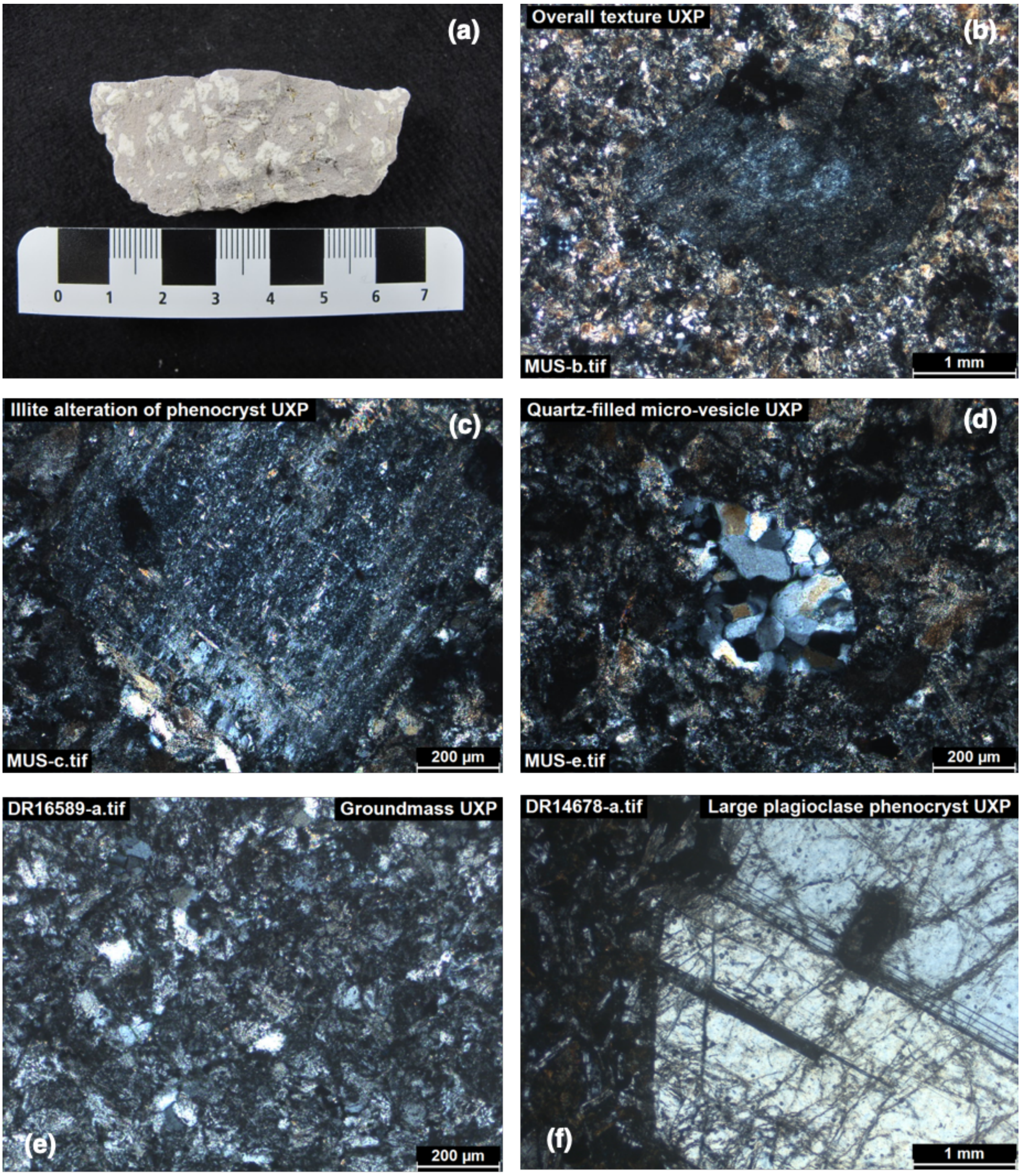
An unmapped basalt 1.7 km ESE of the Juhle Mountain summit was traced SE for a further 250 m (M. Allison and R. Griffiths, pers. comm., July 2017). Low cliffy outcrops up to 10 m high show columnar cooling columns and mineralised amygdales (615–618 E, 873–876, 210–200 m). The basalt lies against resistant Coopernook Conglomerate on its east side and probably represents a protected extension of the mugearitic basalt at Juhle Mountain.

The origin of Juhle Mountain volcanic feature is unclear on present field relationships. One scenario invokes a volcanic neck that erupted batches of fractionating magmas from an underlying chamber. Alternatively, a felsic vent eroded by flanking drainages then became surrounded by later basalt flows which solidified and buttressed the structure from erosion. More precise dating of the basalts and/or geophysical testing of their likely underlying depths are needed to test these potential genetic origins.

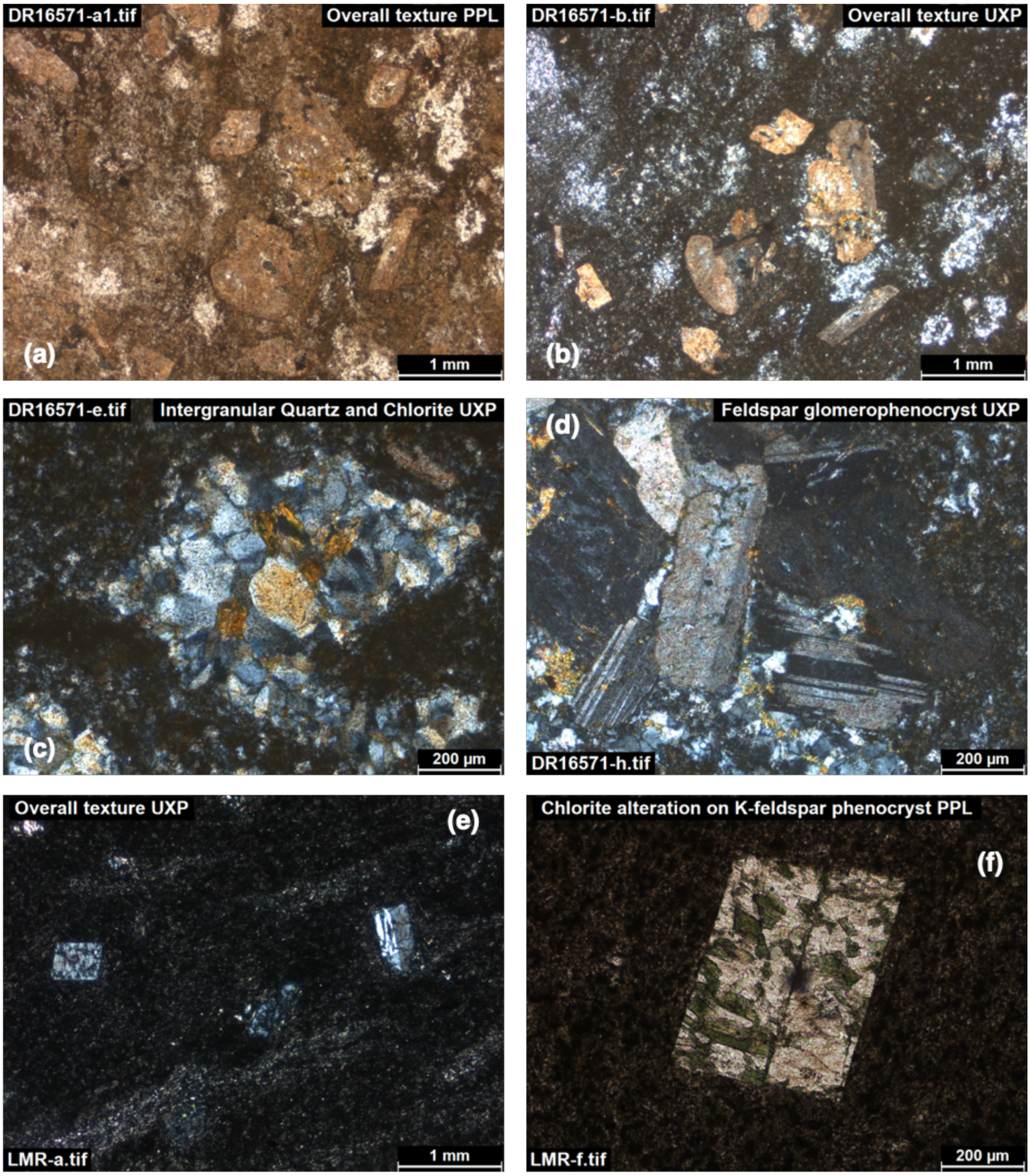
Southern dyke cluster

Extended workings at Fords Road quarry, west Moorland, in May 2018, exposed a ten m high, one m wide olivine-bearing mafic dyke intruding steeply dipping Carboniferous bed along partly curved chilled contact margins (Coopernook; 652, 854, 50–60 m). The quarry exposes three dykes of wide petrological range, although their precise relative ages are unknown. Besides the alkaline limburgitic composition for the western dyke, a massive NE–SW-trending coarse alkali feldspar-phyric rhyolite dyke (652, 853, 30 m) and a flanking vitrophyre dyke (652, 853, 20 m) are exposed inside the eastern quarry entrance.

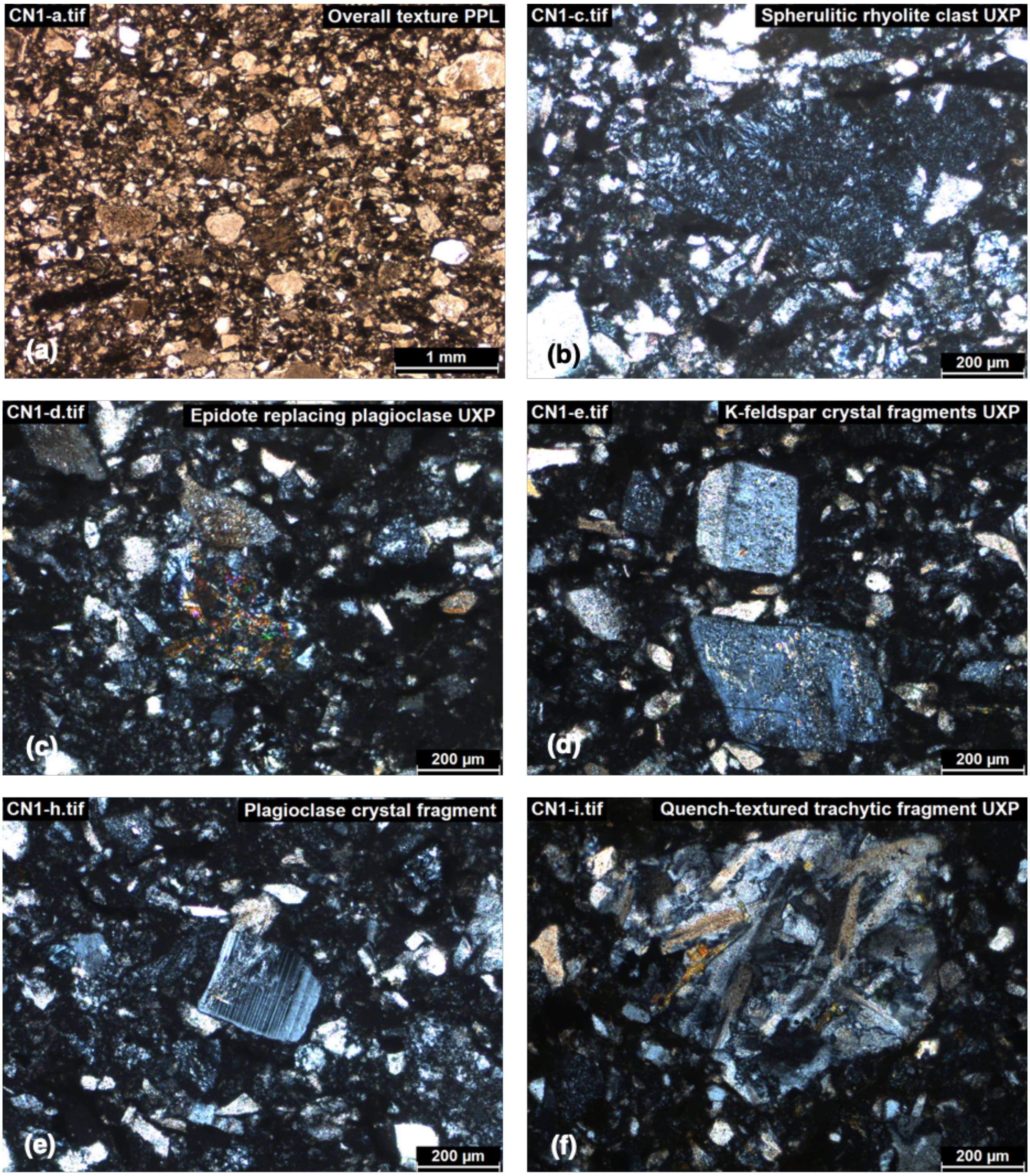
Appendix 2. Additional photomicrographic suites and descriptions, Lorne Basin



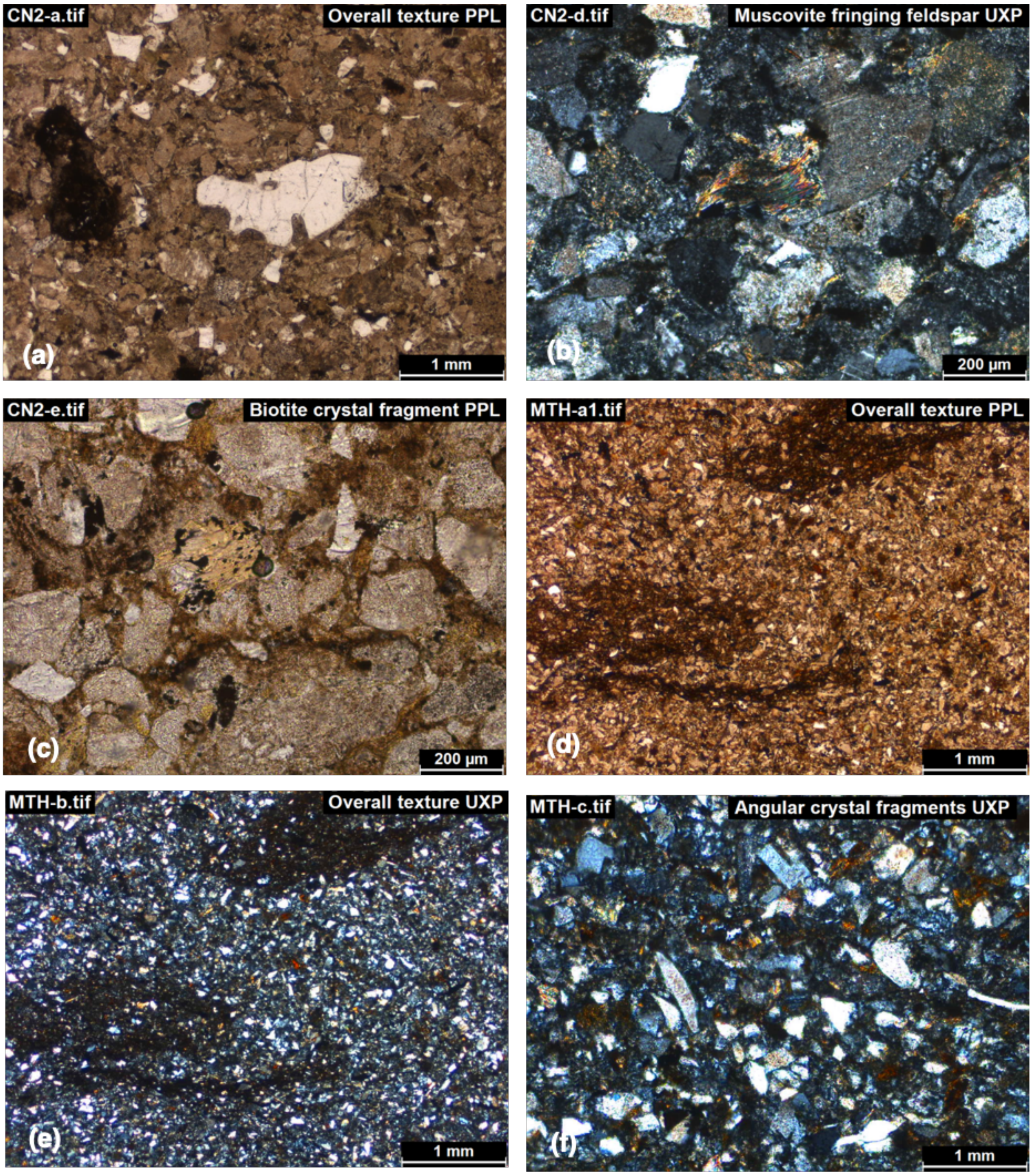
DR16574: Porphyritic rhyolite (a–d) DR16589: rhyolite (e); DR14678 porphyritic andesite (f)



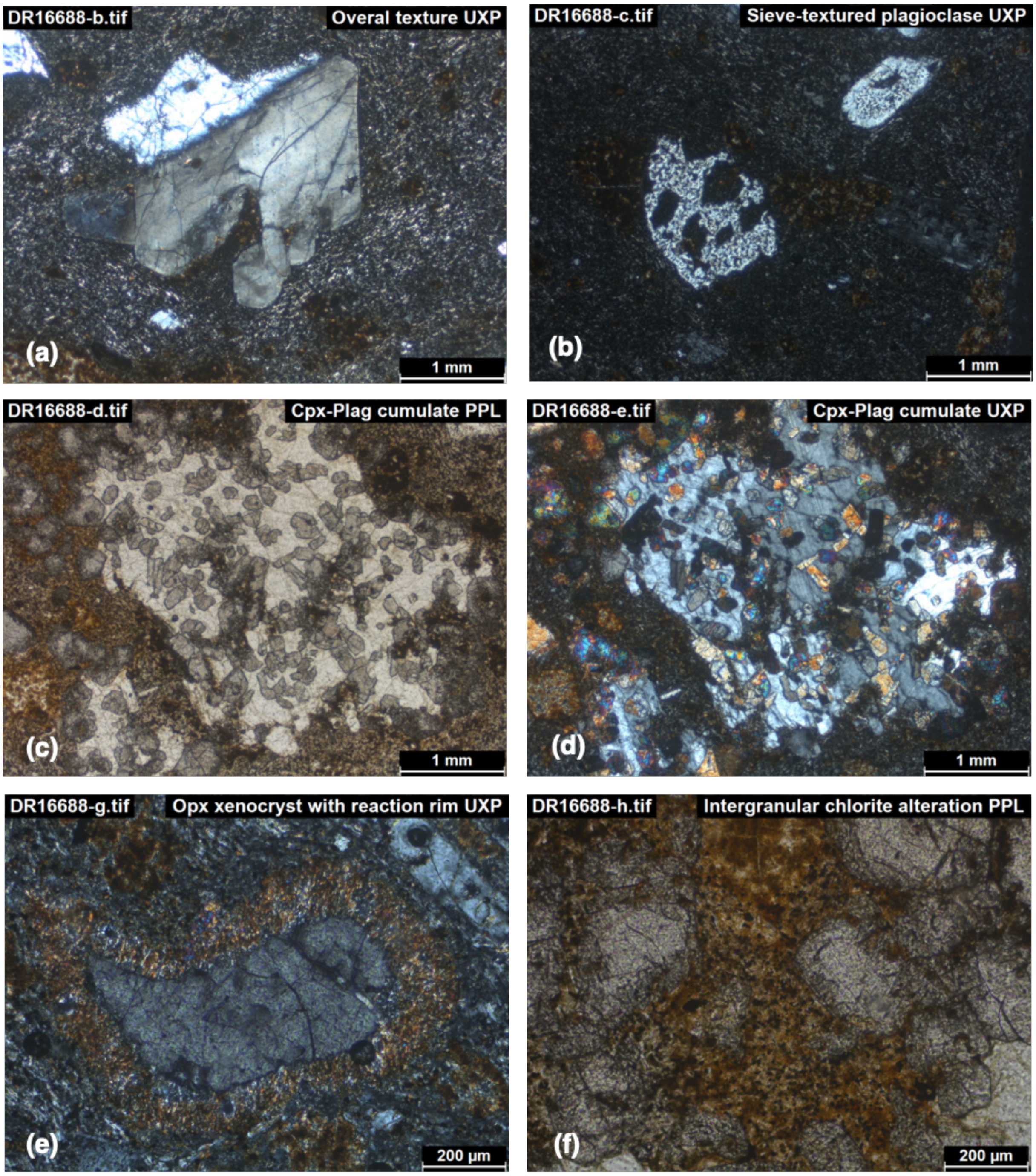
Mount Lorne Summit; DR16571 (a–d); LMR (e–f).



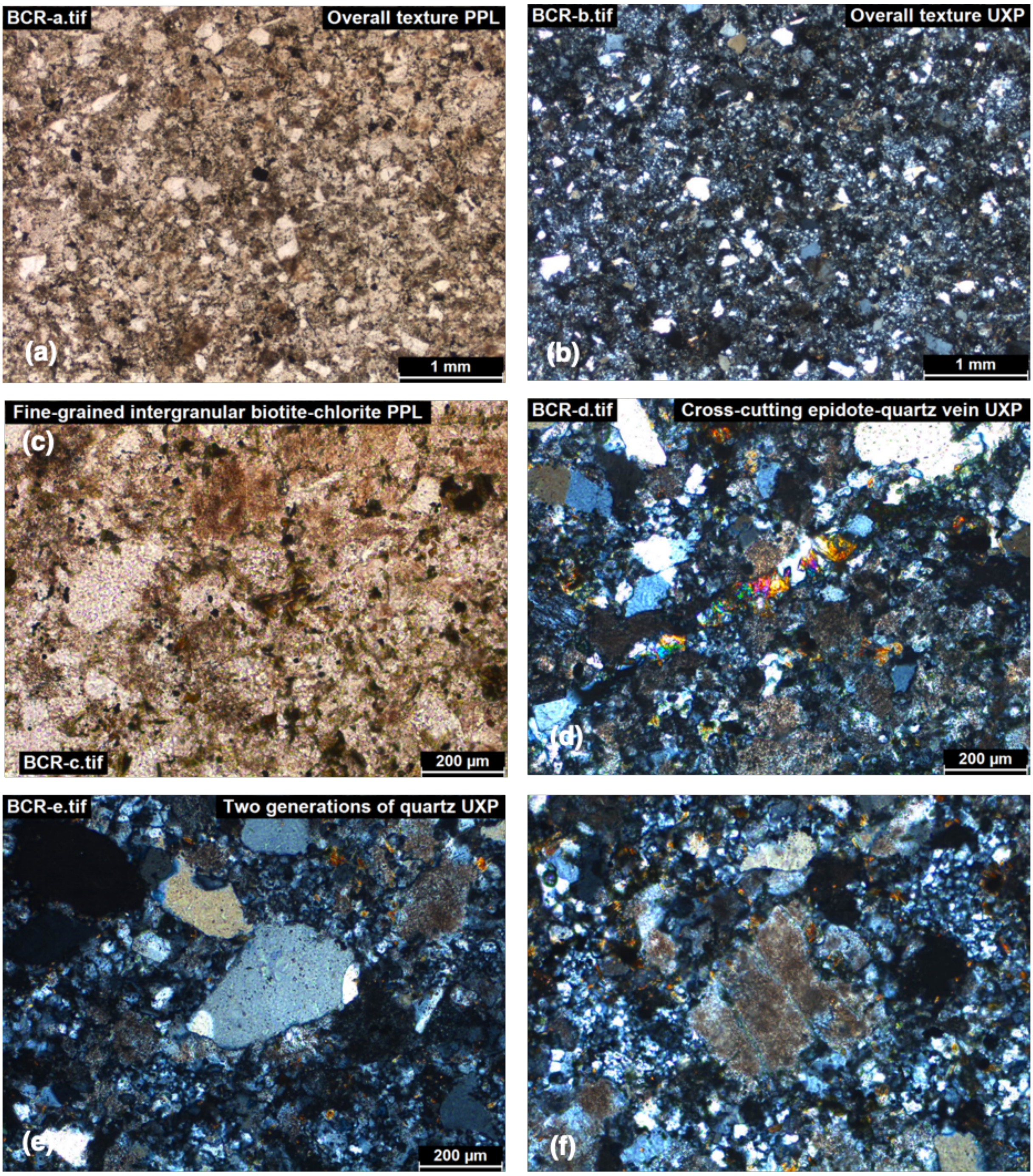
Cold Nob (CN1): rhyolitic breccia.



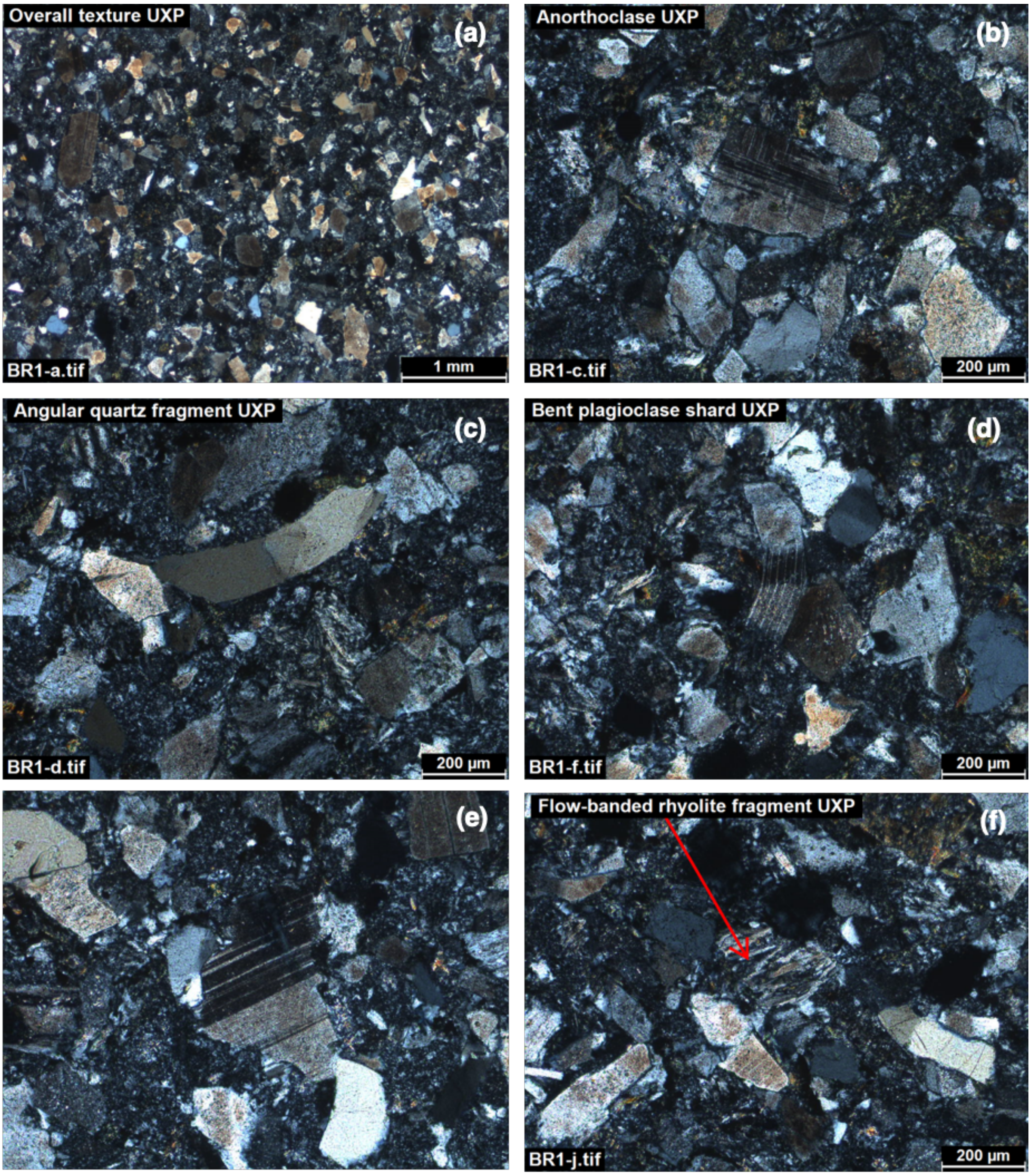
Cold Nob ridge top (CN2): rhyolitic breccia (a–c); Hyndmans Road-Cold Nob junction (MTH): rhyolitic breccia (d–f).



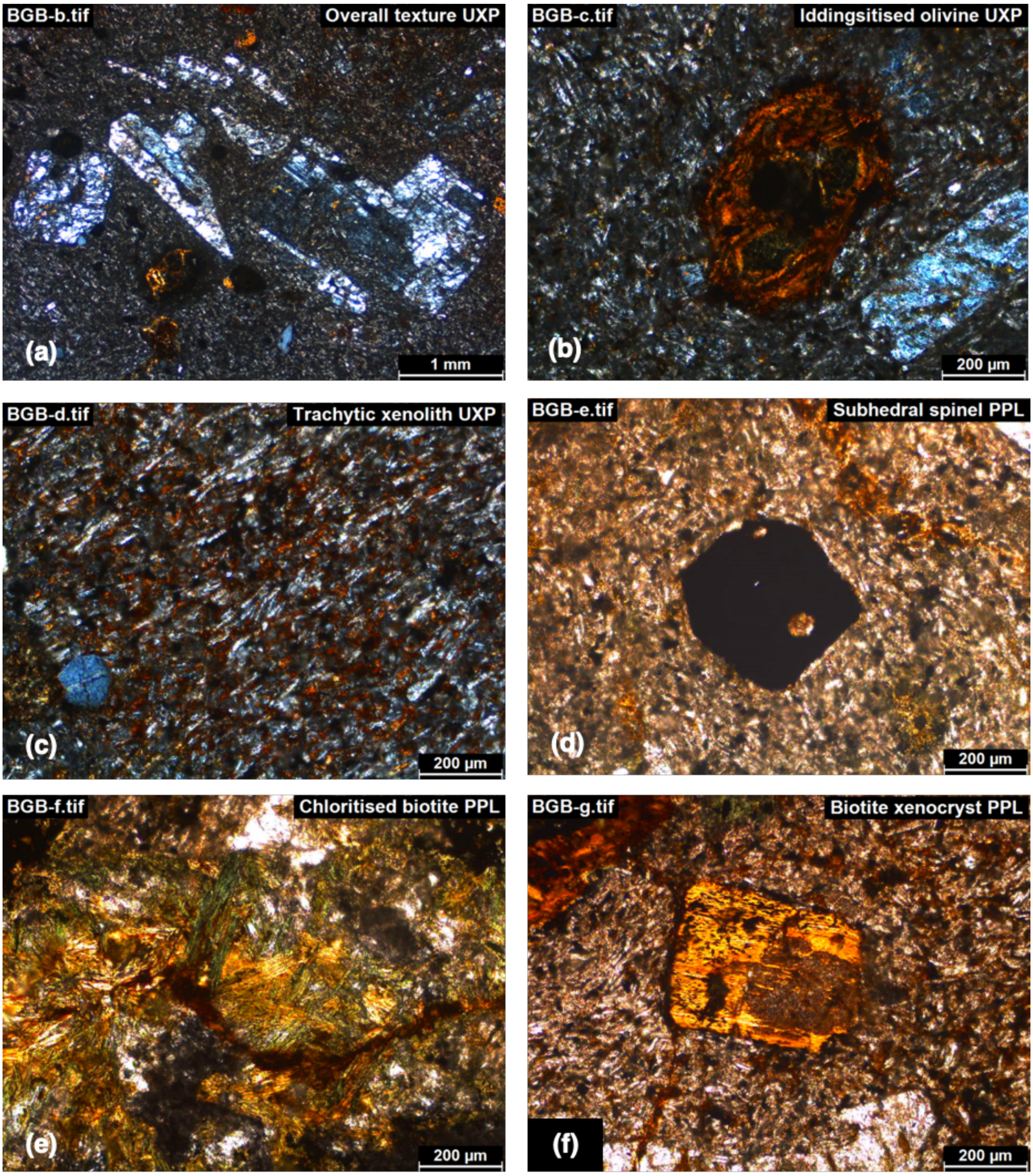
Mount Comboyne Road flow (DR16688) (a–f)



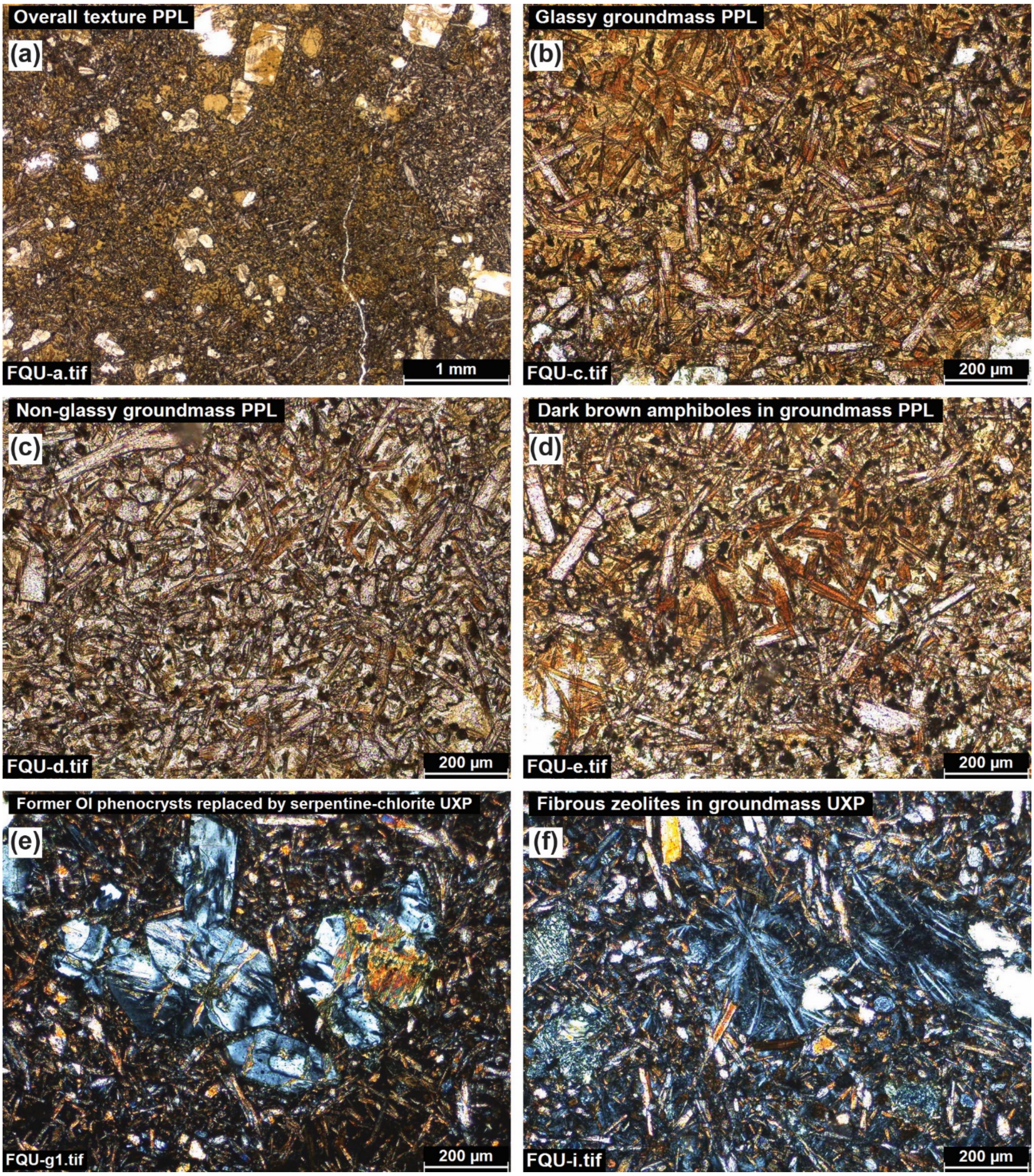
Back Creek micro-breccia (BCR): rhyolitic micro-breccia (a–f).



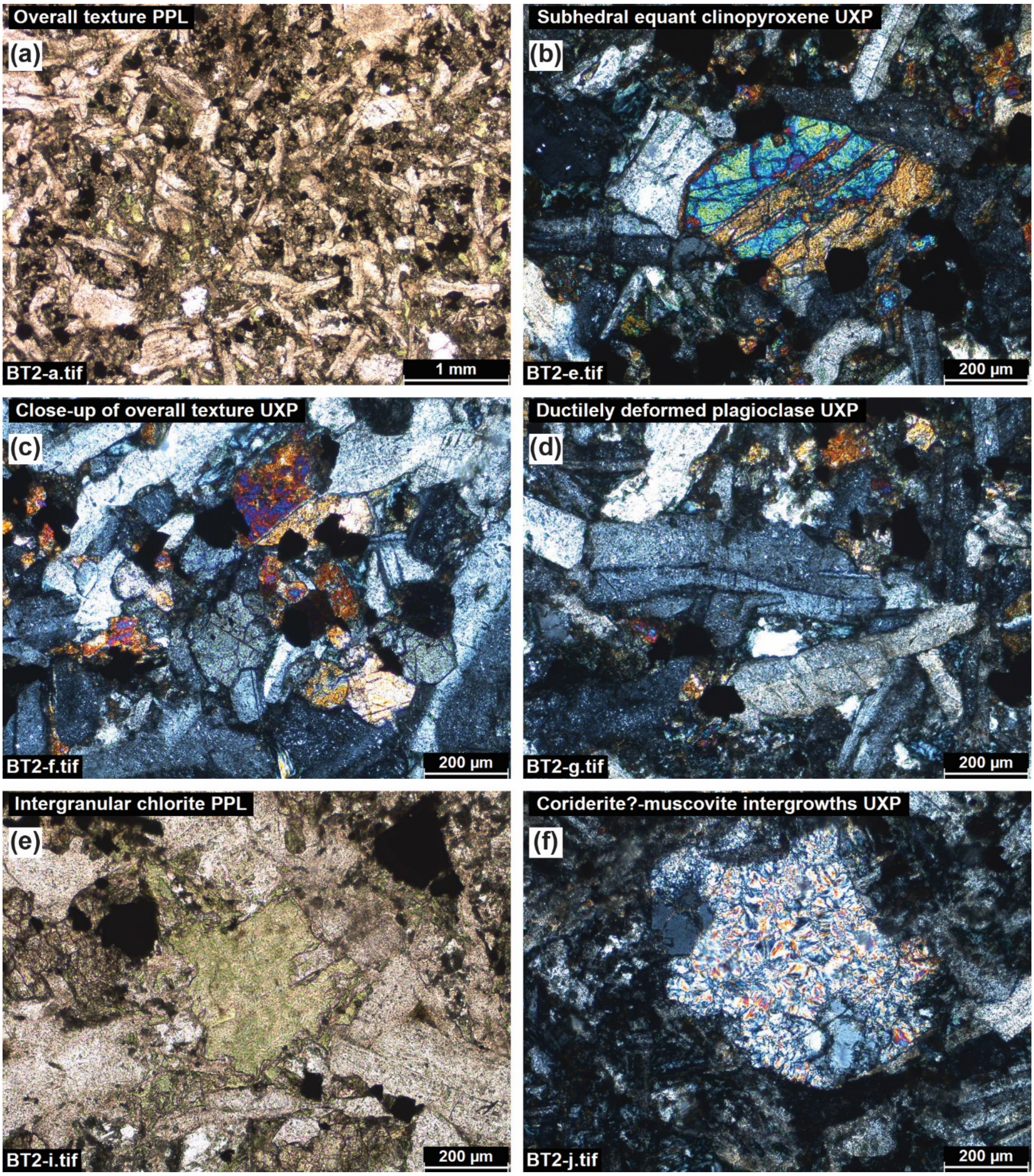
Black Creek rhyolitic micro-breccia (BR1) (a–f).



Big Gum basalt (BGB) (a–f).

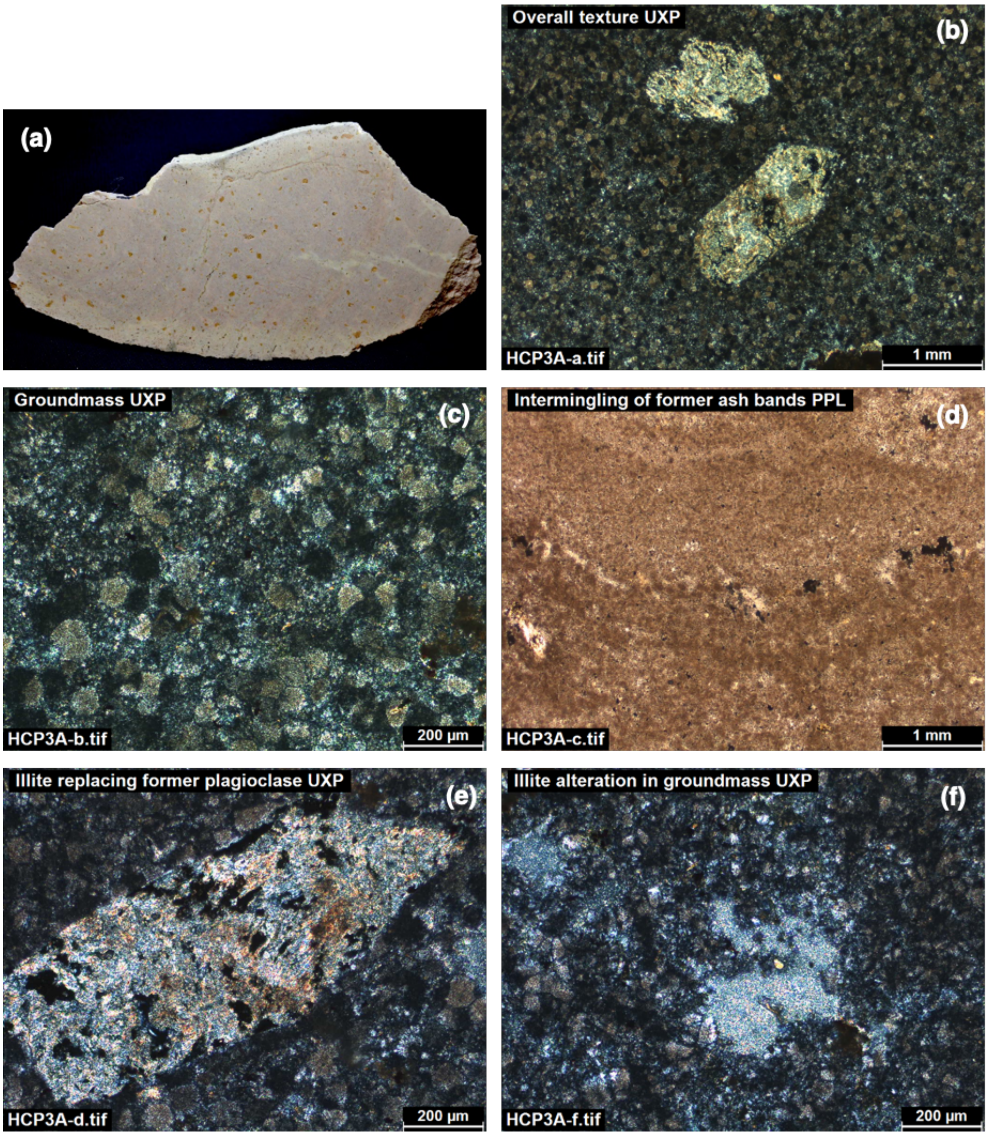


Fords Road Quarry (FQU); limburgitic mafic dyke (a–f).



Holey Flat Summit (BT2): micro-monzonite (a–f).

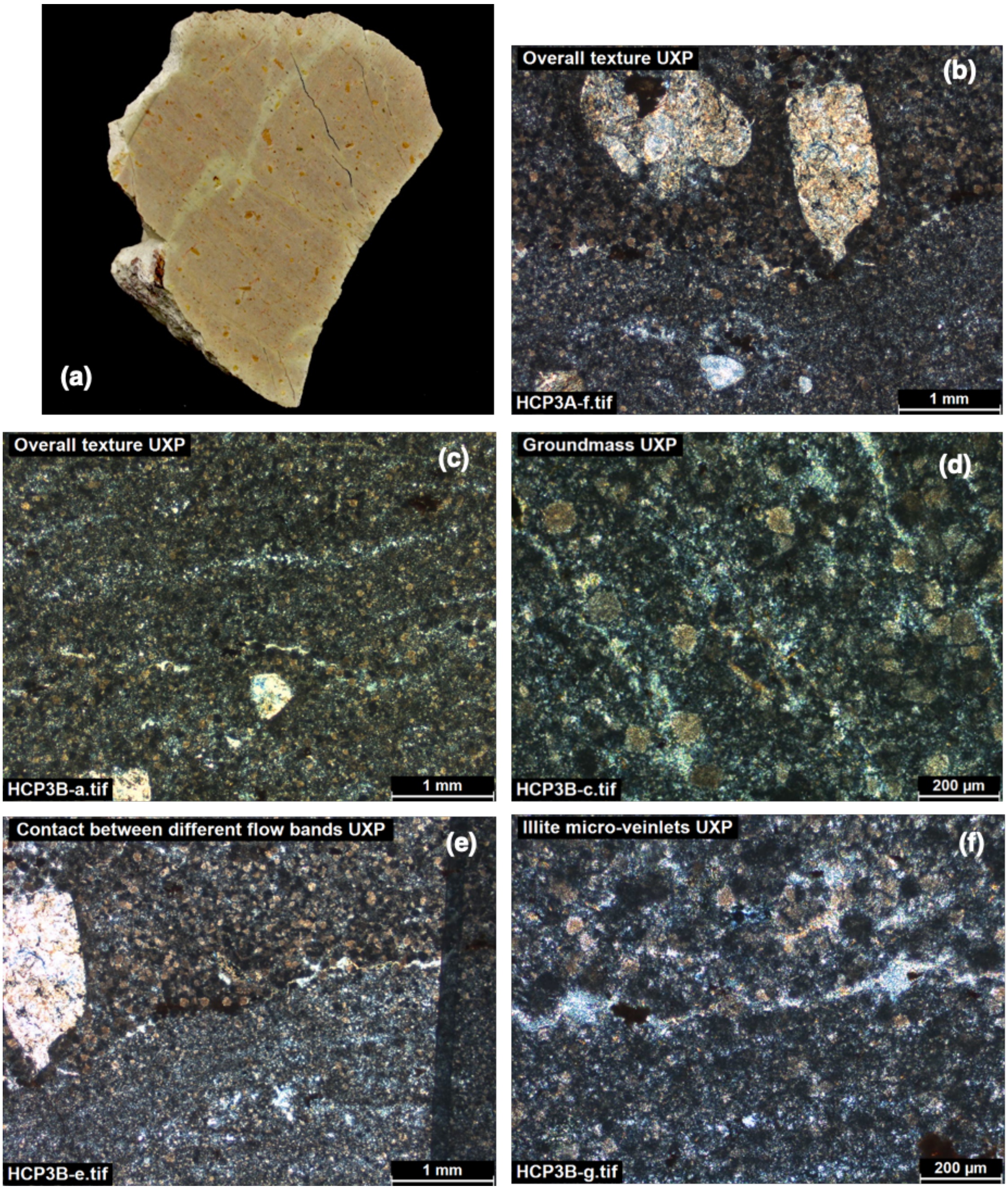
Appendix 3. 2008–2009 Pacific Highway road-cuttings Lorne Basin samples



HCP3A: Massive rhyolite, Herons Creek Pile 3 South

Images showing the characteristic features of HCP3A. (a) hand-specimen image showing widely disseminated altered orange feldspar phenocrysts, weak banding and a very fine-grained groundmass; (b) petrographic image showing the typical texture comprising subrounded former phenocrysts of feldspar (now completely replaced by fine-grained illite) set in a fine-grained quartzo-feldspathic groundmass UXP; (c) petrographic image showing a close-up of the groundmass comprising equant-shaped feldspar grains and finer grained mixtures of feldspars and quartz and overprinting carbonate-illite alteration UXP; (d) petrographic image showing mingling of former very fine layers PPL; (e) petrographic image showing subhedral prismatic former feldspar phenocryst now replaced by illite UXP; (f) close-up of groundmass showing pervasive illite-carbonate alteration of the groundmass UXP.

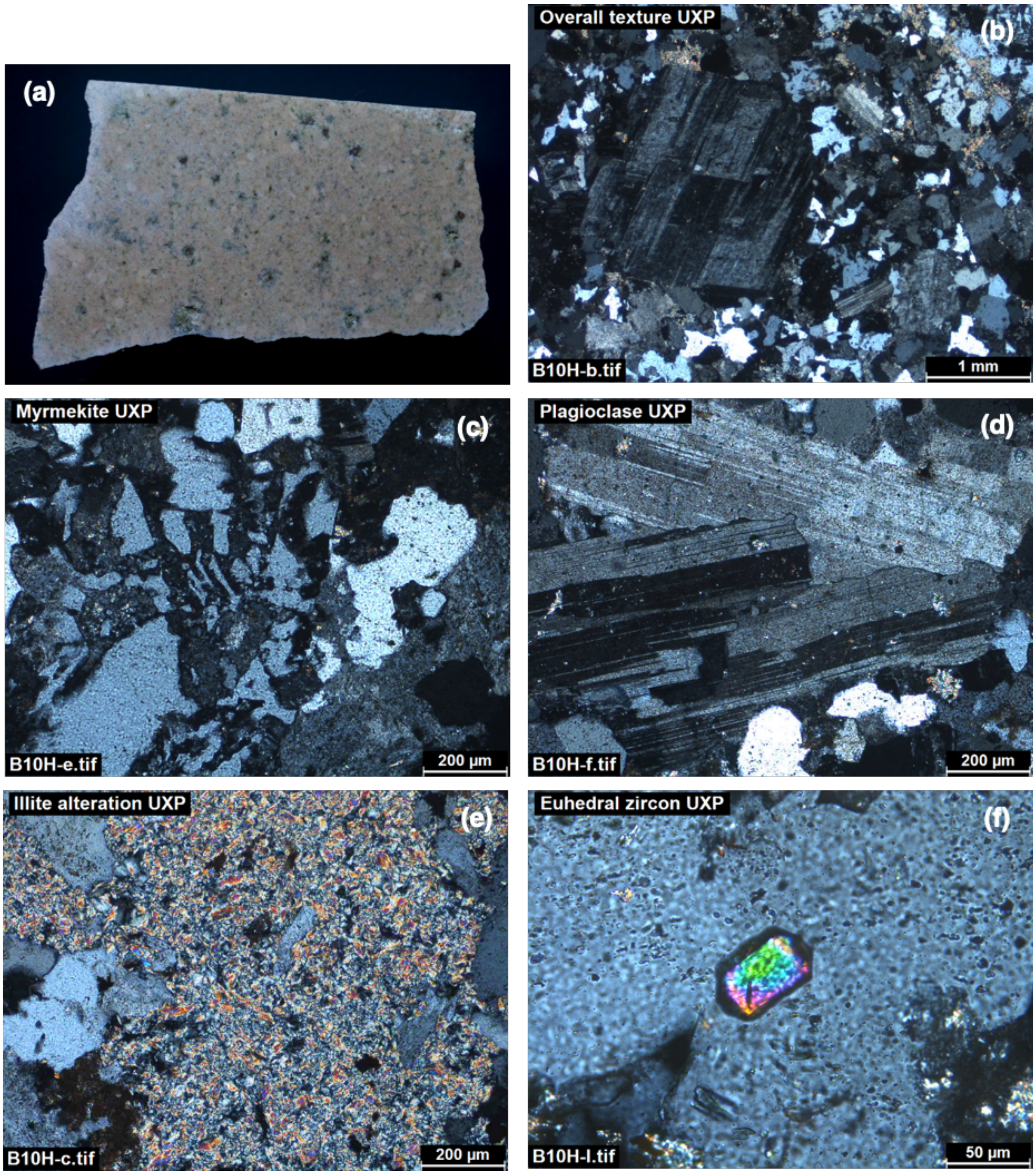
In hand-specimen, this is a highly altered fine porphyritic weakly banded rhyolite with distinctive orange-coloured feldspar phenocrysts in a fine-grained groundmass. In thin-section, it comprises subhedral, equant to subprismatic former feldspar phenocrysts to 2 mm (now completely replaced by illite) set in a very fine-grained non-aligned quartzo-feldspathic groundmass. There is distinctive banding defined by both variations in grain-size and quartz/feldspar ratio. There is pervasive and moderately intense illite-carbonate alteration, micro-veinlets of banding-parallel illite and siderite-goethite spotting overprinting illite.



HCP3B: Banded dyke, Herons Creek Pile 3 South

Images of HCP3B showing characteristic features. (a) hand-specimen image showing the flow-banded structure, sparse feldspar phenocrysts and distinctive alteration; (b) petrographic image of the typical texture in thin-section showing distinctive banding and subrounded former feldspar phenocrysts (now replaced by illite) set in a fine-grained quartzo-feldspathic groundmass UXP; (c) petrographic image showing thin quartz-rich bands and sparse former feldspar phenocrysts (now replaced by illite) UXP; (d) petrographic image showing close-up of groundmass comprising non-aligned feldspar laths and spherulitic quartz UXP; (e) petrographic image showing contact between flow bands of differing grain-size and composition UXP; (f) close-up showing pervasive thin micro-veinlets of illite and carbonate spotting UXP.

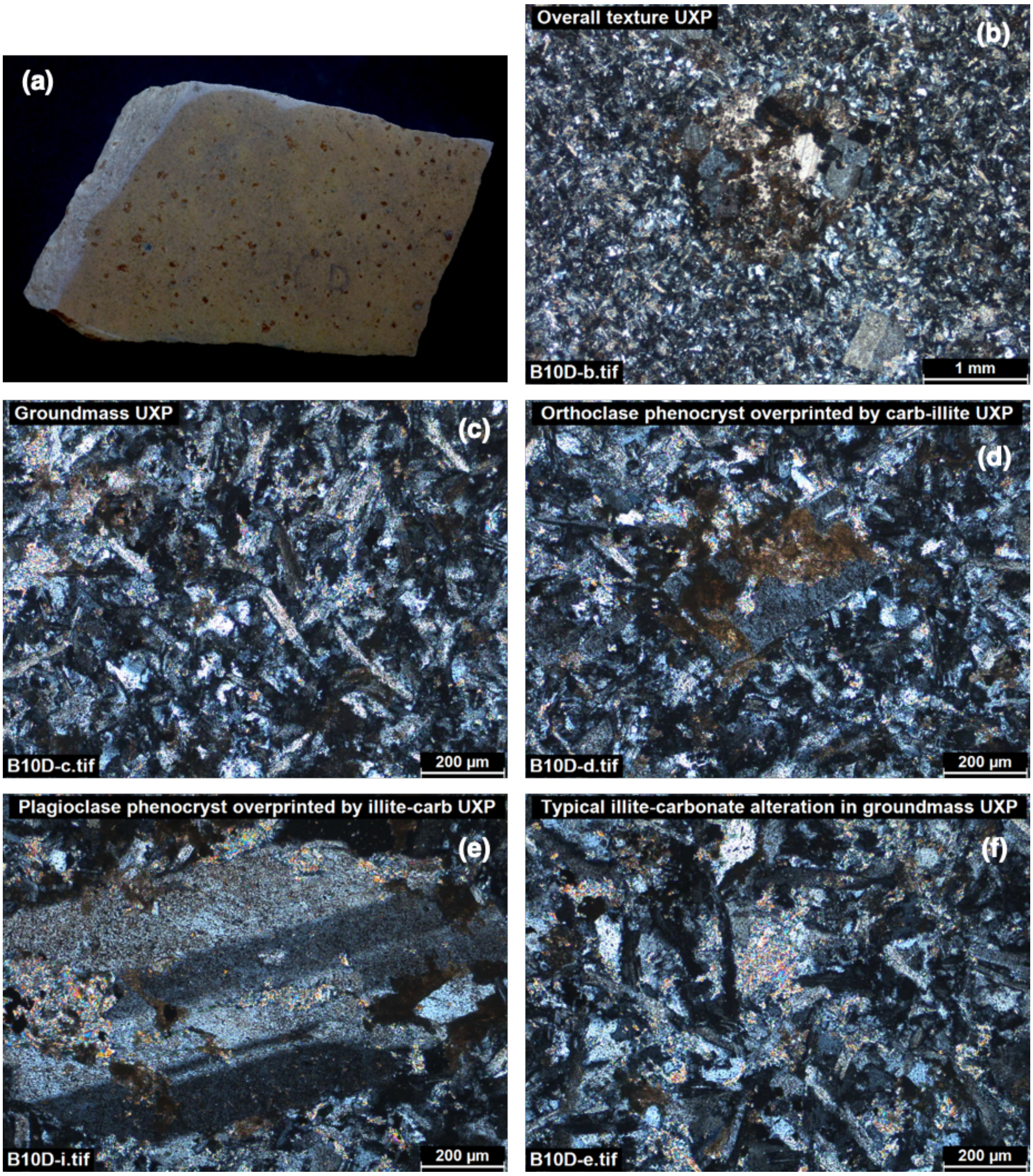
In hand-specimen, this is a pervasively intensely altered porphyritic flow-banded rhyolite. In thin-section it comprises equant to subprismatic subrounded former feldspar phenocrysts (now completely replaced by illite) to 1.5 mm set in a fine-grained quartzo-feldspathic groundmass. There is patchy illite alteration of the groundmass and pervasive but weak siderite spotting.



CH37420: Dyke, Brothers Cut 10 (GR472690MGAe – 6491283MGAn)

Images of sample 374200 (B10DH). (a) Hand-specimen image showing massive unfoliated nature and medium-grain size; (b) petrographic image showing overall texture consisting of relatively large phenocrystic plagioclase in finer-grained quartzo-feldspathic groundmass UXP; (c) photomicrograph showing distinctive myrmerkitic texture (quartz-K-feldspar intergrowths) which are characteristic of this rock UXP (d) photomicrograph showing relatively unaltered interlocking prismatic plagioclase grains UXP; (e) photomicrograph showing moderately intense overprinting illite alteration (UXP); (f) photomicrograph showing euhedral short prismatic zircon inclusion in plagioclase UXP.

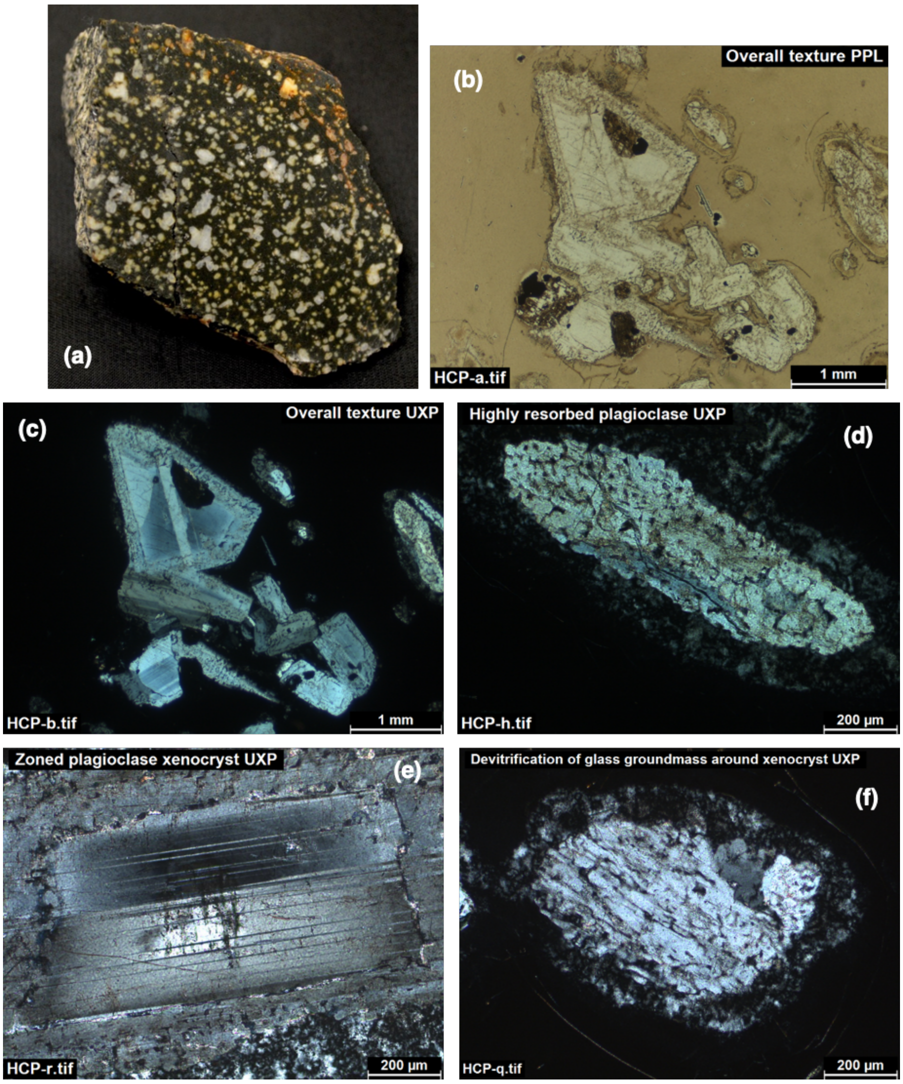
This is a relatively massive and unfoliated quartz diorite. In thin-section, it has a subporphyritic to allotriomorphic texture defined by relatively larger subhedral equant to prismatic plagioclase grains (up to 1 mm) and euhedral equant-shaped microcline (to 2 mm) along with common interstitial myrmekitic intergrowths of quartz-K-feldspar and interstitial smaller grains of plagioclase, microcline and late-stage quartz. There are also accessory grains of apatite, opaques and zircon. Pyrite is a relatively common accessory phase as euhedral cubic grains to 200 um. There is patchy weak to moderately intense illite alteration and less common illite-carbonate alteration.



CH47420: Dyke, Brothers Cut 10 (GR472690MGAe – 6491283MGAn)

(a) Hand-specimen image showing mottling from alteration and K-feldspar phenocrysts; (b) photomicrograph showing porphyritic glomerophyric texture UXP; (c) photomicrograph showing the groundmass consisting of non-aligned lath-shaped plagioclase and sanidine with overprinting illite alteration UXP; (d) photomicrograph showing euhedral equant-shaped K-feldspar phenocryst with overprinting illite-carbonate UXP; (e) photomicrograph showing plagioclase phenocryst overprinted by illite-carbonate UXP; (f) photomicrograph showing the typical pervasive weak to moderate illite-carbonate alteration UXP.

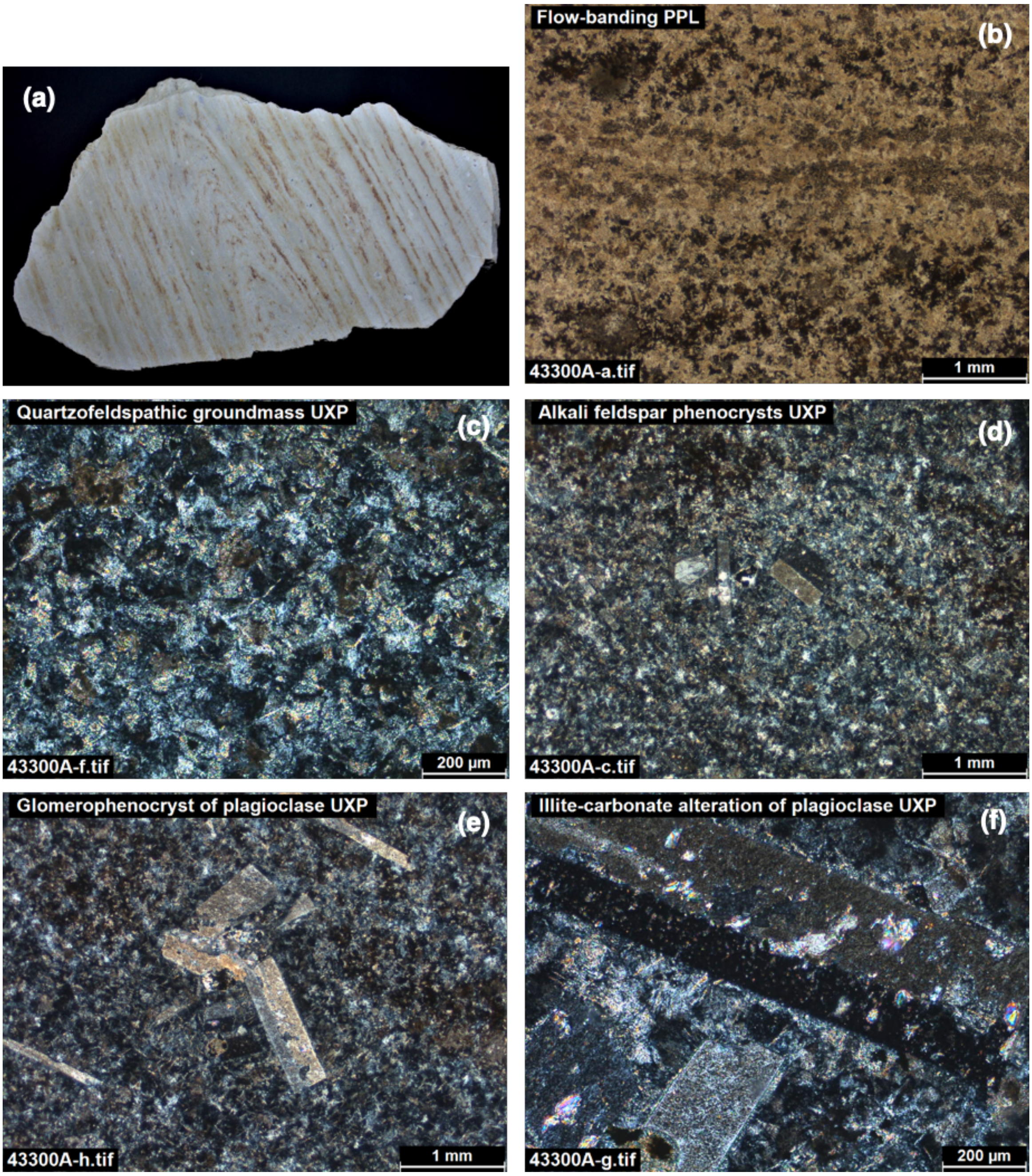
This is a massive mottled beige-pink rhyolite. In thin-section, it has a sparsely glomeroporphyritic texture defined by glomerophenocrysts (up to 1 mm across) of plagioclase and K-feldspar set in a finer-grained groundmass of non-aligned lath-shaped K-feldspar and plagioclase (averaging 0.1 mm), along with minor late-stage interstitial quartz. The microphenocrysts (up to 0.5 mm) are subhedral and short prismatic to tabular in shape and comprise both K-feldspar and plagioclase. The plagioclase grains contain rare spinel inclusions. Alteration is pervasive, weak to moderate in intensity, and largely comprises illite with lesser carbonate (mostly siderite with minor calcite). There is also rare epidote-calcite and muscovite alteration.



CH47900 (HCP): Obsidian/perlite from Ocean Road Kew (GR474155MGAe – 6500015MGAn)

Images of HCP. (a) hand-specimen image showing distinctive colourless phenocrysts in black glassy groundmass (b) petrographic image showing overall texture defined by phenocrysts and glomerophenocrysts of plagioclase with well-developed thin reaction rims in an unaltered brown glass groundmass PPL (c) petrographic image showing a glomerophenocryst of angular compositionally-zoned plagioclase with well-developed reaction rim UXP (d) highly resorbed plagioclase phenocryst UXP (e) distinctively zoned plagioclase xenocryst with highly resorbed margin UXP (f) K-feldspar xenocryst with devitrification of glassy groundmass around it UXP.

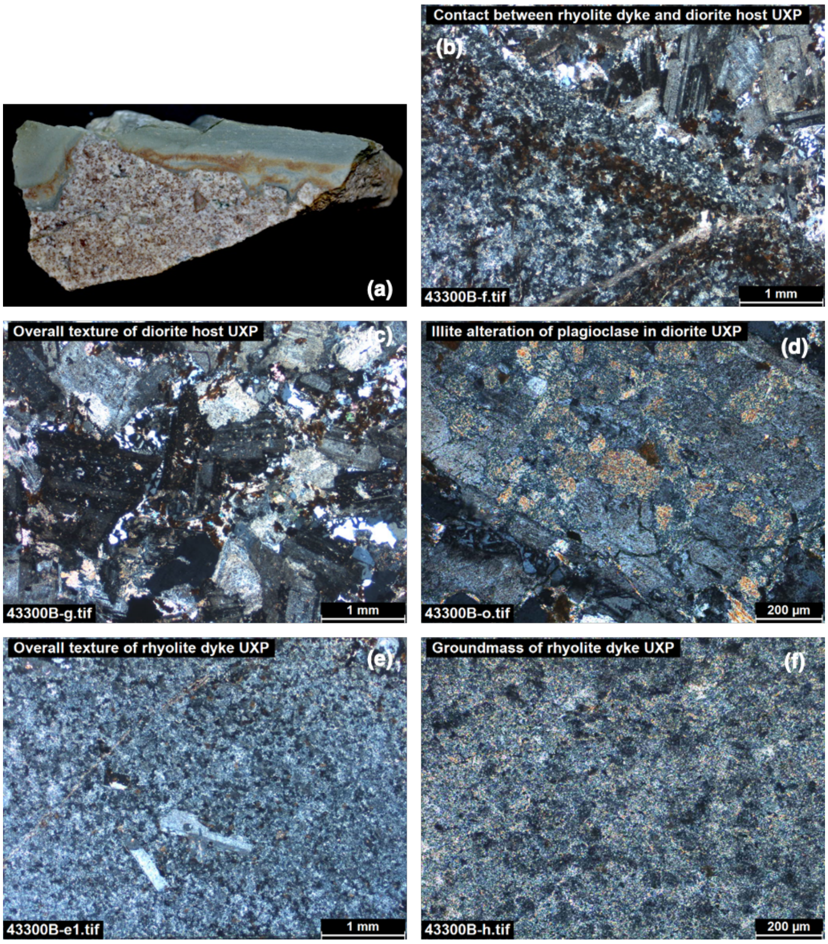
This is a very unusual fresh glassy distinctively porphyritic perlite dyke. In thin-section, it has a distinctively porphyritic to glomeroporphyritic vitrophyric texture defined by phenocrysts and xenocrysts of plagioclase and much rarer K-feldspar with well-developed reaction rims in an unaltered pale brown glass groundmass which in places has well-developed perlitic cracking. Plagioclase phenocrysts are strongly compositionally zoned (rim to core) with partially resorbed grain boundaries. They occur as equant to prismatic angular grains (averaging 2.5 mm) with commonly developed sieve textures and some have hollow cores and zircon inclusions. There are also former olivine inclusions in some of the plagioclase grains. There are uncommon small (0.3 to 0.5 mm) pale green equant to prismatic clinopyroxene grains with resorbed grain boundaries. There are relatively abundant accessory apatite (as euhedral elongate prismatic grains to 0.3 mm) and opaque grains. Partial devitirification of the glass groundmass is confined to the grain boundaries of the phenocryst and xenocrysts. K-feldspar occurs as rare anhedral subprismatic xenocrysts to 0.4 mm.



CH43300A: Fow-banded rhyolite collected from the same location above (flow-banded rhyolite)

Characteristic images of flow-banded rhyolite sample 43300A. (a) Hand-specimen image showing prominent flow-banding; (b) flow-banding in thin-section PPL; (c) close-up of quartzo-feldspathic groundmass comprising non-aligned feldspars, quartz and overprinting illite-carbonate alteration assemblages UXP; (d) subhedral equant-shaped alkali feldspar phenocryst UXP; (e) glomero-phenocryst of subhedral short prismatic plagioclase UXP; close-up of plagioclase phenocryst showing overprinting illite-carbonate alteration UXP.

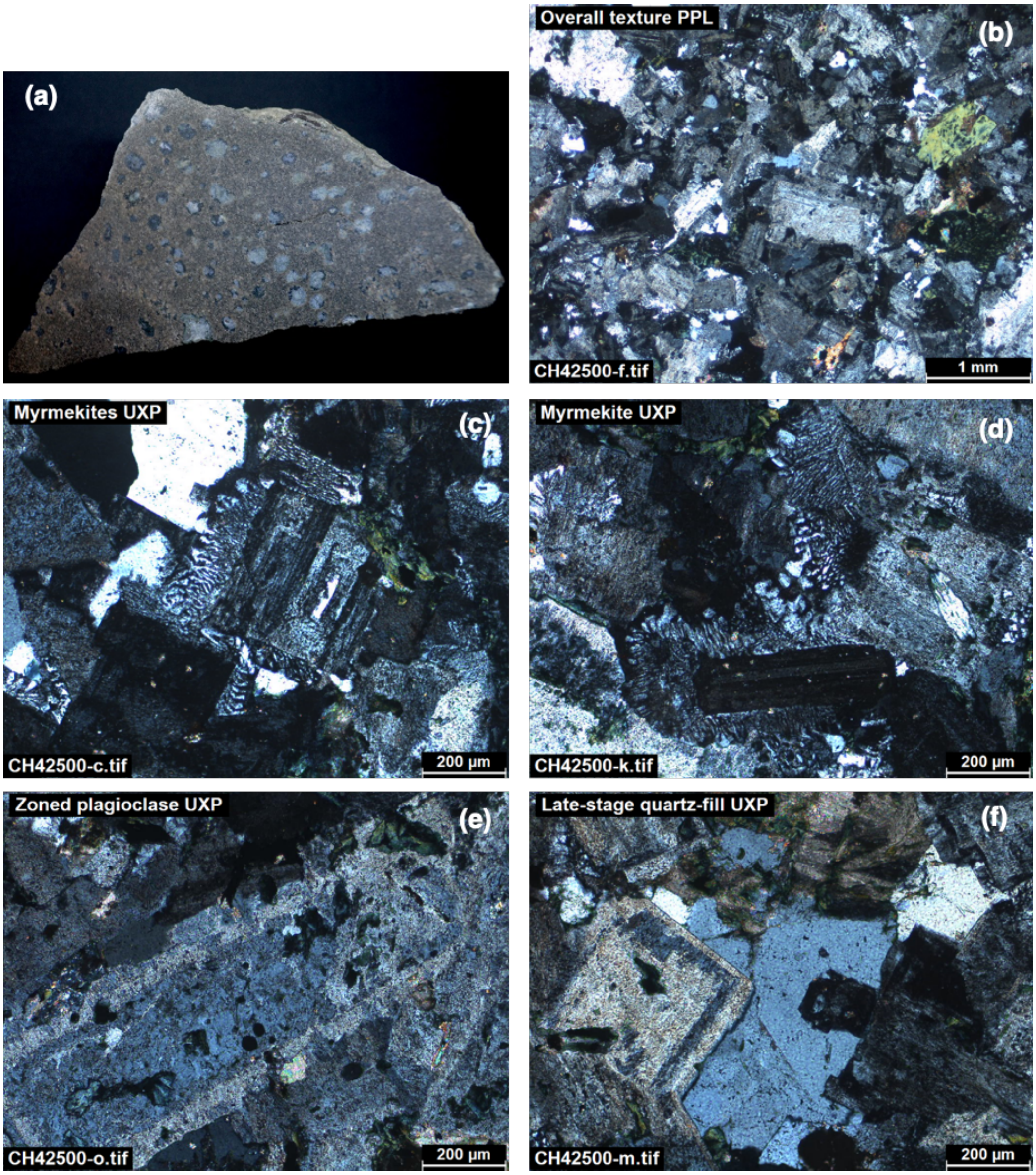
In hand-specimen, this is a distinctly fine-grained, largely aphanitic flow-banded rhyolite. In thin-section it is sparsely porphyritic flow-banded rhyolite consisting of angular euhedral subprismatic to prismatic phenocrysts and glomerophenocrysts of alkali feldspar and plagioclase to 1 mm. They are pervasively partially replaced and overprinted by illite-carbonate. The groundmass comprises non-aligned elongate prismatic quenched feldspars and spherulitic quartz, again with pervasive and moderately intense illite-carbonate alteration. There is also pervasive and moderately intense siderite spotting and micro-veinlets of carbonates.



CH43300B: Collected from the same location above

Images showing characteristic features of 43300B. (a) hand-specimen image showing green-coloured very fine-grained altered volcanic dyke (with goethite staining around contact zone) intruding into equigranular-textured altered medium-grained diorite; (b) petrographic image showing the contact zone between the quartzo-feldspathic rhyolite dyke and diorite with 0.5 mm wide chilled margin and distinctive siderite spotting UXP; (c) petrographic image showing the overall allotriomorphic granular texture of the host diorite defined by interlocking subhedral plagioclase grains with space-fill quartz UXP; (d) petrographic image showing the pervasive but generally weak illite-carbonate alteration within the host diorite UXP; (e) petrographic image showing the overall porphyritic texture of the rhyolite dyke comprising sparse alkali feldspar and plagioclase phenocrysts set in a very fine-grained non-aligned quartzo-feldspathic groundmass UXP; (f) petrographic image showing a close-up of the groundmass within the rhyolite dyke comprising non-aligned elongate prismatic feldspar and very fine-grained quartz with pervasive and relatively intense illite alteration UXP.

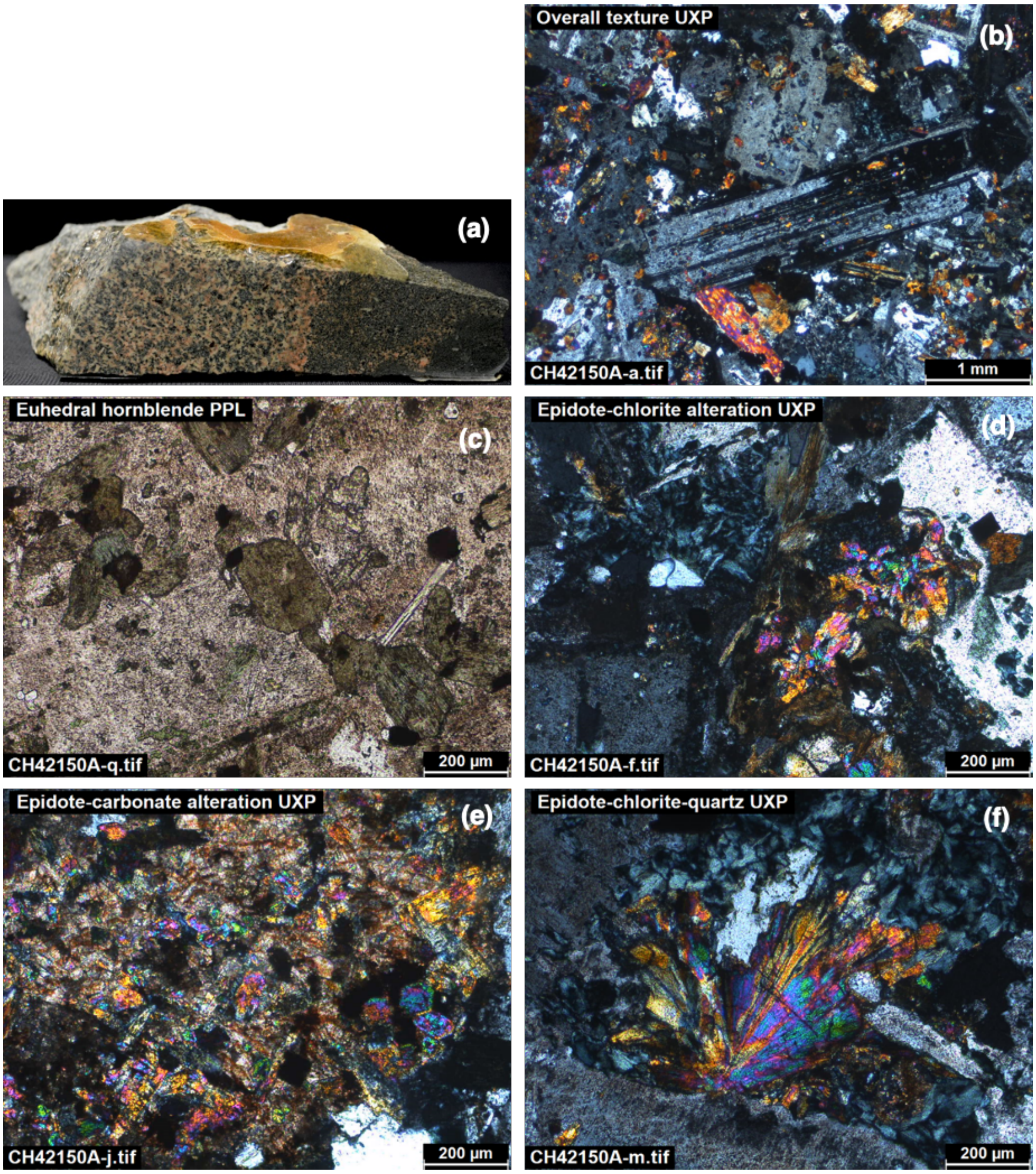
This sample comprises a distinctively green-coloured very fine-grained rhyolitic dyke with goethite staining close to the contact with the host equigranular medium-grained diorite. In thin-section, the rhyolite dyke is sparsely porphyritic with non-aligned angular subprismatic to prismatic phenocrysts of alkali feldspar and plagioclase set in a very fine-grained non-aligned quartzo-feldspathic groundmass (with intense and pervasive illite alteration). Generally, there is moderately intense carbonate alteration throughout although close to the contact zone, there is a 5 mm band of pervasive and intense carbonate alteration (now partially oxidised to goethite). The host diorite has an allotriomorphic granular texture defined by strongly interlocking subhedral grains of plagioclase with minor orthoclase along with intergranular space-fill quartz and minor prehnite. Myrmekites are relatively abundant as are accessory opaques. There is pervasive and moderately intense illite-carbonate alteration and partial replacement of plagioclase by illite-carbonate. There are cross-cutting carbonate veinlets in both the rhyolite and diorite (including the same veinlets which cross-cut both lithologies) but these are better developed in the latter.



CH42500: Monzogranite (GR475369MGAe – 6495289MGAn)

Images of sample 42500, a relatively unfoliated monzogranite. (a) Hand-specimen image suggesting a distinctive porphyritic texture with altered groundmass; (b) photomicrograph showing overall allotriomorphic texture defined by strongly interlocking grains of subhedral plagioclase, microcline, myrmekites (quartz-microcline intergrowths), biotite and late-stage space-fill quartz UXP; (c) photomicrograph showing well-developed myrmekites nucleating around plagioclase grain UXP; (d) photomicrograph showing abundant myrmekites which clearly post-date the plagioclase grains; (e) photomicrograph showing compositionally zoned plagioclase grain UXP; (f) photomicrograph showing euhedral plagioclase grains with late-stage interstitial quartz fill UXP.

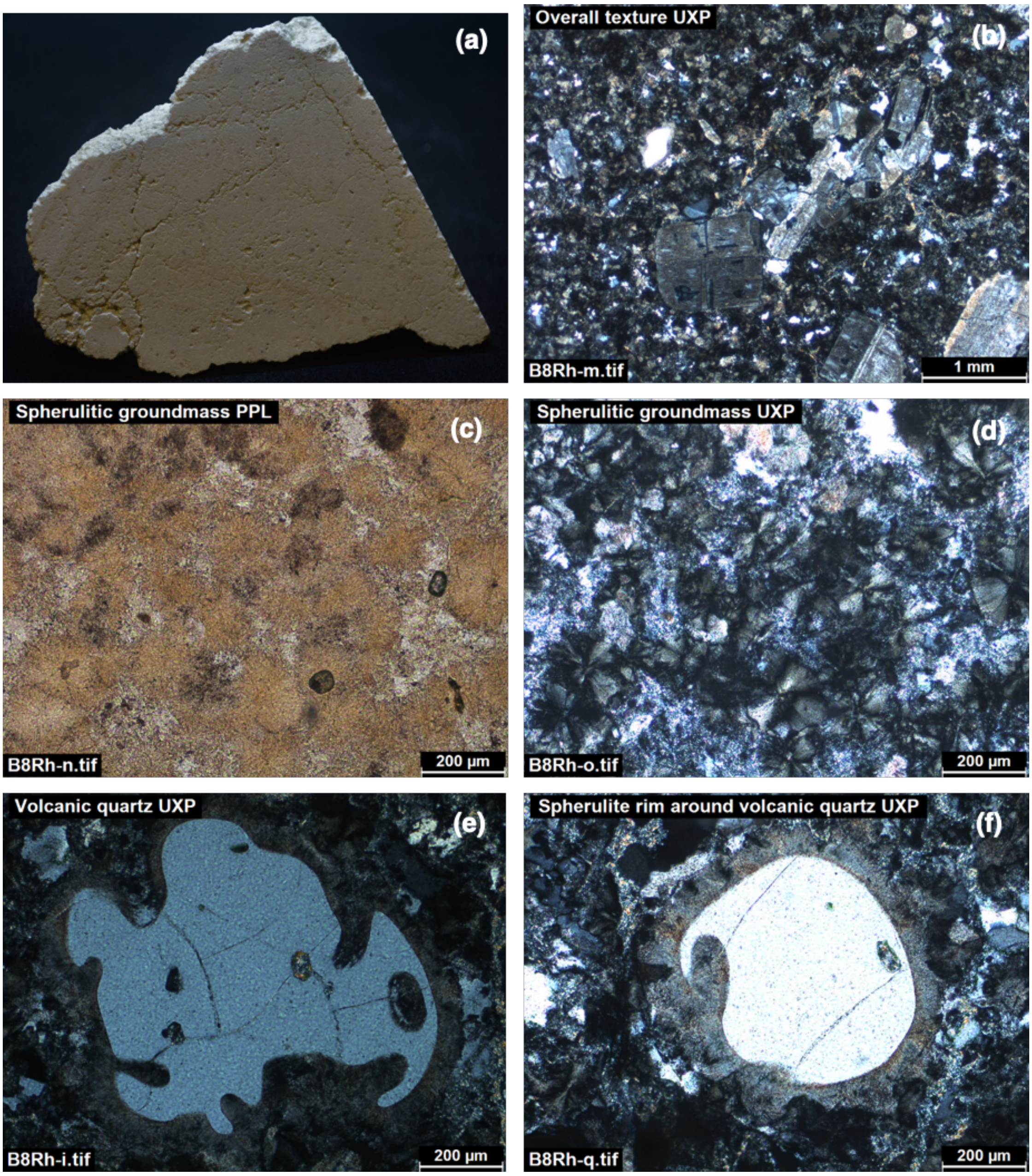
This is a relatively massive and unfoliated monzogranite. In thin-section, it has an allotriomorphic granular texture defined by strongly interlocking subhedral grains of plagioclase, orthoclase and microcline, along with later well-developed myrmektites (K-feldspar-quartz intergrowths), biotite and late-stage quartz-fill grains. It also has pervasive chlorite-carbonate alteration of weak to moderate intensity. There are abundant accessory opaques, commonly occurring as grain aggregates intimately associated with chlorite and rare accessory zircon. Plagioclase occurs as compositionally-zoned (with narrow albite-rich rims) subhedral short prismatic grains. K-feldspar occurs as anhedral to subhedral short prismatic grains and as myrmekitic intergrowths with quartz. Most of the biotite has altered to Fe-rich chlorite.



CH42150A: Diorite (GR475265MGAe – 6494968MGAn)

Selected images of sample CH42150A, an altered diorite. (a) Macro image showing hand-specimen showing lack of foliation and typical allotriomorphic granular texture; (b) Photomicrograph showing allotriomorphic granular texture defined by subhedral plagioclase grains with intergranular spaces occupied by amphiboles, biotite and the alteration minerals chlorite, epidote, zoisite UXP; (c) Photomicrograph showing euhedral hornblende and subhedral plagioclase grains PPL; (d) Photomicrograph showing epidote-chlorite alteration overprinting plagioclase UXP; (e) Photomicrograph showing the typical alteration assemblage of Fe-chlorite, epidote and carbonate that is widely developed in this diorite UXP; (f) Photomicrograph showing stellate aggregate of epidote nucleating of a plagioclase grain and intimately associated with Fe-chlorite and quartz UXP.

This is a pervasively altered relatively massive and undeformed amphibole-biotite diorite. It has a well-developed allotriomorphic granular texture defined by interlocking subhedral grains of plagioclase and short prismatic amphiboles, along with intergranular biotite and rare quartz. It is moderately pervasively altered, with the alteration assemblage comprising albite-Fe-chlorite-epidote-zoisite-carbonate-quartz. In places, this assemblage clearly overprints the plagioclase. There is also distinctive late-stage quartz-fill. There is also moderately abundant accessory apatite (commonly as needle-like grains) and opaques. Most of the former intergranular biotite has largely been replaced by Fe-chlorite.



CH33700 (B8Rh): Rhyolite, Brothers Cut 8 (GR470720MGAe – 6488300MGAn)

Images of massive rhyolite CH33700. (a) Hand-specimen image showing massive and fine-grained nature of this rhyolite; (b) photomicrograph of the characteristic overall texture showing subrounded phenocrysts and glomerophenocrysts of alkali feldspar and plagioclase and anhedral volcanic quartz grains in a groundmass of non-aligned feldspars and spherulitic quartz UXP; (c) close-up of ground-mass showing subhedral non-aligned feldspars and radial spherulitic quartz PPL; (d) close-up of groundmass showing subhedral non-aligned feldspars and radial spherulitic quartz UXP; (e) equant-shaped anhedral volcanic quartz grain with characteristic embayments UXP; (f) equant-shaped anhedral volcanic quartz grain with characteristic embayments and fibrous quartz reaction rim UXP.

In hand-specimen, this is a massive fine-grained crystal-deficient rhyolite. In thin-section, it comprises subrounded phenocrysts (subhedral, equant to subprismatic and up to 2 mm) and glomeropheno-crysts (up to 5 mm) of alkali feldspar and plagioclase, and relatively abundant anhedral equant-shaped to spherical highly resorbed volcanic quartz grains (up to 1 mm) in a fine-grained quartzo-feldspathic groundmass comprising subrounded subprismatic feldspars, intergranular quartz and pervasive spherulitic quartz. There is pervasive intergranular illite alteration, relatively abundant accessory opaques and rare accessory apatite and zircon.

Appendix 4. Immobile element Zr/TiO_2 vs Nb/Y volcanic rock classification

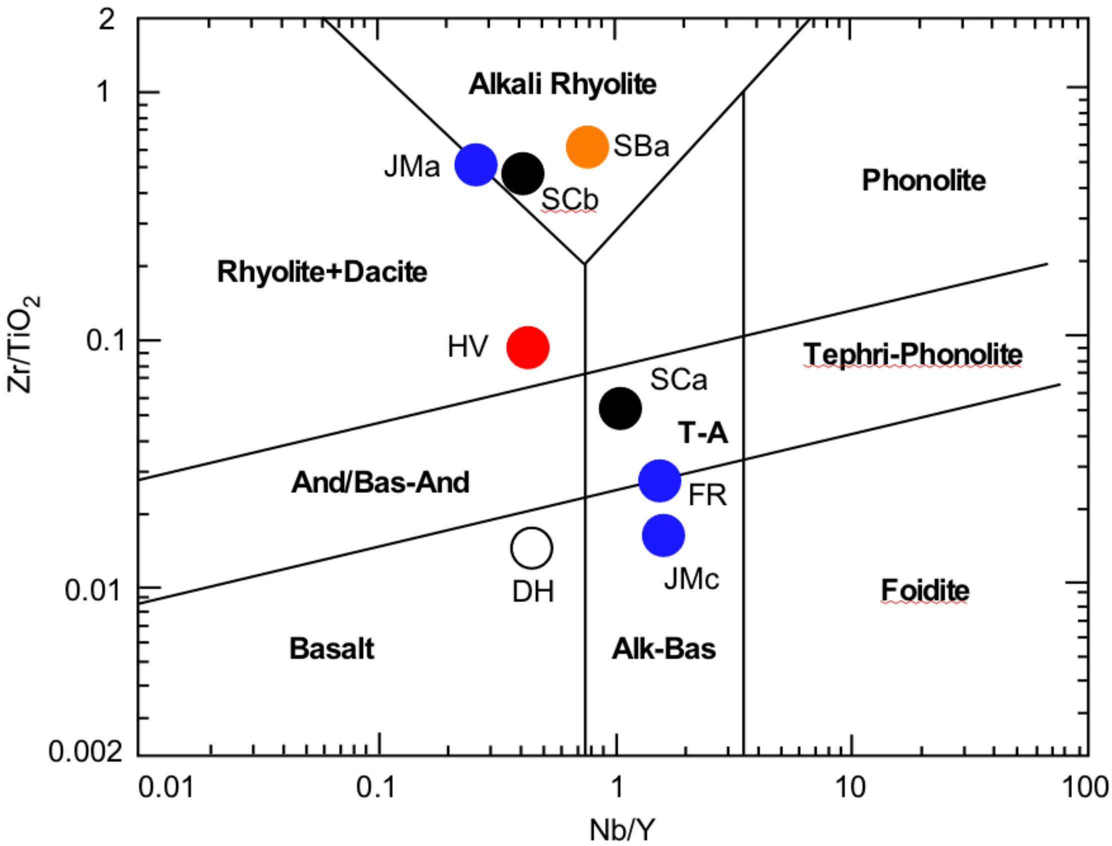


Figure S1. Immobile element Zr/TiO_2 vs Nb/Y volcanic rock classification diagram of Winchester and Floyd (1977) for Lorne Basin volcanic suites. Colours and symbols for plots as in main paper.

Table S1a. Localities of age-dated and analysed igneous rocks, Lorne Basin. Grid Refs after GDA 1994.

Code, Locality (code)/ Sample no	1: 25 000 Map sheet	Long. E/Lat. S	Grid Ref [asl]	Rock/type	Methods
Mesozoic					
Volcanic Resources Quarry, S side, Milligans Road (MR), DR 16574	Byabarra	152º 41.40’ 31º 31.52’	704 E, 122 N [70 m]	Rhyolite, flow	ZFT, SQ
Bago Vineyard Rd, 0.4 km, SE of Milligans Road jntersection (BG), DR 16589	Byabarra	152º 41.95’ 31º 31.90’	714 E, 114 N [55 m]	Rhyolite, flow	ZFT, SQ
Central summit area, North Brother (NB), DR 16560	Laurieton	152º 47.00’ 31º 39.00’	790 E, 971 N [490 m]	Granodiorite, pluton	XRF, ICP-MS
Batar Creek Quarry, E Stoney Creek Road (SC a, b), DR 16773, DR 16738	Lorne	152º 41.83’ 31º 40.14’	708 E, 962 N [130 m]	Rhyolite, plug/dyke	ZFT, XRF, ICP-MS
Farm Road, 2.5 km NW of Hannam Vale (HV), DR 16539	Lorne	152º 34.72’ 31º 41.64’	602 E, 934 N [100 m]	Rhyolite, flow	XRF, ICP-MS
Main face, Boral Quarry, Middle Brother (MBa), DR 16700	Lorne	152º 41.95’ 31º 42.89’	716 E, 912 N [50 m]	Diorite, pluton	XRF, ICP-MS
Main face, Boral Quarry, Middle Brother (MBb), DR 16701	Lorne	152º 41.95’ 31º 42.89’	716 E, 912 N [50 m]	Diorite, pluton	XRF, ICP-MS
Stewarts River Road, N flank, South Brother (SBa), DR 16532	Lorne	152º 40.29’ 31º 44.24’	688 E, 887 N [200 m]	Rhyolite, dyke	ZFT, XRF, ICP-MS
Stewarts River Road South Brother (SBb), DR 16533	Lorne	152º 40.24’ 31º 44.33’	687 E, 885 N [270 m]	Monzonite, pluton	ZFT, XRF, ICP-MS
SW margin, base, South Brother (SBc), DR 16518	Coopernook	152º 39.5’ 31º 45.5’	678 E, 868 N [100 m]	Monzonite, pluton	XRF, ICP-MS
Cenozoic (Comboyne Province) and other					
Blackbutt Road, 3.3 km ESE Mount Comboyne (BR), DR 16623	Byabarra	152º 35.32’ 31º 34.81’	602 E, 535 N [330 m]	Basalt, flow	K–Ar, XRF, ICP-MS
E Stumms track, 4 km NW of Hannam Vale (ST), DR 16841	Lorne	152º 34.32’ 31º 41.03’	594 E, 945 N [280 m]	Basalt, flow	K–Ar
Farm/MacIntyres Road, 3.6 km, NW Hannam Vale (FR), DR 16840	Lorne	152º 34.68’ 31º 41.65’	600 E, 939 N [180 m]	Basalt, flow	K–Ar, XRF, ICP-MS
N side Kylies Beach, Diamond Head (DH), DR 14678	Laurieton	152º 48.0’ 31º 44.0	812 E, 893 N [58 m]	Basalt, flow?	XRF, ICP-MS
Upper west slope, Juhle Mountain (JMc), DR 16688	Lorne	152º 34.57’ 31º 44.39’	598 E, 883 N [240 m]	Basalt, flow?	XRF, ICP-MS
Upper north slope, Juhle Mountain (JMa), DR 16696, DR 16662, 411	Lorne	152º 34.71’ 31º 44.35’	601 E, 883 N [260 m]	Rhyolite plug/flow?	Ar/Ar, XRF, ICP-MS
Lower east slope, Juhle Mountain (JMb), DR 16661, DR 16697	Lorne	152º 34.87’ 31º 44.32’	604 E, 883 N [240 m]	Basalt, flow?	K–Ar, XRF, ICP-MS

Table S1b. Photomicrography, localities, volcanic rock type, Lorne Basin. Grid Refs after GDA 1994.

Code, Locality (code)/ Sample no	1: 25 000 Map Sheet	Grid Ref [asl]	Rock/type	Figure site	Methods
Lorne Mountain base, NW flank (LMB)	Lorne	674 E, 988 N [90 m]	Rhyolite, plug	Figure 4	PPL, UXP (a)–(f)
Lorne Mountain, S summit (LMS), DR16571	Lorne	676 E, 987 N [220 m]	Rhyolite, plug	Appendix 2	PPL, UXP (a)–(d)
Lorne Mountain, central plateau (LMR)	Lorne	675 E, 986 N [150 m]	Trachyte, dyke?	Appendix 2	PPL, UXP (e)–(f)
Rock Nob, Cold Nob, Mt Tirrandubundeba region (MTR)	Byabarra	645 E, 058 N [250 m]	Rhyolite, plug	Figure 5	PPL, UXP (a)–(b)
Cold Nob ridge, SE base, Mt Tirrandubundeba region (MTC)	Byabarra	644 E, 059 N [300 m]	Rhyolite, volcaniclastic	Figure 5	PPL, UXP (c)–(f)
Cold Nob ridge, SE flank, Mt Tirrandubundeba region (CN1)	Byabarra	642 E, 065 N [330 m]	Rhyolite, volcaniclastic	Appendix 2	PPL, UXP (a)–(f)
Cold Nob ridge, summit, Mt Tirrandubundeba region (CN2)	Byabarra	641 E, 067 N [360 m]	Rhyolite, volcaniclastic		PPL, UXP (a)–(f)
Hyndmans–Cold Nob junction Mt Tirrandubundeba region (MTH)	Byabarra	615 E, 083 N [370 m]	Rhyolite, volcaniclastic		PPL, UXP (a)–(f)
W. Hyndmans Road junction, Mt Tirrandubundeba region (Mt Tir.)	Byabarra	617 E, 082 N [370 m]	Pitchstone, dyke	Figure 6	PPL, UXP (a)–(f)
Juhle Mountain, upper W flank (JMc), DR 16688	Lorne	598 E, 883 N [240 m]	Basalt, plug?	Figure 7	UXP, PPL (a)–(b)
Juhle Mountain, lower E flank (JMb), DR 16697	Lorne	604 E, 883 N [240 m]	Basalt, plug?	Figure 7	PPL, UXP (c)–(e)
Juhle Mountain, N summit (JMa), DR 16698	Lorne	601 E, 883 N [260 m]	Rhyotrachyte, plug?	Figure 7	PPL (f)
Blackbutt Road, 3.3 km, ESE Mt Comboyne (BR), DR 16668	Byabarra	602 E, 535 N [330 m]	Basalt, flow	Appendix 2	UXP, PPL (a)–(f)
Milligans Road, S side, VR quarry (MR), DR 16574	Byabarra	704 E, 122 N [70 m]	Rhyolite, flow		PPL, UXP (a)–(d)
Bago Vineyard Road, 0.4 km SE of Milligans Road (BG), DR 16589	Byabarra	714 E, 114 N [55 m]	Rhyolite, flow		UXP (e)
Diamond Head, N side, Kylies Beach (DH), DR 14678	Laurieton	812 E, 893 N [58 m]	Mafic, dyke?		UXP (f)
Black Creek Road, 1 km SE of The Ridge Way junction (BCR)	Byabarra	686 E, 015 N [30 m]	Rhyolite, volcaniclastic		PPL, UXP (a)–(f)
Blackbutt Road, SE of west Perrot Road junction (BR1)	Byabarra	677 E, 073 N [260 m]	Rhyolite, volcaniclastic		PPL, UXP (a)–(f)
Big Gum Road, N side, 0.8 km S of McCollums Road junction (BGB)	Lorne	677 E, 945 N [240 m]	Basalt, flow?		UXP, PPL (a)–(f)
Holey Flat summit, W end, Northern Access Road (BT2)	Lorne	619 E, 892 N [300 m]	Monzonite, stock?		PPL, UXP (a)–(f)
Ford Road quarry, W side, West Moorland (FQU)	Coopernook	604 E, 833 N [240 m]	Limburgite, dyke		PPL, UXP (a)–(f)

Table S2. List of K–Ar age analyses, Cenozoic volcanic rocks, Lorne Basin.

Sample site, (DR No.)	Rock/type	K (wt%)	Rad ^{40}Ar (mol/gm)	Rad ^{40}Ar (%)	Age (Ma)	Error (Ma)
11, 16623	Basalt/hawaiite	1.42	3.4161E–11	46.34	13.82	± 0.38
12, 16841	Basalt/mugearite	2.13	5.8061E–11	64.06	15.65	± 0.33
13, 16840	Basalt/mugearite	2.57	5.9255E–11	78.34	13.30	± 0.27
16, 16696	Trachyrhyolite	4.75	1.5132E–10	21.50	18.27	± 0.50
17, 16661	Basalt/mugearite	2.27	5.7912E–11	60.3	14.74	± 0.46

11, this paper; **12**, **13**, **17**, Sutherland *et al.* (2012); **16**, Sutherland (2003). Analysts: H. Zwingmann, A. Todd, CSIRO Petroleum Laboratory, Perth, WA.

Table S3. SIROQUANT analytical estimates, Triassic–Cretaceous rhyolites, Lorne Basin.

Sample No. (material)	Fit ($\chi 2$)	Mineral mode % (error)	'Pseudo analysis'	'Pseudo norm'
DR 16574 (phenocrysts)	3.50	albite-Ca 61.6 (0.80) orthoclase 9.9 (0.63) kaolinite 19.7 (0.58) illite 8.8 (0.63)	SiO_2 59.4 Al_2O_3 26.6 CaO 2.1 K_2O 2.7 Na_2O 6.4 H_2O 3.2	Q 9.5 Or 16.5 Ab 53.5 An 10.0 C 10.4 Ab/Ab+An 0.84
DR 16574 (matrix)	2.39	quartz 55.2 (0.71) orthoclase 13.3 (0.44) albite-Ca 21.7 (0.60) anorthoclase 4.6 (0.70) illite 5.1 (0.54)	SiO_2 0.8 Al_2O_3 10.2 CaO 0.8 K_2O 3.1 Na_2O 2.5 H_2O 0.2	Q 33.4 Or 18.2 Ab 21.4 Ath 3.4 C 1.3 Ab/Ab+An 0.86
DR 16574 (whole rock) (40% phenocrysts plus 60% matrix)		quartz 33.1 orthoclase 12.0 albite-Ca 47.6 anorthoclase 2.8 kaolinite 7.9 illite 6.6	SiO_2 73.8 Al_2O_3 16.7 CaO 1.2 K_2O 3.0 Na_2O 4.1 H_2O 1.4	Q 37.4 Or 17.6 Ab 34.0 Ath 6.1 C 4.9 Ab/Ab+An 0.85
DR 16589 (whole rock)	2.46	quartz 42.3 (0.51) orthoclase 30.6 (0.61) albite-Ca 25.8 (0.66) kaolinite 1.2 (0.01) illite 0.2 (0.21)	SiO_2 79.4 Al_2O_3 11.9 CaO 0.8 K_2O 5.2 Na_2O 2.6 H_2O 0.2	Q 42.9 Or 30.8 Ab 21.8 An 4.1 C 0.5 Ab/Ab+An 0.85
DR 16532 (phenocrysts 25%)	3.34	quartz 7.9 (0.3) albite (an_{16}) 61.5 (0.8) orthoclase 30.6 (0.8)	SiO_2 70.0 Al_2O_3 17.6 K_2O 5.2 Na_2O 7.3 Whole Rock mineral mode	Q 7.9 Ab 61.5 Or 30.6
DR 16532 (groundmass 75%)	3.42	quartz 34.3 (0.5) albite (an_{16}) 37.2 (0.7) anorthoclase 22.8 (0.8) orthoclase 0.0 arfvedsonite 5.8 (0.3)	quartz 27.7% (2.0% phenocrysts, 25.7% matrix) albite 43.3% (15.4% phenocrysts, 27.9% matrix) anorthoclase 17.1% (17.1% matrix) orthoclase 7.7% (7.7% phenocrysts) arfvedsonite (4.4% matrix)	
DR 16532 (Whole Rock) (75% matrix)		quartz 27.7 orthoclase 7.7 albite-Ca 43.3 anorthoclase 17.1 arfvedsonite 4.4		
DR 19288 (Whole Rock)	2.42	quartz 37.6 (0.4) albite (an_{28}) 37.7 (0.5) orthoclase 19.2 (0.5) 'Illite' 4.0 (0.5) kaolinite 1.5 (0.5)	SiO_2 76.0 Al_2O_3 14.7 CaO 2.0 Na_2O 3.3 K_2O 3.7 H_2O 0.4	

Analysts R. E. Pogson and D. McGeeney

Table S4. Chemical character/IUGS classification, dated/analysed rocks, Lorne Basin.

Sample No.	D.I	Mg No.	Plag (ab) %	Or %	Q %	Na_2O/K_2O	Assigned Name
Mesozoic rocks							
16574[1]	95.5	–	40.1 ($ab_{85.4}$)	17.6	37.4	1.35	Porphyritic sodic rhyodacite
16560	86.9	27.0	50.3 ($ab_{84.7}$)	21.9	20.9	1.41	Porphyritic micro-granodiorite
16700	56.2	39.3	55.3 ($ab_{67.9}$)	10.2	8.9	2.57	Micro-quartz monzodiorite
16701	42.1	59.1	61.6 ($ab_{50.5}$)	4.4	6.5	4.91	Micro-quartz diorite
16539	87.6	27.5	39.8 ($ab_{82.1}$)	15.7	39.3	1.46	Sodic rhyodacite
16738	93.8	17.5	47.0 ($ab_{94.3}$)	21.1	29.0	1.47	Sodic dacite
16733	94.3	41.4	39.7 ($ab_{93.4}$)	22.2	35.0	1.17	Sodic rhyodacite
16589[1]	95.4	–	25.9 ($ab_{84.2}$)	30.8	42.9	0.49	Potassic rhyodacite
16533	70.5	31.3	59.1 ($ab_{86.3}$)	10.9	8.6	3.26	Micro-quartz monzodiorite
16518	80.9	14.6	63.1 ($ab_{96.3}$)	11.9	8.3	3.56	Micro-quartz monzogabbro
16532[1]	94.9	7.2	42.8 ($ab_{82.1}$)	24.3	28.4	1.22	Sodic rhyodacite
19228[1]	88.5	–	38.4 ($ab_{73.8}$)	22.5	39.1	0.89	Potassic rhyodacite
Cenozoic and other rocks							
16623	46.5	50.5	52.0 ($ab_{64.2}$)	11.0		2.37	Porphyritic hawaiite
14678	54.4	60.7	51.7 ($ab_{72.9}$)	13.2		2.32	Basaltic trachyandesite
16688	50.9	45.8	54.4 ($ab_{68.6}$)	13.6		1.91	Porphyritic hawaiite
16663	55.1	33.7	53.7 ($ab_{72.7}$)	16.1		1.69	Mugearite
16840	60.9	27.0	49.7 ($ab_{82.0}$)	17.8	2.5	1.60	Mugearite
16662	90.3	0.00	44.5 (ab_{100})	33.7	12.1	1.16	Sodic rhyolite

[1] character and classification based on ~ values determined by SIROQUANT mineral estimations.

Table S5. Granitoid magma types, Lorne Basin Mesozoic–Cenozoic Suites.

Sample ID	NB	MBa	MBb	SBa	SBb	SBc	SCa	SCb	HV	JMa
10000Ga*/Al	2.53	2.65	1.98	4.90	3.68	3.81	2.49	3.67	2.72	5.86
Zr ppm	160	104	100	650	470	440	220	317	274	1623
Type	I	TA	I	A	A	A	I	A	A	A
Nb ppm	14.1	14.2	5.9	46	21	17.5	16	13.3	13.6	13.3
Type	I	TA	I	A	A	A	I	A	A	A
Ce ppm	59.9	49.9	22.7	7.5	45.5	50	38.1	16	50	194
Type	I	TA	I	TA	TA	TA	I	TA	TA	A
Y ppm	33.3	38.6	16.5	62	53	47	17.4	34.5	24.4	51.3
Type	I	TA	I	TA	TA	TA	I	TA	TA	TA
Na+K/Al	0.92	0.60	0.80	1.07	0.80	0.94	0.85	0.89	0.84	1.27
Type	TI	TA	I	A	TA	A	I	A	TA	A
Na_2O+K_2O	8.84	6.10	4.37	8.95	9.27	9.16	8.02	8.66	6.36	12.2
Type	TI	TA	I	A	A	A	I	A	TA	A
K_2O/MgO	8.16	0.70	0.26	50.5	1.19	3.94	171	50.6	10.4	>56
Type	I	TA	I	A	TA	TA	T I	A	A	A
Na_2O+K_2O/CaO	4.78	1.00	0.51	52.6	2.69	4.18	14.9	12.9	2.66	12.3
Type	I	TA	I	A	TA	TA	T I	TA	TA	TA
$FeO^{tot.}/MgO$	4.82	3.74	2.36	28.7	4.89	12.9	8.18	10.6	5.80	>2.2
Type	I	TA	I	A	TA	A	A	A	TA	TA

Maximum Limits for I-types: 10000Ga*/Al 2.6; Zr ppm (240); Nb ppm (20); Ce ppm (100); Y ppm (80); Na+K/Al (Agpaitic Index, 0.85); Na_2O+K_2O wt % (8.5); K_2O/MgO (10); Na_2O+K_2O/CaO (16); FeO^{tot}/MgO (10). **I** (I-type); **A** (A-type); **TI** (transitional I, A); **TA** (transitional A, I). After Whalen *et al.* (1987).

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