SUPPLEMENTARY MATERIAL VOLCANICA

Supplementary Material for: Catastrophic caldera-forming pyroclastic eruptions and climate perturbations: the result of tectonic and magmatic controls on the Paleocene-Eocene Kilchrist Caldera, Isle of Skye, NW Scotland

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Drake et al. [2022] should be cited if this material is used independently of the article.

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Table S1: Grid reference of figures and sample numbers

Rock type/feature	Figure number in paper/ supplementary file	Grid reference/ log/ height (in metres)	Sample number
Paleosol	Figure 4A	NG 59635 20663, Log 16, 290 m	SD/51
Amygdaloidal basalt	Figure 4B, Figure S1B	NG 59625 20664, Log 16, 320 m	
Tholeiitic basalt	Figure 4C	NG 96142 20690, Log 16, 355 m	SD/58
Fall deposit	Figure 4D	NG 59640 20645, Log 16, 295 m	SD/52
Hawaiite	Figure S1A	NG 58107 23851, Log 15, 5 m	
sT- cooling joints	Figure 5A	NG 59999 20876, Log 9, 3 m	SD/217
sT (XP)	Figure 5B	NG 59999 20876, Log 9, 2 m	SD/217a
mLTacc	Figure 5C	NG 58238 22102, Log 4, 21 m	
mLT acc scan (XP)	Figure 5D	NG 58238 22102, Log 4, 21 m	SD/5d
mLT acc scan (PPL)	Figure S2A	NG 58238 22102, Log 4, 21 m	SD/5d
sT- underside cooling joints	Figure S2B	NG 59999 20876, Log 9, 3 m	SD/217
sT thin section (XP)	Figure S2C	NG 59999 20876, Log 9, 3 m	
sT thin section (PPL)	Figure S2D	NG 59999 20876, Log 9, 3 m	
mLTacc	Figure S2E	NG 58230 22095, Log 4, 8 m	
mLTacc	Figure S2F	NG 58230 22095, Log 4, 8 m	
mLT acc EMP image	Figure S2G	NG 58238 22102, Log 4, 21 m	SD/5d
mLTacc- oblate	Figure S2H	NG 58238 22102, Log 4, 21 m	
mBr containing quartzite block	Figure 6A	NG 59992 20854, Log 9, 9 m	
mLT	Figure 6B	NG 59574 20917, Log 16, 630 m	SD/76
mLT (XP) resorbed quartz	Figure 6C	NG 60673 20643, Log 13, 19 m	SD/226a
mBr/mLTi faulted contact	Figure 6D	NG 59583 20818, Log 16, 500m	
mLT type III enclave	Figure 6E	NG59805 20997, Log 18, 220 m	SD/89
mBr clast supported (thin section XP)	Figure S3A	NG 59677 20417, Log 16, 25 m	SD/33
mBr clast supported	Figure S3B	NG 59677 20417, Log 16, 25 m	SD/33
dsLT	Figure S4A	NG 59802 20301	
mLT	Figure S4B	NG 59676 21028, Log 10, 40 m	SD/219
mLT- thin section calcite	Figure S5A	NG 59682 20508, Log 16, 142 m	SD/36
mLT (XP) disequilibrium-fan spherulite	Figure S5B	NG 60673 20643, Log 13,18 m	SD/226
mLT (XP) disequilibrium- alk fspa	Figure S5C	NG 60673 20643, Log 13,18 m	SD/226
mLT (XP basaltic lapilli	Figure S5D	NG 59676 21028, Log 10, 40 m	SD/219
mLTi containing type III enclaves	Figure 7A	NG 59619 20757, Log 16, 447 m	
mLTi fiamme/cooling joints	Figure 7B	NG 59620 20756, Log 16, 440 m	
mLTi matrix	Figure 7C	NG 59355 21087, Log 18, 292 m	SD/93
mLTi containing type III enclaves	Figure 7D	NG 59619 20754, Log 16, 442 m	
mLTe eutaxitic fabric	Figure 7E	NG 59424 20980, Log 14, 305 m	
mLTe (PPL)	Figure 7F	NG 59565 20901, Log 16, 610 m	SD74
mLTi type II enclave	Figure S6A	NG 59625 20773, Log 16,445m	SD/64
mLTi melt globule	Figure S6B	NG 59692 21051, Log 10, 62m	SD/219a
mLTi swallow tail fiamme	Figure S6C	NG 59625 20773, Log 16, 445 m	SD/64
mLTi mechanically fractured fiamme	Figure S6D	NG 59625 20773, Log 16, 445 m	SD/64
mLTi containing fiamme	Figure S6E	NG 59625 20773, Log 16, 445 m	SD/64
mLTi Type III enclave	Figure S6F	NG 59603 20795, Log 16, 476m	SD/66
mLTi containing fiamme/enclaves	Figure S6G	NG 59625 20773, Log 16, 445 m	SD/64
mLTi (56.14 ± 0.19 Ma)	Figure 17C, D	NG 59618 20783 (Log 16 445m)	SD ANS1
mLT lava-like	Figure 8A	NG 59345 21145, Log 18, 318 m	SD/83
mLT lava-like (XP)	Figure 8B	NG 59345 21145, Log 18, 318 m	SD/83
mLT lava-like parataxitic fabric (PPL)	Figure 8C	NG 59346 21146, Log 18, 316 m	SD/82

Table S1 [cont.]: Grid reference of figures and sample numbers

Rock type/feature	Figure number in paper/ supplementary file	Grid reference/ log/ height (in metres)	Sample number
Tuff filling fissure- Allt Coire Forsaidth	Figure 8D	NG 6026821232	
Tuff filling fissure	Figure 8E	NG 59623 20840	
Tuff filling fissure	Figure 8F	NG 59623 20840	
mLTe- eutaxitic fabric	Figure S7A	NG 58094 23560, Log 8, 5 m	SD/216
mLTe- eutaxitic/swallow tails	Figure S7B	NG 58094 23560, Log 8, 5 m	SD/216
mLTe- rotated lapilli	Figure S7C	NG 60307 21223, Log 12, 47 m	
Mafic enclaves in mLTe	Figure S7D	NG 59659 20985, Log 10, 5 m	
mLTe cooling joints	Figure S7E	NG 58226 22093, Log 4, 3m	
mLTe (PPL)	Figure S7F	NG 59355 20997, Log 18, 242 m	SD/85
mLTe (PPL)	Figure S7G	NG 59355 21155, Log 18, 315 m	SD86
mLTe- type II enclaves	Figure S7H	NG 58094 23560, Log 8, 5 m	SD/216
mLT lava-like- recumbent folding	Figure S8A	NG 59346 21146, Log 18, 316 m	SD/82
mLT lava-like- parataxitic fabric	Figure S8B	NG 59346 21146, Log 18, 316 m	SD/82
mLT lava-like- recumbent folding	Figure S8C	NG 59346 21146, Log 18, 316 m	SD/82
mLT lava-like- type II enclaves	Figure S8C	NG 59346 21146, Log 18, 316 m	SD/82
mLT lava like micro-folding (PPL)	Figure S9A	NG 57994 23274, Log 7, 15 m	SD/210
mLT lava-like parataxitic fabric (XP)	Figure S9B	NG 59346 21146, Log 18, 316 m	SD/82
mLT lava like micro hinge (PPL)	Figure S9C	NG 57994 23274, Log 7, 15 m	SD/210
mLT lava like micro hinge (XP)	Figure S9D	NG 57994 23274, Log 7, 15 m	SD/210
mLT lava-like	Figure S10A	NG 60180 21230	
Fissure filled tuff in dyke	Figure S10B	NG 62154 23527	AB/1A
Spherules in fissure filled rhyolitic tuff	Figure S10C	NG 62154 23527	AB/1B
mLT lava-like	Figure S10D	NG 61803 23119	
Tuff filling fissure	Figure S10E	NG 59589 20965	
Grading within mBr	Figure 9A	NG 54301 25012	SD/B2
Granite lithic lapilli inclusion in basic dyke (56.45 ± 0.15 Ma)	Figure 9B/ Figure 17A, B	NG 54301 25012	SD BS/01
sT	Figure 9C	NG 54301 24908	SD/B4
mLTacc	Figure 9D	NG 54325 24866	
dsLT	Figure 9E	NG 54328 24646	
mLT matrix to clast supported	Figure 9F	NG 54308 24994	SD/B3
mBr- gabbro blocks	Figure 9G	NG 54345 24591	
Granitic inclusions in dyke	Figure 10A	NG 63191 20477	SD/252 SD/BS01
Granitic inclusion clusters in dyke	Figure 10B	NG 63191 20477	SD/252 SD/BS01

Table S2: Abbreviations for lithologies used on Kilchrist map (Figure 3) and logged sections (Logs A, Logs B) after (and modified from) Branney and Kokelaar [1992, 2002].

Ignimbrites	Lithology
mLT	Massive lapilli tuff
dsLT	Diffuse stratified lapilli tuff
mBr	Massive breccia
dslB	Diffuse stratified lithic breccia
mLTacc	Massive lapilli tuff accretionary lapilli bearing
mLTi	Massive lapilli tuff incipiently welded
mLTe	Massive lapilli tuff with eutaxitic fabric
mLT lava-like	Massive lapilli tuff lava-like
sT	Stratified tuff
Extrusives	
bas	Basalt
mug	Mugearite
haw	Hawaiite
Intrusives	
Tuff	Tuff filling fissures
Brecciated tuff	Brecciated tuff within fissure
Rhy	Rhyolitic dyke
KH	Kilchrist hybrid, mixed magma intrusive
Others	
paleo	Paleosol
pep	Peperite
ash lay	Ash layer

1 Sampling and Methods

Mapping at Kilchrist was conducted over two field seasons with particular emphasis placed on detailed logging (Figures S3 and S4) in order to correlate lithofacies and establish an eruption history. Thin section analysis was conducted on both polarising microscope and electron microprobe.

Major element mineral analyses were obtained using a Jeol JXA8100 Superprobe (WDS) with an Oxford Instruments AZtec system (EDS) at Birkbeck College, University of London. EDS analysis was carried out using an accelerating voltage of 15 kV, current of 1 µA, and a beam diameter of 1 µm. with an acquisition time for 20 seconds. A proxy to bulk elemental whole rock analysis, was determined by multiple area (100 × 40 µm) scan analysis of representative matrix, carefully avoiding lithic lapilli in the case of ignimbrites, and phenocrysts in the case of lava. Analyses were calibrated against standards of natural silicates, oxides and Specpure metals with the data corrected using a ZAF program.

2 KVF lithofacies (additional notes in conjunction with Section 4 main text)

Basic lavas (Tholeiite, Hawaiite, Mugearite)

Tholeiitic basalts and highly subordinate hawaiites and mugearites comprise the basic lavas at Kilchrist. Volumetrically, basic lavas are the dominant rock type in the study area, and may be cut by sporadic, ≤0.5 m-thick, NNW–NW-trending dykes of the regional Paleocene swarm. Lava stratigraphy is best observed in Allt nan Suidheachan (Log 16) where four shallowly inclined flows crop out over 90 m along the stream bed. The dip of these lavas is ≤10° towards the SSE which suggests a maximum true total thickness of ~8 m. Each flow is capped by either a paleosol, or tuff layer and at the base of the uppermost lava, peperite is recorded.

In the west of the study area around Creagan Dubh both hawaiites (Figure S1A) and mugearites form the prominent crags. However, whilst contact relationships between lava types at Creagan Dubh are absent, the lowermost hawaiite flows are ~50 % thicker than overlying mugearite flows. The mugearite is aphanitic, blocky, and cut by irregular joints. Elsewhere cross cutting relationships between basalt, ignimbrite and intrusive igneous rocks are numerous, and lava flows are frequently intercalated with ignimbrite lithofacies for example mLT and mBr around Allt Nan Suidheachan, (Log 16, Logs B). It is not possible to correlate lava flows in the south with flows at either Creagan Dubh (Log 15, Logs A) or NW of Loch Cill Chriosd to establish any temporal relationship. Chemically, tholeiite lavas at both Kilchrist and Creagan Dubh are akin to the Skye Main Lava Series [Bell and Williamson 1994]. Such lavas plot in the same geochemical fields as mafic enclaves contained within mLT (Figure S11). The inter-lava flow tuff layers are interpreted as fall deposits which were produced in eruptions that occurred between emplacement of lavas.

Basalt may be aphanitic, amygdaloidal or porphyritic, and is commonly highly altered and brecciated. Zeolites occur towards the top and bases of individual tholeiitic flows (Figure S1B). The majority are oblate towards the top of flows, and larger and less rounded, towards flow bases. EMP analysis shows tholeiitic olivine basalt is the most common basic lava at Kilchrist and typically contains altered augite and forsterite, turbid calcium rich feldspars, and chloritised clinopyroxene with calcite reaction rims. Fayalite frequently has ≤30 µm thick ferro-richterite reaction rims. Clino-pyroxenes are commonly twinned and possess resorbed margins. The youngest lavas in the south and west of the study area are hawaiites and are exposed in Allt nan Suidheachan (Log 16, Logs B) and Creagan Dubh (Log 15, Logs A). They lack amygdales, possess abundant olivine phenocrysts (Fo_{78-55}), labradorite (An_{55-61}), chloritized clinopyroxene, and sporadic magnetite. In thin section mugearite contains andesine-labradorite (An_{30-55}) phenocrysts and has a flow aligned groundmass.

Paleosols, ash horizons, peperite

Paleosols are fossil lateritic soils that form by *in situ* weathering, oxidation and leaching of extrusive eruptive products (principally basalt) under warm, wet, conditions [Bell and Harris 1986; Bell et al. 1996; Emeleus et al. 1996]. The presence of paleosols indicates that flows were not continuous and that hiatuses were long enough for primitive soils to form on flow tops. Two paleosols and a laminated tuff layer crop out intercalated between tholeiite lava flows in Allt nan Suidheach in the south of the mapping area (Log 16 290–296 m, Logs B). The paleosols are ≤5 cm thick, dark red, fine-grained, fissile and grade down over ≤10 cm into underlying flows and there is a reduction in colour intensity with depth. Conversely the tuff layer retains a deep red colour throughout its profile, is fine grained, laminated, fissile and has a sharp contact with underlying lava. In thin section the tuff layer contains euhedral augite, quartz, plagioclase, and heterogeneous lithic fragments. Such features could not have been produced in a primitive soil. Under EMP backscatter former glass shards, and axiolitic devitrification of frequently broken bubble wall margins are evident within the tuff layer. The layer is composed of highly oxidized, altered glass, within an altered granular matrix, containing mafic lithic fragments, anhedral oligoclase, and quartz. The SiO_2 matrix content is 24.97 % whilst FeO is 32.95 %. Groundmass phases include K-feldspar, zircon, and sporadic chrome spinel with magnetite rims (≤25 µm thick). Basaltic and granitic fragments with embayed margins are present in the groundmass. Rare, localised, peperite is present as a ≤20 cm thick layer at the base of the uppermost tholeiitic lava in Allt nan Suidheachan (log 16, 335m, Figure S4, NG 59625 20664). Here lobate mafic clots ≤4 cm in length are surrounded by ≤70 % ash -granular matrix which is highly friable. Clots may either be completely isolated within the matrix, or clustered together in a jigsaw-fit separated by matrix. Slight normal grading of mafic clots [Brown and Bell 2007] is evident within the layer. The presence of peperite provides evidence that paleosurfaces were locally covered with unconsolidated, likely wet, sediment and that lava interacted with these [White et al. 2000]. Grading indicates that settling of larger mafic clasts within the sediment occurred during peperite formation [Brown and Bell 2007].

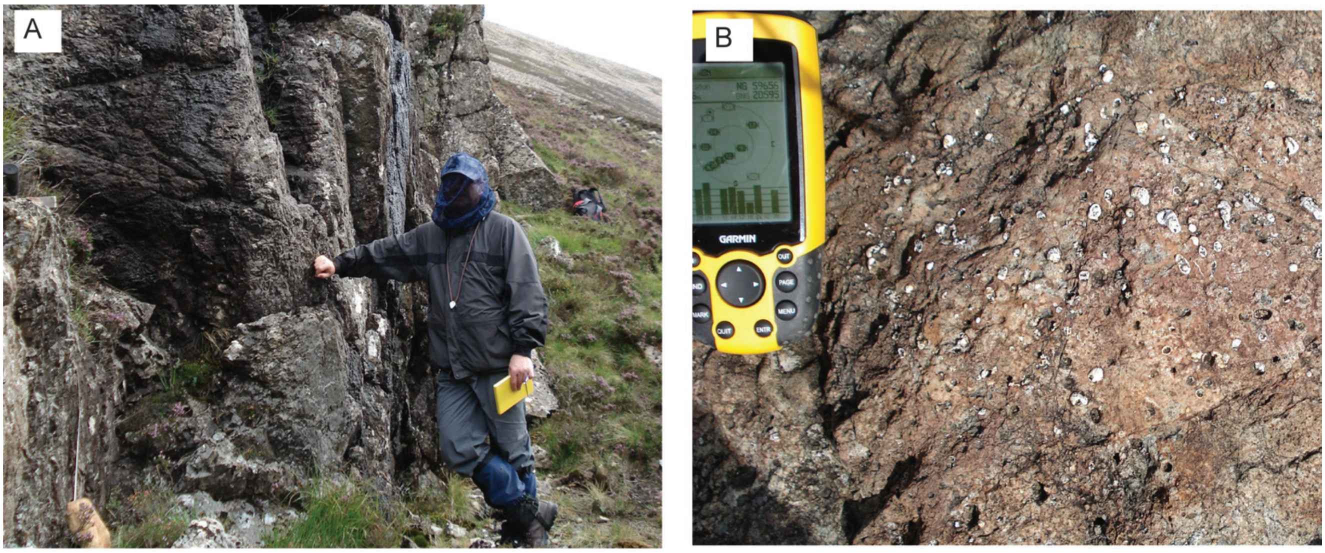


Figure S1: Field characteristics of KVF lavas. [A] Blocky hawaiite lava at Creagan Dubh (Log 15, 5m height, Logs A). [B] Laterally discontinuous zeolite rich regions within amygdaloidal basalt. Frequently such regions grade into aphanitic fractured basalt (Log 16, 320 m height, Logs B).

Stratified tuff (sT)

Rhyolitic stratified tuffs (sT) are rare in the study area and only found in one stream section (Log 9, Logs B). This unit is ~3.5 m thick, columnar jointed and laterally extensive for ~20 m (Figure S2B). It is juxtaposed on the east bank with both mBr and mLT in a faulted contact. Columnar joints which pervade the unit, are variably 4–5 sided, spaced ≤30 cm apart, and plunge 60→040 (Figure S5B). At macroscale alternating fine grained, melanocratic and leucocratic laminations ≤1 mm thick are orientated at ~90° to these columns. The rock has a matrix content of ≥95%, and contains sporadic arkosic sandstone lithic fragments ≤8 mm diameter. Such lithics are frequently draped with ash (Figure S2C, D).

Stratified tuff matrix is rhyolitic, and comprises quartz, K-feldspar, albite, titanite, chlorite, and sporadic allenite, and zircon crystals. The leucocratic laminations comprise normally graded domains (≤70 µm thick) of quartz and alkali feldspar which alternate with thinner ungraded (≤10 µm thick), melanocratic domains of chloritized quartz, magnetite and ilmenite. Changes in chemistry are reflected between these alternating laminations, and opaque minerals and chlorite are the principal minerals in melanocratic layers, and only found sporadically in leucocratic layers. Cross-stratification within leucocratic laminations (Figure S2A) is evident within several layers together with evidence of loading, syn-sedimentary faulting, and normal ash grading.

The fine-grained laminations and ash drapes within sT indicate deposition were generated via direct fall-out from eruption ash clouds. Ash was necessarily hot, due to the presence of contractional cooling joints, which were probably developed as a result of rapid burial that accounted for minimal heat loss. Such contractional cooling joints within sT have previously been reported from Taupo, New Zealand [Wilson and Walker 1985]. Loading and cross stratification within sT indicates sub-aqueous reworking took place following deposition and probably accounts for the unit preservation. Brittle offset of layers was probably induced by volcano-tectonic induced faulting which was contemporaneous with eruptions.

Accretionary lapilli bearing mLT (mLTacc)

Ash aggregate-bearing units fringe the Eastern Red Hill granites laterally over 1.5 km (logs 1, 4, 6, 8, Logs A), range in thickness from 80 cm to 3 m, and contain accretionary lapilli together with sporadic cored accretionary lapilli. The most complete ash aggregate-bearing section contains two units of matrix-supported mLTacc (Log 4, 9, and 23 m, Logs A). Both units have a fine-grained, crystal-poor, vitroclastic matrix (≥90 %), which contains concentric (spherical to sub-spherical) accretionary lapilli, with normally graded, multiple laminae (Figure SF/2c-d). At outcrop fabric within mLTacc is highlighted by sub-parallel linear trails of cored rounded accretionary lapilli, and oblate accretionary lapilli. The lower mLTacc unit (Log 4, Logs A) is approximately 2.5 m thick, and contains ≤5 % rounded to sub-rounded (Figure S2F) accretionary lapilli (≤15 mm diameter) *sensu* Thordarson [2004]. Within individual accretionary lapilli, laminae are normally graded from core to rim (Figure S2G) and whilst the majority in the upper unit (Log 4, Logs A) are highly spherical, a few are oblate (Figure S2H). Conversely the upper unit contains numerous broken, angular accretionary lapilli fragments, together with ~5 % cored accretionary lapilli that have up to 4 parallel- sub parallel concentric layers, and an armoured outer layer (≤1 mm thick). Pellets as described by Brown et al. [2010] are not evident within the study area. Chemically mLTacc matrix varies from basaltic andesite to dacite (??), is fine-grained, contains broken glass shards, and small basaltic (labradorite-bytownite, magnetite and chlorite-after clinopyroxene) and granitic (albite, quartz, k-feldspar, rutile, and illmenite) lithic fragments (≤50–130 µm). Matrix phases may comprise K-feldspar, quartz, clinopyroxene, Ca-plagioclase,

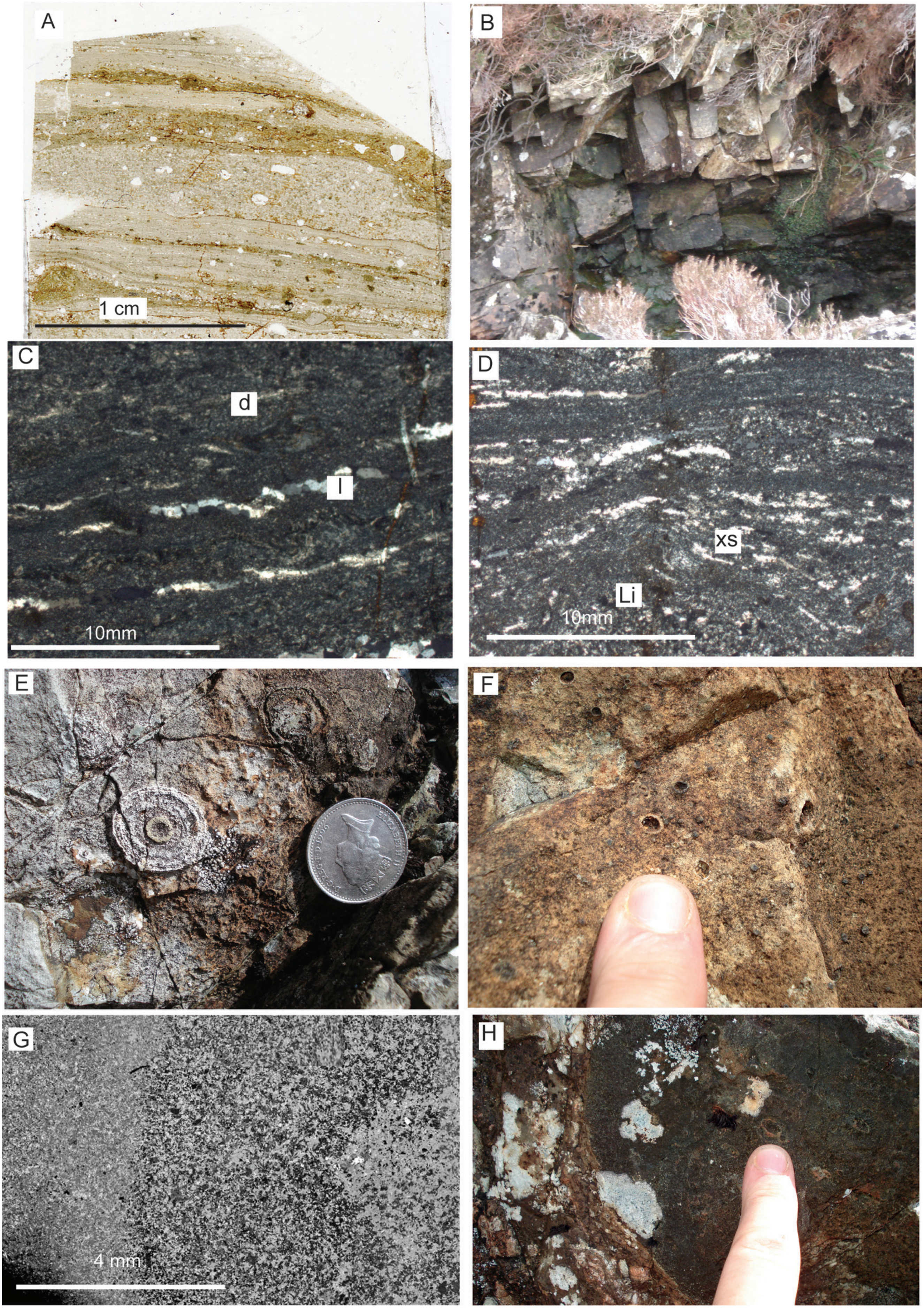


Figure S2: (Caption next page)

Figure S2: (Previous page) Field and petrographic characteristics of stratified tuff (sT) and accretionary lapilli bearing massive lapilli tuff (mLTacc). [A] PPL scan of sT from Cnoc nan Uan Subtle changes in ash chemistry are reflected in layer colouration. Melanocratic layers are richer in magnetite, ilmenite and titanite and have been chloritized. [B] Underside of steeply plunging columnar cooling joints within sT on the west bank of Cnoc nan Uan (Log 9, 3 m height, Logs B). [C] XP image of slide in [D] showing sporadic quartz-rich sandstone lithic lapilli (L) with fabric draped around it. To the upper right of the lithic lapilli, quartz rich domains are truncated below an upper layer of laterally continuous quartz crystals. This cross-stratification (xs) provides compelling way-up evidence (to top of photomicrograph), and may indicate re-working, in a sub-aqueous environment. [D] PPL image showing sporadic quartz-rich sandstone lithic lapilli (L) with fabric draped around it. To the upper right of the lithic lapilli, quartz rich domains are truncated below an upper layer of laterally continuous quartz crystals. This cross-stratification (xs) provides compelling way-up evidence (to top of photomicrograph), and may indicate re-working, in a sub-aqueous environment. [E] Accretionary lapilli (Log 4, 8 m height, Logs A) comprising weathered out core and concentric laminations within a silicic, matrix rich, mLTacc. [F] Accretionary lapilli laminations are graded from chloritised cores to finer grained, marginal rims. [G] EMP stitched image of an individual lapilli (core to right), with lapillus laminae grading normally towards left of image. (Log 4, 23 m height, Logs A). Note the sharp nature of individual concentric laminations. [H] Oblate accretionary lapilli which have been syn-post depositionally deformed in a soft state during PDC transportation.

oligoclase, zircon, chrome, spinel, rutile, epidote, and biotite and ~75 % of samples are chemically more evolved from core to rim.

It is envisaged that ash pellets acting as nucleation points, grew into accretionary lapilli by rapid coalescence of wet ash within warm turbulent up drafted plumes. The growing accretionary lapilli then reached a critical density, and fell into underlying PDCs, where they continued to grow, and accrete, during transportation. Such a scenario is similar to that envisaged to have produced mLTacc deposits in the 273 ka Poris ignimbrite, Tenerife [Brown et al. 2010]. At Kilchrist, both mLTacc units are very fine grained, and highly matrix supported, which suggests they were deposited from cool moist currents [Branney and Kokelaar 1992]. Normally graded laminations within individual lapilli, probably reflect cohesional variations within the generating ash clouds [Moore and Peck 1962], or changes in available moisture content within the thermally stratified transporting PDC. The presence of oblate accretionary lapilli indicates that parts of transporting PDCs contained enough moisture to promote syn-post depositional soft-state deformation.

Massive breccia (mBr) and diffuse-stratified lithic breccia (dslBr)

Massive breccia (mBr) covers a lateral extent of ~2.5 km, and commonly forms the steep crags south of Beinn Dearg Bheag, west of Cnoc Nam Forsaidh, and on Meall Coire Forsaidh and frequently succeeds mLT gradationally, both vertically and laterally, over distances of 1–5 m. mBr units typically possess erosive bases (Logs 18, 16,10,15, 5, Figure S4), and range in thickness from 1–20 m, apart from units around Meall Coire Forsaidh which range from 35–60 m in thickness. In this study we differentiate between mBr containing small blocks (64–256 mm) and mBr containing large blocks (256 mm). Matrix supported mBr may possess a localised incipient welding fabric, evidenced by slight imbrication patterns of lithic lapilli, and streaked out pumices with length: width ratios of <5:1. Compositionally blocks are heterolithic and may be fractured (Figure S3B) comprising arkosic sandstone, amygdaloidal and aphanitic basalt, quartzite, calcareous sandstone, dolostone, mLTi, mLTe, mLT lava-like, and mBr. Blocks reach a maximum size of ~1 m × 60 cm in mBr and may be angular to sub-angular or sub-rounded. mBr units commonly exhibit lithic grading patterns, i.e. ungraded, graded or reverse graded (Figure S3B). Reverse graded mBr is the most common breccia lithofacies. Exfoliation and thermal spalling of blocks (log 16, 50 m height, Logs B) is a common feature of reverse graded mBr. Frequently rounded blocks have exfoliated thermally spalled rims pervasive to a depth of ~1.5 cm with fine-grained ash present between individual layers. Columnar cooling joints (15 cm–1.1 m diameter) are common within mBr with a block population <17 cm diameter. Such columns may be either poorly developed (1–3 sided), or well developed (5–6 sided). Column development is not apparent in mBr that contains blocks >17 cm diameter. Matrix supported mBr may contain sporadic gas-escape structures including lithophysae and elutriation pipes (e.g. Log 15, 200 m height, Logs A). Lithophysal cavities may be oblate to amorphous, and in places fringed with marginal epidote. Localised imbrication of blocks within breccia is evident near the contact with Meall Dearg Bheag and on steep crags composed of breccia for example Meall Coire Forsaidh. Such imbrication is a useful indicator of both flow direction and way-up. Massive breccia may be juxtaposed with other ignimbrites across fault planes. For example, matrix supported mBr in Allt nan Suidheachan (Log 16, 500 m, Logs B) is faulted against incipiently welded mLTi and a ≤10 cm thick layer of angular mLTi fault gouge is evident at the fault plane.

Matrix within mBr is typically dacite-rhyolitic in composition (Figure S12) and contains former vitric chloritised bubble wall shards, sub-rounded quartz crystals, K-feldspar, albite, chlorite, zircon, epidote, titanite, and sporadic allanite, pyrite, and calcite. Frequently, matrix appears isotropic due to glass replacement by very fine-grained chlorite. Matrix lithics may be highly variable (e.g. granitic lapilli, basalt, mLT, mLTi, mLT lava-like). Mechanical fracture of matrix lithic lapilli is common at both macro-scale and in thin section. Within the matrix sporadic, aphanitic type II mafic enclaves [Troll et al. 2004] are strongly deformed around lithic fragments. Such mafic enclaves lack chilled margins. The numerous heat-derived features within mBr (contractional cooling

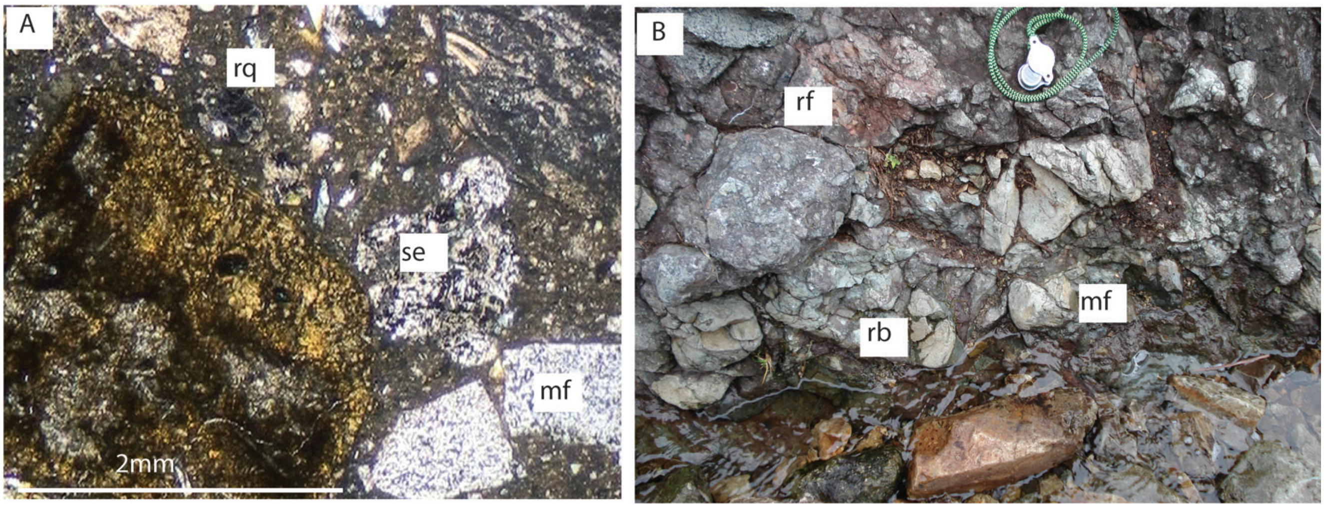


Figure S3: Field and petrographic characteristics of massive breccia (mBr). [A] Photomicrograph of mBr (log 16, 25 m, Logs B) showing planar mechanical fracture (mf) of quartzite lithic lapilli (bottom right-hand corner). Unwelded glass shards in top right-hand corner and a lobate margined silicic enclave (se) in mid-ground, are in close proximity to a rounded quartz crystal (rq). XP field of view 2 mm. [B] Heterolithic blocks within clast-supported, reverse graded mBr containing blocks of rounded red arkosic sandstone with radial fractures (rf), rounded blocks (rb), mechanical fracture (mf) of angular quartzite (right and below hand lens for scale—5 cm length), sub-rounded blocks of aphanitic basalt and reddish arkosic sandstone (Log 16, 50 m height, Logs B).

joints, lithophysae, thermal spalling of blocks, together with inter-layer ash, provide compelling evidence of genesis within 'hot' high particle concentration PDCs. Conditions at aggrading depositional flow boundaries were dominated by fluid-escape processes [Branney and Kokelaar 2002], where temporal and spatial changes in supply and filtering of components took place. Mechanically fractured, and faceted blocks within mBr, indicate block collision and abrasion during transportation. Sporadic alignment of lapilli within mBr matrix, together with slight deformation of matrix around lithic lapilli suggests transporting PDCs were turbulent. The graded nature of mBr deposits indicates eruptions were non steady state, and periodically waxed and waned in terms of vent energy output, and therefore had capacity to transport different sizes of block. Electron Micro-Probe area scans of mBr matrix samples indicates considerable chemical heterogeneity exists within individual mBr units and that matrix may be chemically variable over samples ≤1 m apart. This suggests deposition of mBr probably took place via incremental progressive aggradation [Branney and Kokelaar 1992] within 'hot' PDCs. The presence of mafic enclaves within mBr matrix indicate basic melt fractions were periodically incorporated into highly silicic PDCs [Sparks et al. 1977; Eichelberger 1980; Folch and Martí 1998].

Diffuse stratification of lithic blocks largely comprised of quartzite, mLT-lava like, and basalt crop out around the upper reaches of log 16 (Logs B, NG 59488 21333). Diffusely stratified lithic- breccia (dslBr) may contain a bi-modal block population where lithics comprised of mBr and mLTi are block sized, and basalt blocks are generally smaller (around NG 59325 21324). In close proximity small blocks of mLTi and mLT lava-like have been deformed plastically which suggests they were incorporated into PDCs in a molten–semi molten state. Diffusely stratified lithic breccias are highly localised, frequently die out laterally over several metres into mLT, and generally crop out in stage 4 KVF units (discussed in main text).

Massive lapilli tuff (mLT) and diffuse-stratified lapilli tuff (dsLT)

Silicic mLT is the most abundant type of ignimbrite within the study area, and is typically 30–95 % matrix supported, cropping out as ≤10 m thick, laterally impersistent units, which frequently interdigitate with other ignimbrite lithofacies. Most mLT is preceded or succeeded by mBr, with gradational contacts taking place over 10s of cm. mLT lapilli populations are heterolithic with ungraded mLT being most common (Figure S4B), followed by reverse graded, and highly subordinate normally graded mLT. Units display complex grading patterns Most mLT units are poorly sorted, matrix-supported, <10 m thick, non-stratified, and crop out as laterally discontinuous units. Their matrix varies from coarse to granular, is highly variable in colour (mid- to light-grey, to dark green, chlorite-epidote altered), and contains ubiquitous sub - rounded quartz crystals ≤2 mm diameter. Most lapilli are highly angular to sub angular, and the dominant clast types are arkosic sandstone and quartzite. Subordinate clast types are amygdaloidal basalt, dolostone, mLT, mLTe, mLT lava-like, and mBr. Normally graded mLT frequently contain sporadic outsized angular blocks (Log 3, Figure S3). Within the most complete logged section (Log 16, Logs B) basalt (aphantic, porphyritic, and amygdaloidal) is the most abundant lapilli type within mLT, together with arkosic sandstone.

At the macroscale 'heat' derived features such as lithophysae, contractional cooling joints, and thermal spalling are common features within mLT. Sporadic, ellipsoid to lenticular shaped, hollow lithophysae ≤5 × 3 cm, are evident around Creagan Dubh (Log 15, 212 m height, Logs A) throughout unit profiles. Contractional cooling joints are also common within mLT (Log 13 at 12 m height, log 10 at 30 and 75m height and log 6 at 25 m height; Logs B), and are often poorly developed, with columns spaced ≤30 cm apart. The majority of columnar joints are planar-slightly curved, and spaced ≤15 cm apart. mLT units at Kilchrist are highly variable both chemically and petrographically, and predominantly matrix supported. Matrix may be vitric or fine- medium grained, and variably basaltic-basaltic andesite-rhyolitic-trachytic in chemistry (Figure S12). mLT units are heterolithic with respect to lithics, and may contain sub-rounded to sub-angular basalt, arkosic sandstone, quartzite, calcareous sandstone, pumice, mLT, mLTi, mLTe, and mBr lapilli which are commonly chloritised. Sub angular to sub-rounded matrix lithic fragments (60–250 µm size fraction) are common, and are granitic (K-feldspar, quartz and chlorite or K-feldspar, titanite, quartz and Ca-rich epidote), to basaltic (labradorite, chlorite, allanite, rutile, calcite, and opaques) in affinity.

Ubiquitous sub-rounded quartz crystals ≤2 mm diameter, type III mafic enclaves, type II enclaves, alkali feldspars with fritted margins (Figure S5C) and marginal chlorite, and fan spherulites (Figure S5B) are common within matrix. Resorbed quartz crystals and mafic enclaves occur throughout matrix supported mLT units and are frequently chloritised with chilled margins. They may be either very fine-grained, or possess ≤40 % randomly orientated feldspar laths, and have highly irregular lobate margins. Undeformed silicic bubble wall glass shards (Figure S5D) may be apparent within lapilli pressure shadows and often former glass is devitrified, and amorphous. Calcite is present within numerous samples as both groundmass crystals (Figure S5A), and as late-stage cross cutting vein infill. Frequently quartz crystals located in pressure shadows between lithic lapilli have 120° triple junctions.

The absence of volcanic bombs, and the presence of cooling joints, lithophysae, and thermal spalling of lapilli, argues for transportation and deposition within 'hot' PDCs. Conditions within PDCs fluctuated throughout eruption duration, (evidenced by grading profiles of lapilli) and fluid escape-dominated processes operated at flow boundary zones within aggrading PDCs. Ungraded mLT deposits indicate steady state eruptions, together with sustained PDC deposition, and constant eruption plume heights. Reverse graded mLT was also deposited at a fluid-escape dominated depositional flow boundary zone [Branney and Kokelaar 2002], where temporal and spatial changes in supply and filtering of current components took place. Increasing lapilli size within reverse graded profiles, likely reflect increases in vent/conduit mass flux, together with changes in size and height of eruption columns during sustained eruptions [Branney and Kokelaar 2002]. Mechanical fracture of lapilli indicate collision of lithics took place in high concentration PDCs. Such collisions were probably enhanced by seismic rupturing [Smith et al. 2010]. Normally graded mLT (coarse tail grading of lithic lapilli) were probably deposited in conditions of waning mass flux/current flow, where PDCs were unable to transport the size of lithic lapilli that mBr depositing PDCs carried. Conversely normally graded lithic profiles probably reflect decreasing availability of lithics for scavenging, due to the paleo-surface being rapidly buried by aggrading PDCs, or may be due to selective filtering [Branney and Kokelaar 2002]. Spalled lithic lapilli within mLT matrix are rare features, and indicate cooling and reheating of lithics took place during transportation in host PDCs.

Diffuse stratified lapilli tuff (dsLT) crops out sporadically throughout, and within, the extent of the southern inner ring fault, and typically comprises millimetre to decimetre layering of coarse ash, to granule sized matrix. Within individual outcrops stratification whilst parallel, may thicken, or rarely splay into mLT. Individual dsLT units are overwhelmingly laterally discontinuous over distances of ≤5 m, and vertically may pass into mBr or mLT, either gradationally over distances ≤1 m, or sharply. Angular to sub-rounded lithic lapilli may form laterally discontinuous parallel to sub-parallel alignment between stratified matrix (around NG 59802 20301). Units of dsLT may also be variably reverse to normally graded (Figure S4A), with respect to lithic lapilli. Individual lithic lapilli within dsLT are frequently mechanically fractured, and sporadic sub-rounded to rounded lapilli may have outer margins with curviplanar spalled like fractures.

The lateral gradation of dsLT into mLT over a few metres indicates that particle concentrations, and shear gradients within the flow boundary zone of aggrading PDCs, varied between fluid escape dominated to traction dominated. Diffuse stratification is interpreted as indicating subtle unsteadiness within the flow-boundary zone of sustained depositing PDCs [Branney and Kokelaar 2002]. Such unsteadiness has been attributed to either successive surges in fluctuating sustained currents, frictional effects within granular flow-dominated flow boundary zones, or, periodic turbulent eddies [Branney and Kokelaar 2002].

Massive lapilli tuff, incipiently welded (mLTi)

mLTi crops out both south and west of the Eastern Red Hills laterally over ~400 m south of Beinn Dearg Bheag (Log 10, 16–18, Logs B), and ~1 km west of Beinn Dearg Mhor (Log 1 and 15, Logs A). These units are frequently laterally discontinuous over distances of ≤5 m, and grade into mLT, mBr, mLTe, or mLT lava-like. In the west units are much thinner, less numerous, and contact relationships between mLTi and adjacent lithologies both laterally or vertically, are frequently absent due to lack of exposure. Where present, contacts are either gradational, undulatory, or sharp and erosive. mLTi units frequently contain cooling joints (SF6c) which may be poorly-well developed, with individual columns spaced between 5–60 cm. mLTi varies in matrix content (≤80 %), lithic type, fabric intensity, and grading profiles. Lapilli may comprise sub-angular to sub-rounded basalt, quartzite, arkose, or mLTe. Fiamme (≤15 cm in length) are common in matrix and frequently have swallow tails (Figure S6E, G). Parallel to sub-parallel alignment of reverse graded fiamme is common (Log 16, 445m height, Logs B). Increase in fiamme length to width ratio (from ~3:1 to >10:1) over distances of ≤2 m is often accompanied by a subtle reverse grading of both lithic lapilli (Logs 1, 15, 16, Logs A, Logs B, and type III mafic enclaves. mLTi groundmass is rhyolitic (Figure S12), and contains deformed bubble wall shards, sporadic resorbed crystal phases, and angular to sub-angular fragments of quartz rich

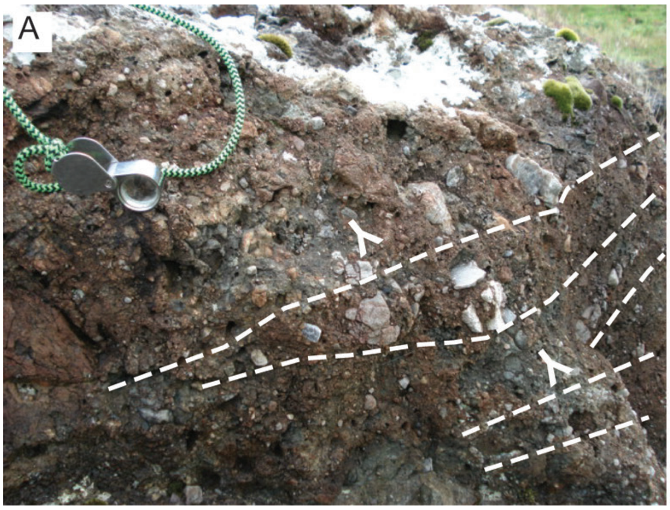


Figure S4: Field characteristics of diffuse stratified lapilli tuff (dsLT). [A] Reverse graded to normal graded dsLT (NG 59802 20301) containing mechanically fractured sub-rounded arkose lapilli. Hatched white lines indicate a very weak stratification. The unit youngs (Y) to top left of photo. [B] Ungraded mLT containing mechanically fractured sub-rounded arkosic lithic lapilli (Log 10, 40 m height, Figure S4).

lithic lapilli. Ubiquitous sub-rounded matrix quartz crystals ≤550 µm, have embayed margins mantled by Fe-rich chlorite, and are frequently mechanically fractured. Matrix quartz and K-feldspar, are frequently inter-grown with chloritized pumices. mLTi matrix displays a pronounced incipient fabric (Figure S6A) and may contain recrystallised silicate melt globules (Figure S6B), varietal allanite and pyrite, together with accessory polycrase, xenotime, and dendritic zircon. Incipient welding of matrix fabric is evidenced by glass shards (≤2 µm across) which have been deflected around lithic lapilli (Figure S6A). Deformation of this glass occurred as a result of syn–post-depositional shear and loading, which forced shards into a preferred orientation [Branney and Kokelaar 2002]. However, glass shards next to lithic lapilli are often situated within pressure shadows and are less deformed. Outside of pressure shadows fiamme are commonly mechanically fractured and sheared (Figure S6D). Different states of welding intensity, indicated by varying intensity of shard deformation, are often apparent within the same thin section. Type III mafic enclaves ≤400 µm across, are common within the matrix (Figure S6F). They possess lobate margins, and may or may not have chilled margins. Where evident, chilled margins are ≤30 µm thick. Matrix fabric is frequently deformed around enclaves which indicates enclaves were rigid when entrained within PDCs (Figure S6F). The poor sorting and absence of tractional stratification within mLTi units suggest that deposition took place within high-concentration, fluid-escape dominated, depositional flow boundary zones of 'hot' PDCs [Branney and Kokelaar 2002]. Reverse grading of fiamme, and lithic lapilli, suggests vent mass flux was non-steady state, and periodically increased in intensity. Repeating cycles of mLTi and mLTe (evident over distances of ~10s of metres) suggests that fluctuations in both conduit energy levels, and eruption plume heights varied temporally. Reverse grading of mLTi units towards the top of Logs 17 and 18 (Logs B) suggests flux levels increased towards the latter stages of mLTi producing eruptions. Within these units, reverse grading of mafic blebs also suggests increased tapping of sub-surface mafic melt, and enhanced magma mingling took place towards the latter stages of those eruptions.

Massive lapilli tuff with eutaxitic fabric (mLTe)

Field identification of mLTe is frequently hampered by lack of evident microfabric, which is only later apparent in thin section. This problem is well known in ancient volcanic terrains, and has recently been highlighted at the Sgurr of Eigg [Brown and Bell 2013]. However, mLTe with pronounced eutaxitic fabric (Figure S7A, B) crops out to the south and west of Beinn Dearg Bheag (Logs 10,13,14,16,17,18, Logs B) and west of Beinn Dearg Mhor (Logs 1,2,6,7,15, Logs A). Individual mLTe units may range from 1-40 m in thickness, but the vast majority are <4 m thick. There are two notable exceptions. Firstly, a 30 m-thick continuous mLTe unit capped by mLT with a highly erosive base, crops out in the west (Log 7, Logs A). Secondly in the south (Logs 16, 18, Logs B) repeating cycles of mLTi and mLTe, crop out in both tributaries of the upper reaches of Allt nan Suidheachan (Logs 16, 18, Logs B). Some of the mLTe units are ≤25 m thick, (between 730–755 m). In log 16 these repeating mLTi and mLTe cycles have a lateral extent of 55 m, and in log 18 some 197 m. In both of these logged sections alternating deposits of mLTi and mLTe are capped by mBr. Cooling joints are common within mLTe units (Figure S7E), with individual columns spaced 0.6–1.5 m apart, and typically plunging at angles ≤15°. Weathered surfaces are frequently white in colour, whilst fresh rock is commonly black or dark grey. Matrix is fine grained to glassy, and in content ≤90 %. Matrix welding states may be highly variable. Where matrix is intensely welded, lithic lapilli may show evidence of rotation during PDC transportation (Figure S7C). Lithic lapilli within matrix may comprise amygdaloidal basalt, aphanitic basalt, mLT, mLTe, mLT lava-like, arkosic sandstone, or quartzite. Eutaxitic matrix fabric is

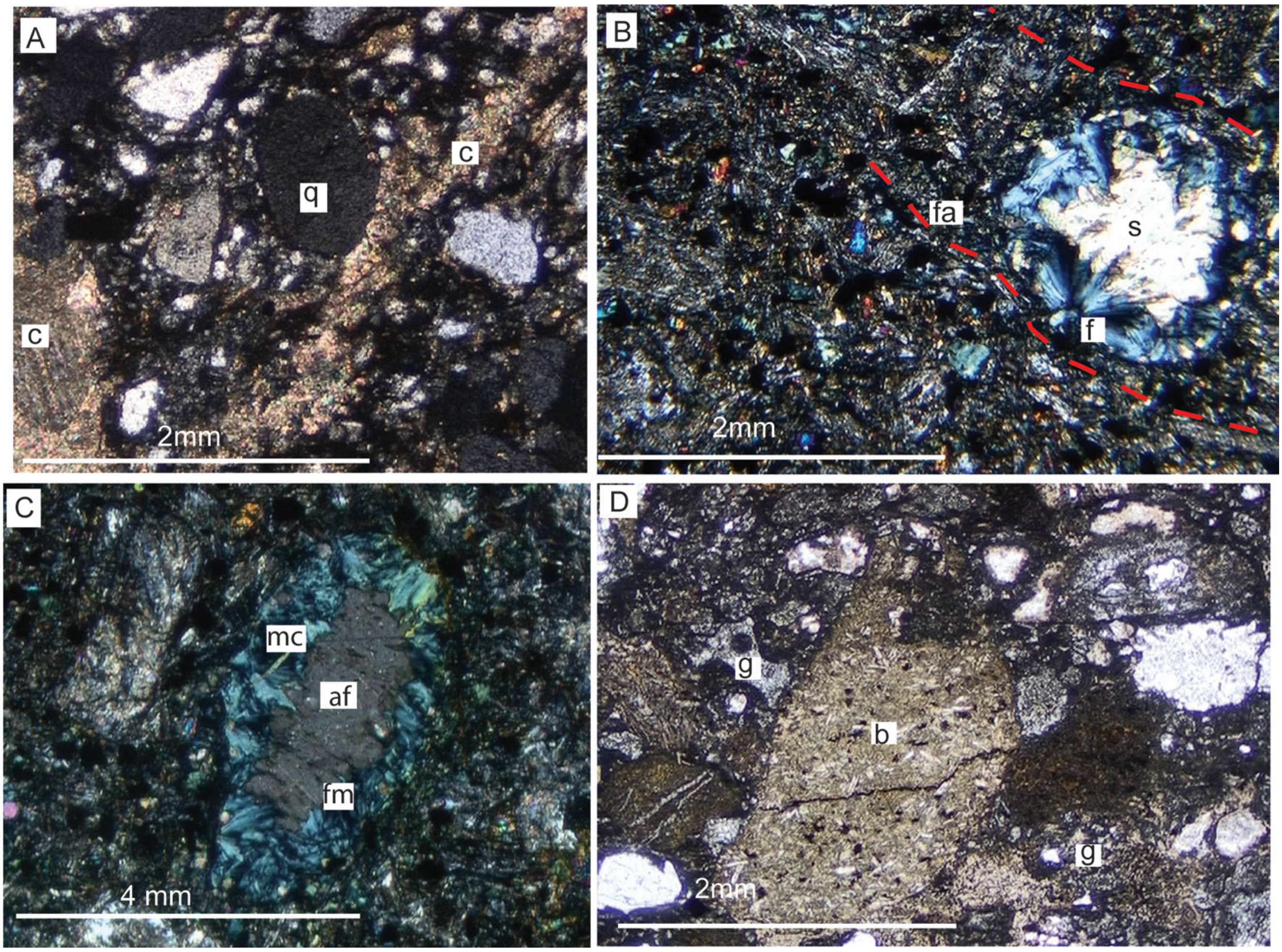


Figure S5: Petrographic characteristics of mLT. [A] Ubiquitous calcite (c) occurs both as sub-rounded lithic lapilli (bottom left), and interstitially as laterally discontinuous bands, evident to the right of a sub-rounded quartz (q) crystal, XP. (Log 16 142 m height, Logs B).[B] XP image of a fan spherulite (s) [after Lofgren 1974] within mLT matrix. Spherulite is composed of quartz fibres (f) radiating from a single point. Nucleation and growth started on the margins of a former gas cavity (lithophysae). Distorted matrix fabric (fa) suggests lithophysae growth was syn-post depositional. Secondary quartz (s) infills the lithophysae (Log 13, 18 m height, Logs B). Type III rounded matrix mafic enclave (me), with highly irregular lobate margins (lm) see (Log 18, 220 m height, Logs B). [C] XP image of alkali feldspar crystal (af) with fritted margins (fm) fringed by marginal chlorite (mc) within matrix supported mLT (Log 13,18 m height, Logs B). XP image of alkali feldspar crystal (af) with fritted margins (fm) fringed by marginal chlorite (mc) within matrix supported mLT (Log 13,18 m height, Logs B). [D] XP image of clast supported mLT containing fine grained, sub-rounded, basaltic lithic lapilli (b) and undeformed glass shards (g). A bubble wall shard is evident to top left of the basaltic lapilli (Log 10, 40 m height, Logs B) XP image of a fan spherulite (s) (after Lofgren, 1974) within mLT matrix. Spherulite is composed of quartz fibres (f) radiating from a single point. Distorted matrix fabric (fa) suggests lithophysae growth was syn-post depositional. Secondary quartz (s) infills the lithophysae (Log 13, 18 m height, Logs B).

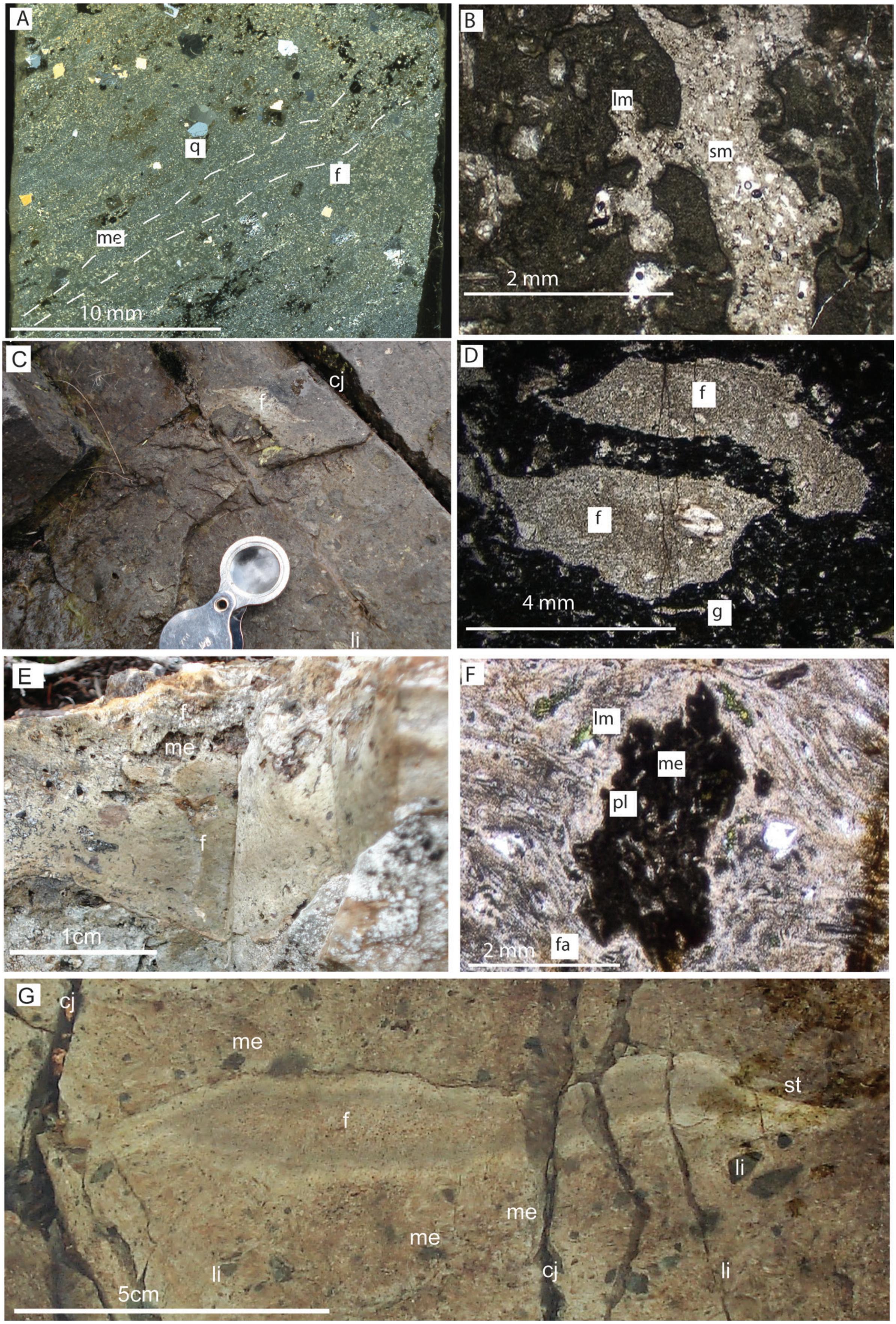


Figure S6: (Caption next page)

Figure S6: (Previous page) Field and thin section characteristics of incipient welded massive lapilli tuff (mLTi). [A] XP Scan of mLTi from Log 16, 445 m height, (Logs B). White hatched lines indicate incipient fabric (f), secondary quartz crystals (q) have overgrown this fabric, which contains type II mafic enclaves (me). [B] silicic melt (sm) globule with lobate margins (lm) above fiamme in [E] XP, (Log 10, 62 m height, Logs B). [C] Close up of cooling joints (cj) in [C] within mLTi showing fiamme (f) and sub-rounded lithic lapilli (li) (Log 16, 445 m height, Logs B). [D] XP photomicrograph of fiamme (f) which has recrystallised to micro-crystalline quartz within a glass (g) matrix. The fabric has been deflected around the fiamme, which itself has been mechanically fractured. (Log 16, 445 m, Logs B). [E] Type II mafic enclave (me) closely associated with swallow tailed fiamme (f) within mLTi. (Log 16, 445 m height, Logs B). [F] A type III mafic enclave (me) with highly irregular lobate margin (lm) and plagioclase laths (pl), within mLTi matrix which has a strong fabric (fa) deflected around the enclave, PPL (Log 16, 476m height, Logs B). [G] Matrix rich mLTi containing fiamme (f), with chloritized core, and swallow tail (st), with a length to width ratio of ≤10:1. Individual fiamme are ≤15 cm in length, (Log 16, 445 m height, Logs B). Note ubiquitous Type II and III mafic enclaves (me), and columnar cooling joints (cj) which are perpendicular to an incipient left-right orientated fabric. Basaltic lithic lapilli (Li) lack lobate margins.

typically deformed around type II and III mafic enclaves (Figure S7G, H). Such enclaves have highly irregular margins, are frequently chloritised, and comprise ≤5 % of matrix content. In hand specimen some enclaves are very fine-grained, whilst others possess up to 20 % randomly orientated felspar crystals, and possess 1–2 mm thick chilled margins.

All mLTe matrix is rhyolitic in composition (Figure S12), extremely fine-grained and commonly contains dominant quartz >55 %. Other matrix phases are alkali feldspar, chlorite, Fe-rich chlorite and accessory allanite and zircon. Rounded quartz, embayed quartz and type II (Figure S7D) and III mafic enclaves are common within matrix. Skeletal allanite frequently occurs as overgrowths around unrounded mechanically fractured matrix quartz. Former glass shards have frequently re-crystallised to quartz, and are mechanically fractured. Often such mechanically fractured quartz has (≤25 µm thick) palagonitised rims. Palagonite rimmed quartz within mLTe deposits has been recorded elsewhere [Ross and Smith 1961; Riehle 1973; Riehle et al. 1995; Freundt 1999]. Cuspate matrix fiamme are frequently streaked out into a pronounced fabric and deformed around matrix lithics (Figure S7F–H). Matrix lithics are commonly ≤4 mm diameter, sub-angular to sub-rounded, and may comprise granite, aphanitic basalt, amygdaloidal basalt, or arkosic sandstone. Un-deformed bubble wall glass shards are visible within pressure shadows adjacent to lithic lapilli. Away from pressure shadows fiamme are streaked out with length:width ratios of ≥20:1. Within thin section both evidence of vitroclastic textures may be destroyed and welding intensity may increase within mLTe samples over distances of <1 mm.

Deposition of mLTe units took place from high-concentration, fluid-escape dominated, depositional flow boundary zones of 'hot' PDCs as indicated by poor sorting and absence of tractional stratification [Branney and Kokelaar 2002]. Temperatures within mLTe producing PDCs were likely to have been >600 °C, because welding of rhyolite has been shown experimentally to commence above this temperature [Bierwith 1982]. Syn-post depositional shearing and compaction, was accompanied by glass shard agglutination, whilst stress free areas existed in pressure shadows around lithic lapilli, where glass shards were largely undeformed. Localised shear stress varied considerably in intensity over very short distances, since eutaxitic and parataxitic fabric commonly occur together in the same thin section. Heat is needed to promote welding, and it is envisaged that air ingestion into eruption columns was therefore minimal, and PDCs were generated via low-fountaining fissure events. The presence of ubiquitous chlorite indicates that fluids and halogens were present during and after the deposition from PDCs [Duffield and Dalrymple 1990]. Type II and type III mafic enclaves within the matrix, indicate mafic melt was being introduced into rhyolitic PDCs throughout eruptions.

Lava like ignimbrite (mLT lava-like)

mLT lava like ignimbrites crop out west of Beinn Dearg Mhor (log 7, Logs A) and south of Beinn Dearg Bheag (log 12, 13, and 16, Logs B), as laterally discontinuous units, 1.8–6 m thick, capped by either mLT or mBr. Upper contacts are sharp and erosive whilst lower contacts are gradational over distances ≤30 cm. In log 7 mBr grades vertically into mLT lava-like over ≤0.5 m and in log 16 mLTe grades into mLT lava-like over ≤20 cm vertically. Similarly, mLT lava-like may grade laterally into mLTe or mLTi over distances ≤2 m (log16, 615–620 m height, Logs B).

In hand specimen mLT lava-like is flow banded, vitrophyric, and contains ≤5 % angular lithic lapilli ≤30 mm diameter. An orange weathered rind pervades ≤2 mm whilst fresh rock is frequently white in colour. Banding is on a sub-mm scale (Figure S8A, B), and comprises contorted leucocratic and melanocratic layers, often forming recumbent folds (Figure S8A, C), antiform- synform pairs, or ptygmatic folds. An intense parataxitic fabric is frequently deflected around lithic lapilli, and amorphous, chloritised, type II mafic inclusions (Figure S8D). Rare lithophysae (≤3 cm long) are present in the matrix, and vary in form from lenticular, amorphous to oblate. mLT lava-like is highly matrix rich (≤95 %), extremely fine grained, and rhyolitic in composition (Figure S12). The main matrix phases are quartz and alkali feldspars, with highly subordinate plagioclase, rutile, chlorite, zircon and monazite. A very strong sub-linear parataxitic fabric pervades the matrix, which is composed of alternating leucocratic and melanocratic layers.

Leucocratic layers are composed of µm thick laminations of quartz, alkali feldspar and rare monazite. Melanocratic layers are highly chloritised, and contain allenite, titanite, and

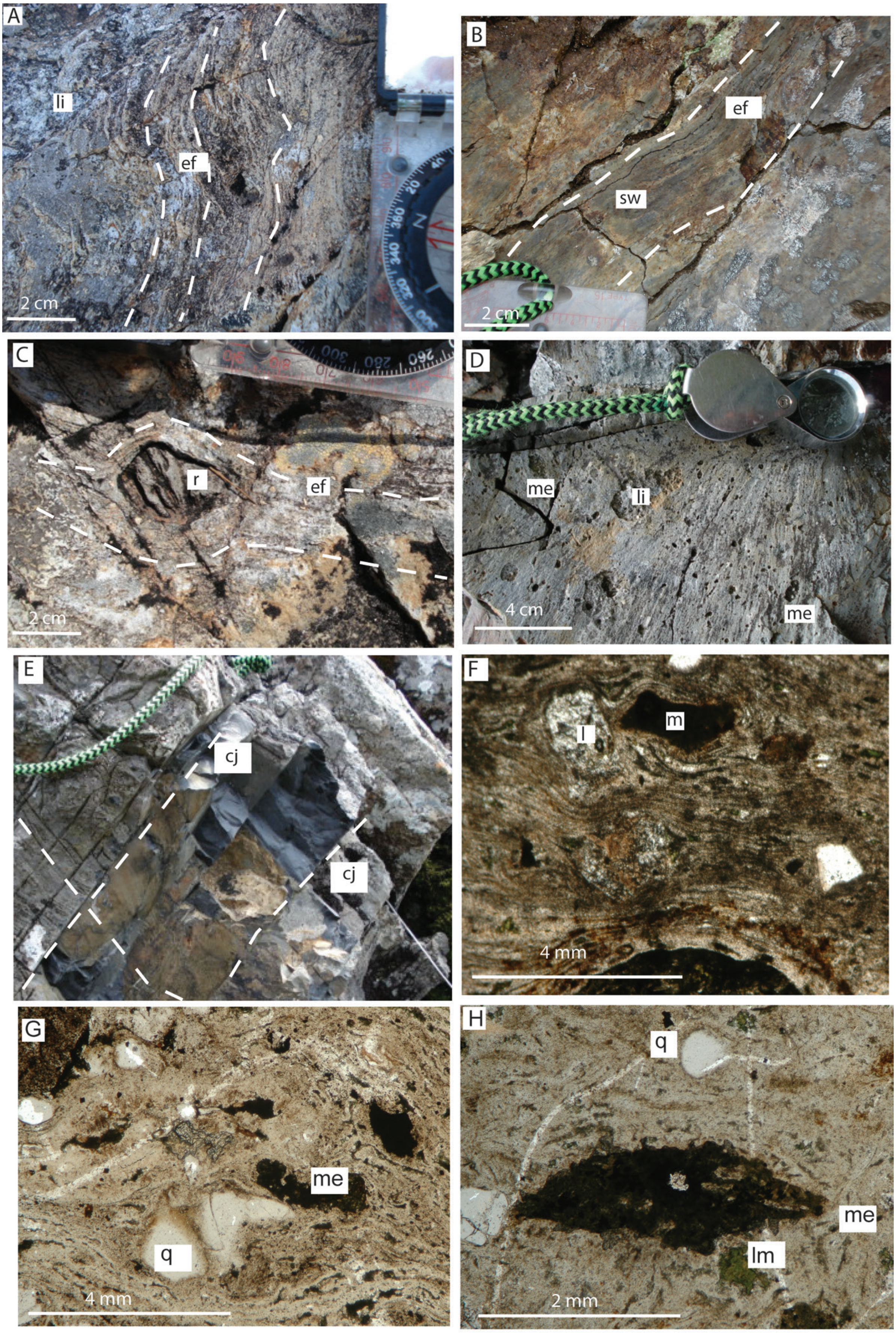


Figure S7: (Caption next page)

Figure S7: (Previous page) Field and petrographic characteristics of massive lapilli tuff with eutaxitic fabric (mLTe). [A] Intensely welded eutaxitic fabric (ef) delineated by hatched white lines deflected around angular rhyolitic lithic lapilli (li) ≤1cm (Log 8, 5 m height, Logs A). Intensely welded eutaxitic fabric (ef) delineated by hatched white lines deflected around angular rhyolitic lithic lapilli (li) ≤1cm (Log 8, 5 m height, Logs A). [B] Same locality where matrix often appears glassy and black. Eutaxitic fabric (ef) is evident top right to bottom left. Fiamme are highly streaked, and virtually closed swallow tails (sw) are evident. [C] lithic lapilli of mLTi incorporated within mLTe (Log 12, 47 m height, Logs B). Note how external eutaxitic fabric (ef) is strongly deflected around rhyolitic mLTi lithic lapilli (r). [D] Type II mafic enclaves (me) and angular chloritized lapilli (li) recorded in Log 10, 5 m height, (Logs B). [E] nature of the angular relationship between columnar cooling joints (cj), and eutaxitic fabric (ef) in [D]), which is orientated approximately perpendicular to columnar jointing. Matrix is highly silicic and frequently glassy. Note strong parallel/eutaxitic fabric (bottom right) evident within the white weathered surface. [F] PPL photomicrograph of pronounced eutaxitic fabric within mLTe (Log 18, 242 m height, Logs B) containing mafic clast (m), butted up against rotated lithic lapilli (l). Note the presence of cuspate fiamme which have been deflected above and below the mafic clast. Eutaxitic fabric (white hatched lines) orientated parallel to chloritised fiamme (f). Note fiamme are reverse graded from bottom to top of photograph (Log 14, 305 m height, Logs B). [G] PPL photomicrograph of mLTe from Log 18, 315 m height, (Logs B). The highly contorted matrix fabric is deflected around angular quartz crystals (q) and ubiquitous streaked out, lobate, type II mafic enclaves (me). [H] PPL photomicrograph of rounded quartz (q), and type II mafic enclave (me) with lobate margin (lm), within a partially chloritised silicic matrix. The enclave clearly post-dates top to bottom trending quartz veins, (Log 8, 5 m height, Logs A).

fan spherulites of quartz [Lofgren 1974]. Spherulites are concentrated at the outer margins of melanocratic layers. Matrix layers have been strongly deformed into a parataxitic fabric [Pioli and Rosi 2005] around crystals, and lithic lapilli (Figure S9B–D). Matrix fabric consists of parallel to rectangular shaped domains which are laterally discontinuous on a micron scale. Compressional features such as en-echelon micro scale 'piggy back' thrust slices occur sporadically throughout mLT lava-like matrix. Extensional features are also evident for example boudinaging of quartz rich parataxitic fabric in the hinge regions of micro-scale antiforms. Elsewhere, antiforms and antiform-synform pairs are common within matrix.

Lithic lapilli within mLT lava-like comprise sub-angular fragments of micro-granite, rhyolite, and sub-rounded basalt. Quench features such as matrix spherulites are very common and may radiate out from a single point source or fringe parataxitic fabric margins in trails. Spherulite cores comprise strain free quartz crystals, with margins frequently interlocking at 120° triple junctions. Spherulite cores are surrounded by radiating fibres of K-feldspar, themselves mantled by quartz. Lithophysae and axiolites are subordinate volumetrically to spherulites within matrix. Spherulites are frequently orientated parallel to parataxitic fabric, and spherulitic rich domains are located between leucocratic or melanocratic domains. They are either radial, or lithophysal spherical structures [Lofgren 1974; Breitkreuz 2013]. Within mLT lava-like matrix fan spherulites are volumetrically subordinate to spherical spherulites. External fabric is frequently deformed around both type II and III mafic enclaves. Individual enclaves may contain plagioclase that is either aligned in a sub-parallel orientation, or randomly orientated. mLT lava-like was deposited incrementally during very hot (≤1000 °C) quasi-single sustained eruptions, from very low, fissure fed fountaining columns [Branney and Kokelaar 1992; 2002]. Macroscale evidence of extremely 'hot' ~1100 °C [Andrews and Branney 2011] emplacement of mLT lava-like deposits is evidenced by the flow banded vitrophyric texture, spherulitic rich domains, and lithophysae. During transportation within PDCs the amount of heat present, topographic gradient, and viscosity, were sufficient to promote rheomorphic flow. This resulted in intense folding (i.e. ptygmatic, recumbent, antiform-synform pairs) and faulting which is evident both at macro and micro-scale (Figure S9A). The post depositional brittle state of mLT lava-like is evidenced by the presence of en-echelon micro faults which were probably caused after the deposit cooled, and passed through the glass transition zone.

Fissures containing rhyolitic tuff are often in close proximity (10 ≤ 40 m) to lava like ignimbrite (logs 12 and 16, Logs B). However, such fissures are not always evident near mLT lava-like deposits (e.g. log 7 and log 13, Logs A, Logs B). During eruptions lava-like ignimbrite producing PDCs were syn-post-depositionally welded and agglutinated on paleo-topography, before cooling through the glass brittle–ductile transition zone [Freundt 1999; Russell et al. 2003]. The very close proximity of fissure fed tuff to outcrops of mLT lava-like and their very similar chemistry (Figures S12 and S13) strongly suggests PDCs were fed from fissures.

The presence of ubiquitous mafic blebs within mLT lava-like matrix indicates magma-mingling took place extensively between rhyolitic, and mafic-rich melt bodies, throughout mLT lava-like producing eruptions. Since the margins of mafic blebs are lobate, and external fabric is deflected around them, a pronounced temperature difference must have existed between host rhyolite, and introduced pulses of mafic melt, during incorporation into PDCs.

Tuff filling fissures (TFF)

Within logs 11,12, and 17 (Logs B) fissure filled tuff ± brecciated tuff crops out along NW–NNW trending linear outcrops. The most extensive of these fissures is 380 m long, links Logs 11 and 17 then broadly parallels the east bank of Allt nan Suidheachan. The fissure resembles a dyke, but lacks either chilled margins, or cooling joints. The fissure is offset and ranges in thickness from ≤5 cm–4 m. Tuff contained within the fissure is fine grained, weathers white, has an intense near vertically orientated fabric, and contains sheath folds whose axes are sub-parallel to the pervasive fabric. They appear as

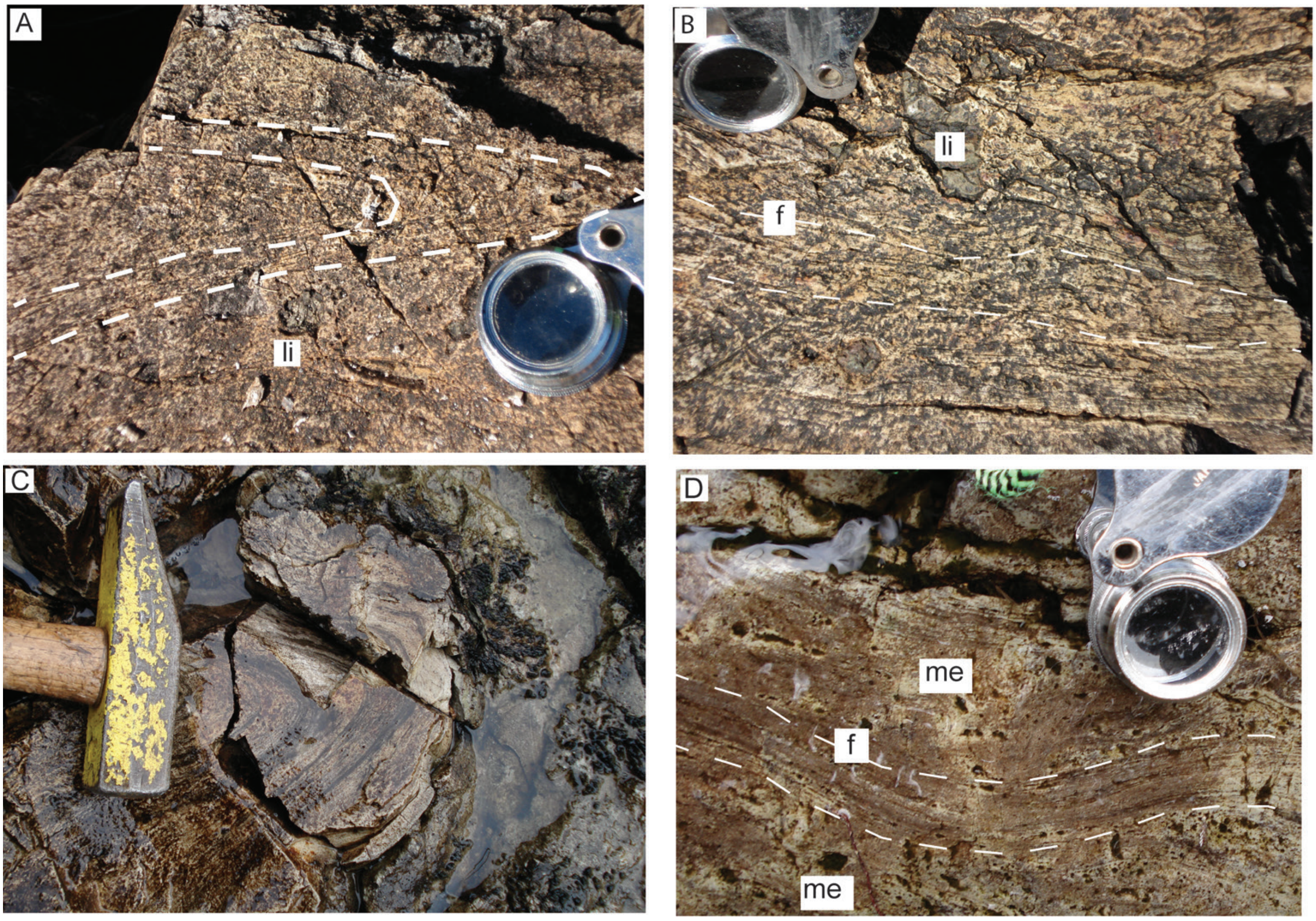


Figure S8: Field and petrographic characteristics of lava-like massive lapilli tuff (mLT lava-like). [A] Intensely folded lava-like ignimbrite, contains angular rhyolitic tuff (li) lapilli ≤1 cm in length. [B] mLT lava-like, (Log 18, 316 m height, Logs B) a flow banded vitrophyre, with intense planar parataxitic fabric (pf). The matrix is deflected around sporadic rhyolitic tuff lapilli (li), towards both top and bottom of image. [C] mLT lava-like, (Log 18, 318 m height, Logs B) which has been rheomorphosed into a recumbent antiform. Hammer head is 17 cm long. [D] Type II mafic enclaves (me) within mLT lava-like ignimbrite with intense fabric (f), (Log 18, 316 m height, Logs B).

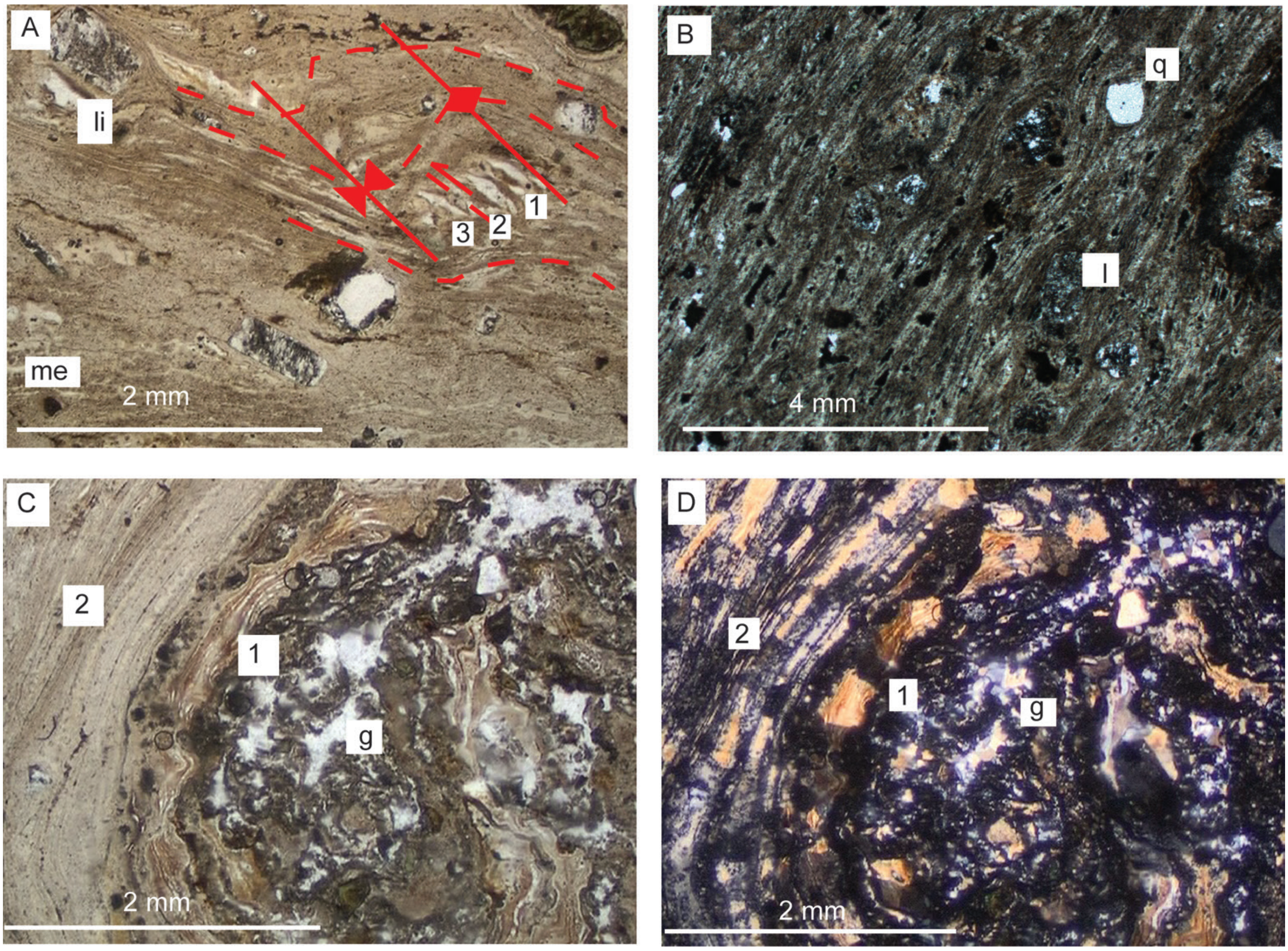


Figure S9: Petrographic characteristics of mLT lava-like. [A] Photomicrograph in PPL showing antiform-synform pair within mLT lava-like matrix (Log 7, 15 m height, Logs A). Vergence was from the right of the image, and produced micro- imbricate thrust slices (1= oldest, 3=youngest). [B] XP image of parataxitic 'banded' fabric with mineralogically different layers (leucocratic and melanocratic). Vitroclastic texture has been destroyed by agglutination and coalescence of glass shards. Parataxitic fabric is deflected around quartz crystals (q), and micro-granite lithic lapilli (l). [C] PPL image of the hinge region within a). Region 1 boudinaged quartz rich layers, are juxtaposed with quartz rich glass (g). Region 2 is much finer grained, and parataxitic like fabric terminations, can be seen in leucocratic layers. [D] XP image of [C] showing intense parataxitic region at 1 and 2. Undeformed glass shards (g) are evident in areas which were subjected to less strain.

'eye like structures on rock surfaces' normal to the transport direction. Fabric is frequently deformed around sub-circular to these oblate sheath folds which are ≤7 cm long, occur in clusters, and comprise a core and ≤5 concentric rings. The kinematics of the sheath folds suggests flow direction of fissure fed tuff was to the SSW. Substantial thicknesses of alternating mLTi and mLTe units, together with a mLT lava-like unit crop out ~30 m SSW of the fissure (Log 16, height 720–790 m and log 18 height 0–318 m, Logs B). Lapilli of fissure-derived tuff are contained within the mLT lava-like exposure.

In hand specimen the tuff contains sporadic angular mafic lithic fragments (≤4 mm diameter) and ubiquitous chloritised type III enclaves ≤1 cm diameter. Intense 'rheomorphic' matrix folding occurs around pumiceous fragments. Lithophysae are common throughout the outcrop. At Allt Coire Forsaidth rhyolitic fissure filled tuff is ~10 m thick and crops out for 170 m along a faulted stream section. The rock is auto-brecciated and is pervaded by randomly orientated elutriation pipes, containing recrystallised glass, and angular quartz fragments. A strong sub-vertical fabric is frequently deformed around weathered in recesses, and auto-brecciated clasts of tuff. Direct contacts between the tuff and mLT lava-like are not evident. However, sub-horizontally flow-banded, vitrophyric, mLT lava-like (Figure S10A) crops out on the opposite stream bank ≤5 m from the tuff strongly suggesting the mLT-lava like was fed from the fissure.

The fissure fed tuffs are rhyolitic (Figure S13) and have extremely similar whole rock geochemistry to adjacent mLT lava-like deposits (Figure S12). Thin sections comprise ≤95 % devitrified glass together with abundant spherical spherules (0.5–4 mm diameter) of radiating crystals of quartz and alkali feldspar. Tuff matrix is frequently pervaded by perlitic cracks and contains type II and III mafic enclaves together with dendritic alkali feldspar crystallites and rare magnetite and pyrite. The extremely close proximity of mLT lava-like and mLTe to fissure fed tuffs, together with similar matrix chemistry suggests high-grade ignimbrites were fissure fed during very 'hot' eruptions in upward flaring multiple conduits (Figure S10B–D). These fissures frequently coincide in orientation with NNW trending dykes of the regional Paleogene swarm. The ubiquitous presence of mafic enclaves within all fissure fed tuff suggests basic magma pulses were incorporated into silicic chambers throughout eruptions. Field evidence further suggests that some fissures were 're-exploited' by later NNW basic dykes of the regional swarm since they chill into, and are juxtaposed with, fissure fed tuff (log 11, Logs B, Figure S10E).

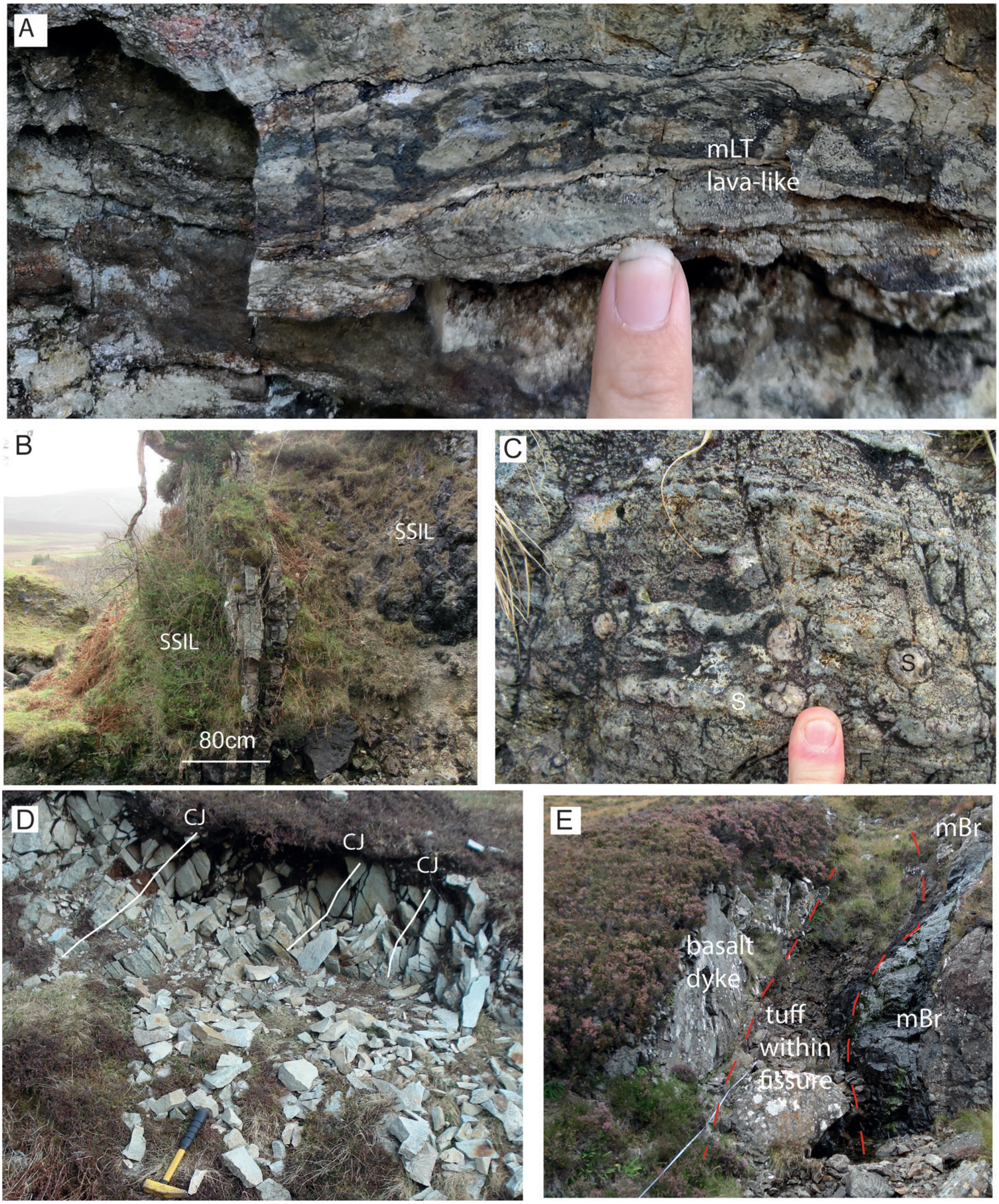


Figure S10: Field characteristics of tuff filling fissures and mLT lava-like in close proximity. [A] Spherulitic lava-like ignimbrite within 50m of tuff filling fissure on western bank of Allt Coire Forsaidh. [B] Silicic tuff filling a fissure (TFF) outside the inner ring fault at Allt a Choire. The fissure is NNW trending, sinuous, and cross cuts Cambro-Ordovician dolostone of the Strath Suardal Formation (SSF). [C] Spherulitic (S) rhyolitic tuff within the fissure at [B] separated by sub-parallel planar fabric, in places fabric is contorted around individual spherulites (NG 62154 23527). [D] Localised 5 m $\times$ 2 m mLT lava-like deposit filling a paleo-depression ~300 m from B and C at NG 61803 23119. Note the presence of cooling joints (CJ). [E] Fissure filled tuff juxtaposed with later basaltic dyke (trending NNW) and mBr (log 11, Logs B). Mafic magma has therefore exploited fissures previously exploited by silicic magma.

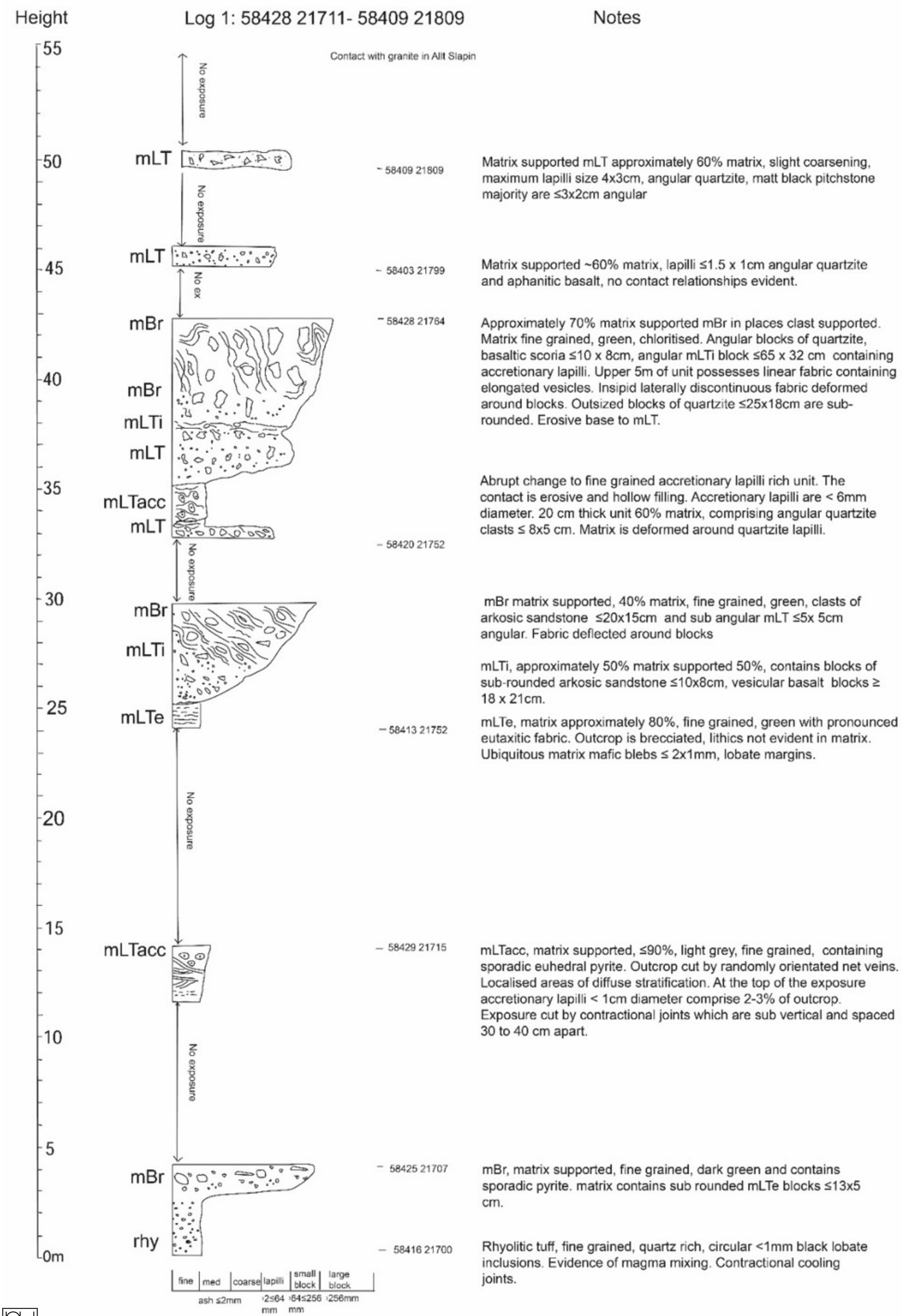
Table S3: Radiometric age determinations on Palaeogene rocks from the Kilchrist area. Ages in millions of years (Ma).

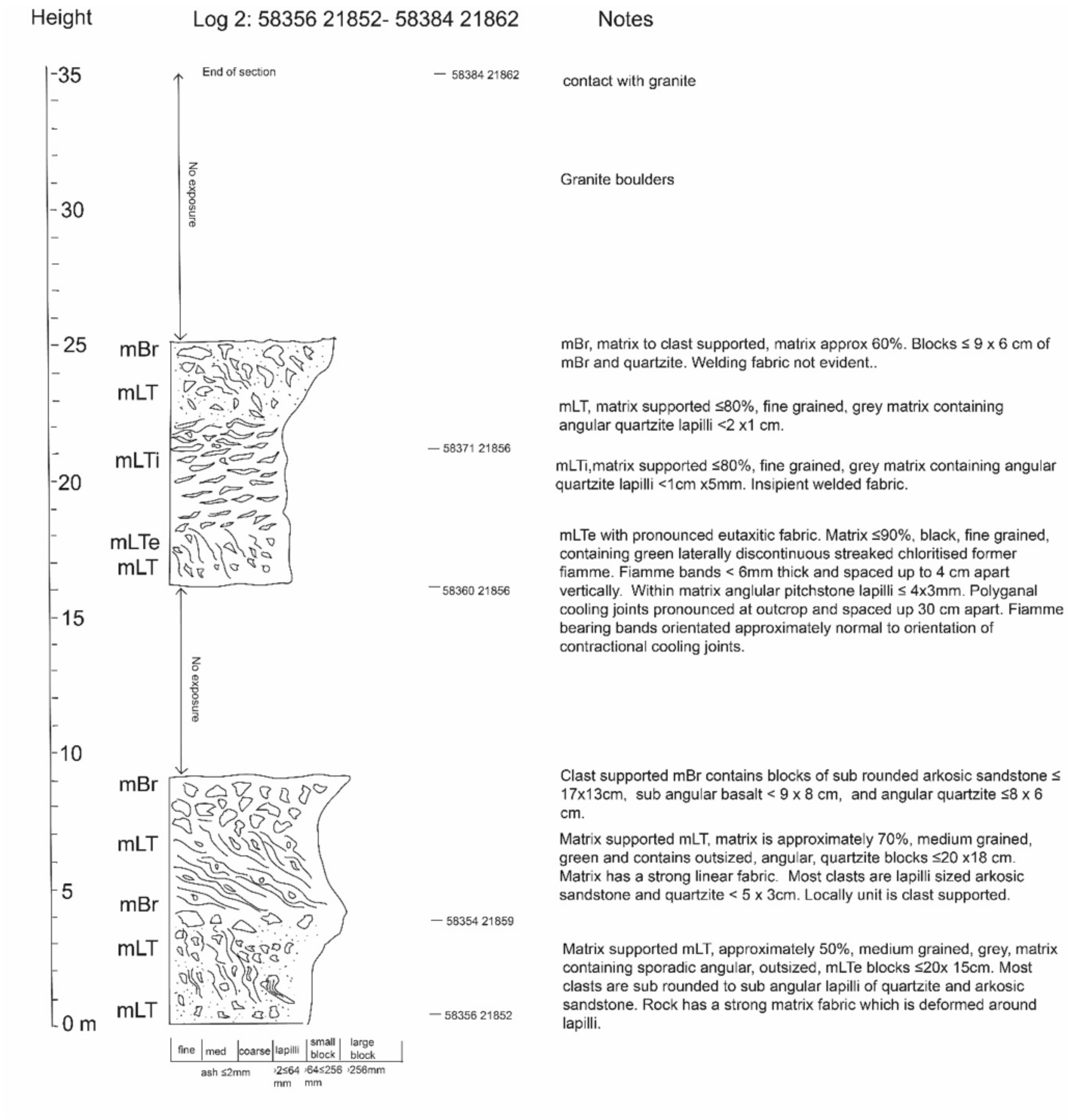
Eastern Red Hills Centre (ERH)	Age (Ma)	System
Silicic inclusions within mafic dyke, Ben Suardal (NG 63191 20477)	56.45 ± 0.19	U-Pb*
mLTi Allt nan Suidheachan (NG 59618 20783)	56.15 ± 0.19	U-Pb*
Beinn an Dubhaich Granite	55.89 ± 0.15	U-Pb†
Pitchstone dyke cutting Beinn na Caillich Granite	55.7 ± 0.10	U-Pb†

* This study;
† Unpublished U-Pb analysis by M. A. Hamilton, Jack Slattery Geochronology Laboratory, Department of Geology, University of Toronto, in Emeleus and Bell [2005].

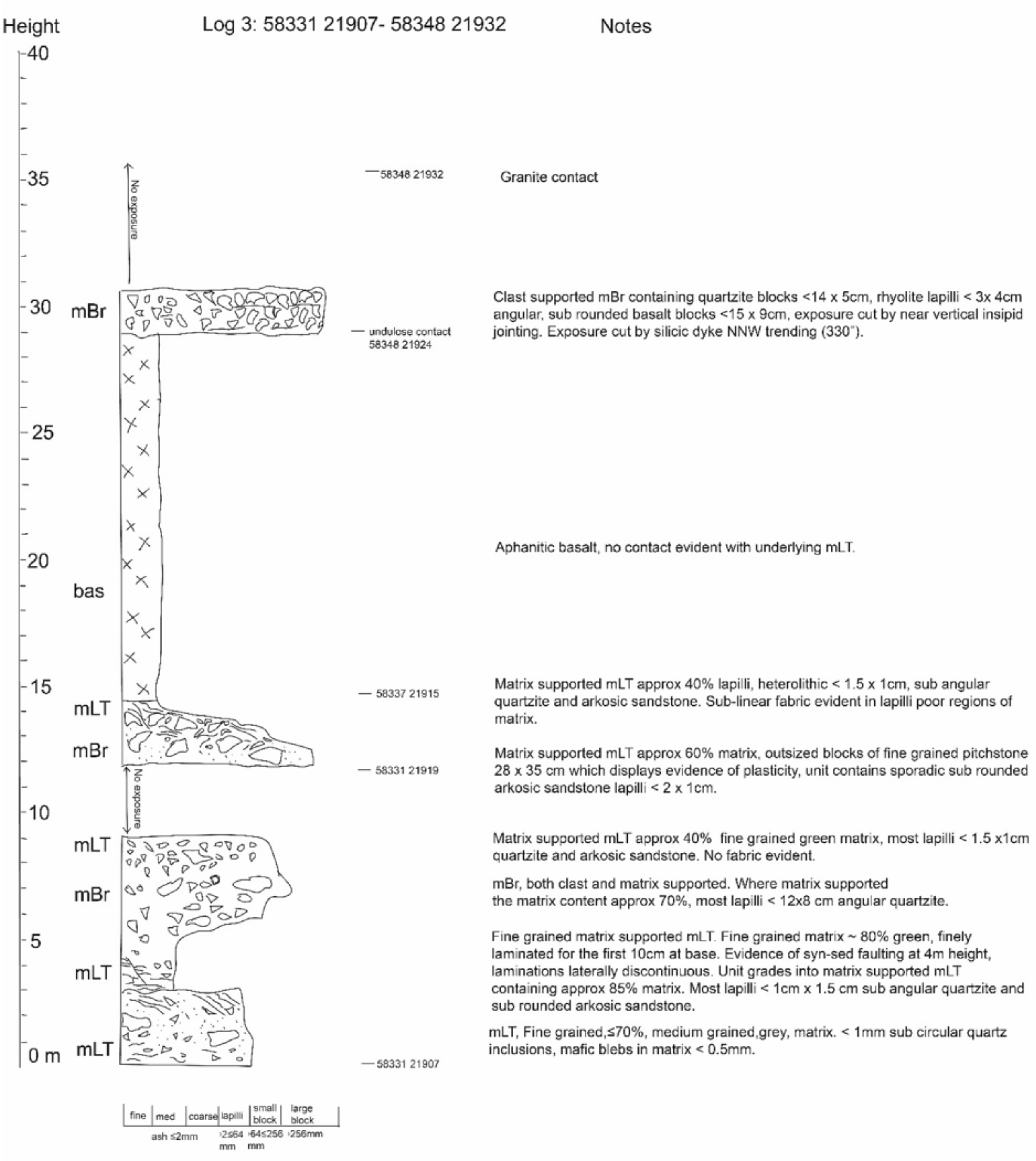
3 Logs A

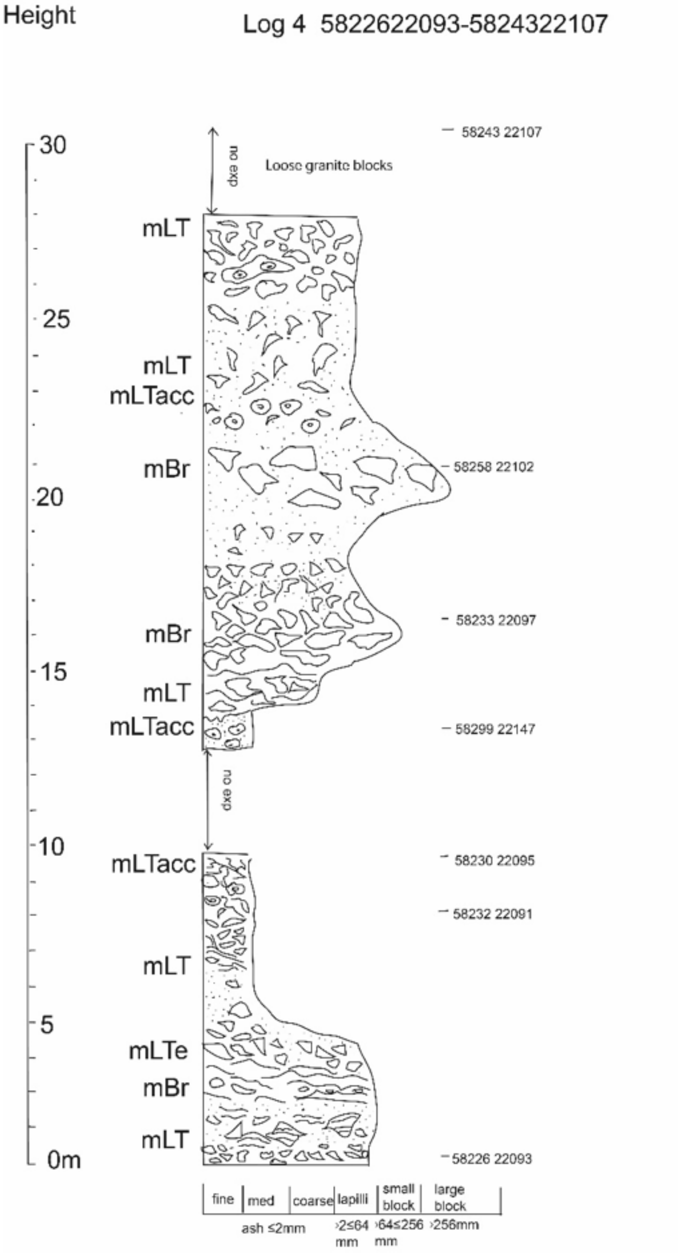
Logs 1–8 and 15 West of Beinn na Caillich Centre





Height
Log 2: 58356 21852- 58384 21862
Notes
35
30
25
20
15
10
5
0 m
End of section
No exposure
58384 21862
contact with granite
Granite boulders
mBr
mLT
mLTi
mLTe
mLT
58371 21856
58360 21856
mBr, matrix to clast supported, matrix approx 60%. Blocks ≤ 9 x 6 cm of mBr and quartzite. Welding fabric not evident..
mLT, matrix supported ≤80%, fine grained, grey matrix containing angular quartzite lapilli <2 x1 cm.
mLTi,matrix supported ≤80%, fine grained, grey matrix containing angular quartzite lapilli <1cm x5mm. Insipient welded fabric.
mLTe with pronounced eutaxitic fabric. Matrix ≤90%, black, fine grained, containing green laterally discontinuous streaked chloritised former fiamme. Fiamme bands < 6mm thick and spaced up to 4 cm apart vertically. Within matrix anglular pitchstone lapilli ≤ 4x3mm. Polyganal cooling joints pronounced at outcrop and spaced up 30 cm apart. Fiamme bearing bands orientated approximately normal to orientation of contractional cooling joints.
No exposure
mBr
mLT
mBr
mLT
mLT
58354 21859
58356 21852
Clast supported mBr contains blocks of sub rounded arkosic sandstone ≤ 17x13cm, sub angular basalt < 9 x 8 cm, and angular quartzite ≤8 x 6 cm.
Matrix supported mLT, matrix is approximately 70%, medium grained, green and contains outsized, angular, quartzite blocks ≤20 x18 cm. Matrix has a strong linear fabric. Most clasts are lapilli sized arkosic sandstone and quartzite < 5 x 3cm. Locally unit is clast supported.
Matrix supported mLT, approximately 50%, medium grained, grey, matrix containing sporadic angular, outsized, mLTe blocks ≤20x 15cm. Most clasts are sub rounded to sub angular lapilli of quartzite and arkosic sandstone. Rock has a strong matrix fabric which is deformed around lapilli.
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
›2≤64 mm
›64≤256 mm
›256mm


Height
Log 3: 58331 21907- 58348 21932
Notes
40
35
30
25
20
15
10
5
0 m
No exposure
mBr
bas
mLT
mBr
mLT
mBr
mLT
mLT
58348 21932
Granite contact
undulose contact
58348 21924
Clast supported mBr containing quartzite blocks <14 x 5cm, rhyolite lapilli < 3x 4cm angular, sub rounded basalt blocks <15 x 9cm, exposure cut by near vertical insipid jointing. Exposure cut by silicic dyke NNW trending (330°).
Aphanitic basalt, no contact evident with underlying mLT.
58337 21915
Matrix supported mLT approx 40% lapilli, heterolithic < 1.5 x 1cm, sub angular quartzite and arkosic sandstone. Sub-linear fabric evident in lapilli poor regions of matrix.
58331 21919
Matrix supported mLT approx 60% matrix, outsized blocks of fine grained pitchstone 28 x 35 cm which displays evidence of plasticity, unit contains sporadic sub rounded arkosic sandstone lapilli < 2 x 1cm.
Matrix supported mLT approx 40% fine grained green matrix, most lapilli < 1.5 x1cm quartzite and arkosic sandstone. No fabric evident.
mBr, both clast and matrix supported. Where matrix supported the matrix content approx 70%, most lapilli < 12x8 cm angular quartzite.
Fine grained matrix supported mLT. Fine grained matrix ~ 80% green, finely laminated for the first 10cm at base. Evidence of syn-sed faulting at 4m height, laminations laterally discontinuous. Unit grades into matrix supported mLT containing approx 85% matrix. Most lapilli < 1cm x 1.5 cm sub angular quartzite and sub rounded arkosic sandstone.
mLT, Fine grained,≤70%, medium grained,grey, matrix. < 1mm sub circular quartz inclusions, mafic blebs in matrix < 0.5mm.
58331 21907
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
›2≤64 mm
›64≤256 mm
›256mm



Notes

Contact with granite

Clast supported mLT contains outsized rhyolitic blocks <26x15 cm which contain accretionary lapilli. Majority of blocks are <26 x 5cm of angular mLTe and sub rounded arkosic sandstone.

Matrix supported mLT comprising 60%, fine grained, green, matrix. Maximum block size 10 x 8 cm of mLTe. Most are ≤5.5cm and sub-angular. Exposure pervaded by cooling joints which are spaced ≤5cm apart.

mLT, matrix supported, ≤ 70% matrix, fine grained, mid grey, which contains concentric accretionary lapilli ≤5mm diameter. Majority of lapilli are sub-angular quartzite <1cm x 5mm.

Coarsening upwards matrix supported mBr, comprises 40%, fine grained matrix, and outsized sub-rounded blocks of arkosic sandstone ≤31x17cm. Most clasts of arkosic sandstone are lapilli and small block sized< 8x4cm.

mLT, clast supported, fining upwards. Angular mLTe lapilli ≤6x4cm. In places unit is matrix supported with up to 50% matrix. Cooling joints sporadically pervade the exposure and are sub-vertical.

Clast supported mBr containing basaltic scoria blocks ≤ 22x9cm with lobate margins. Also angular mLTe blocks ≤9x3cm majority are >6x 3cm.

Erosional contact with overlying mLT which is matrix supported (40% matrix), fine grained, green and contains bomb sized clasts of partially melted arkosic sandstone ≤15x12cm. Accretionary lapilli occur sporadically throughout different levels in unit with maximum diameter of 1.5cm.

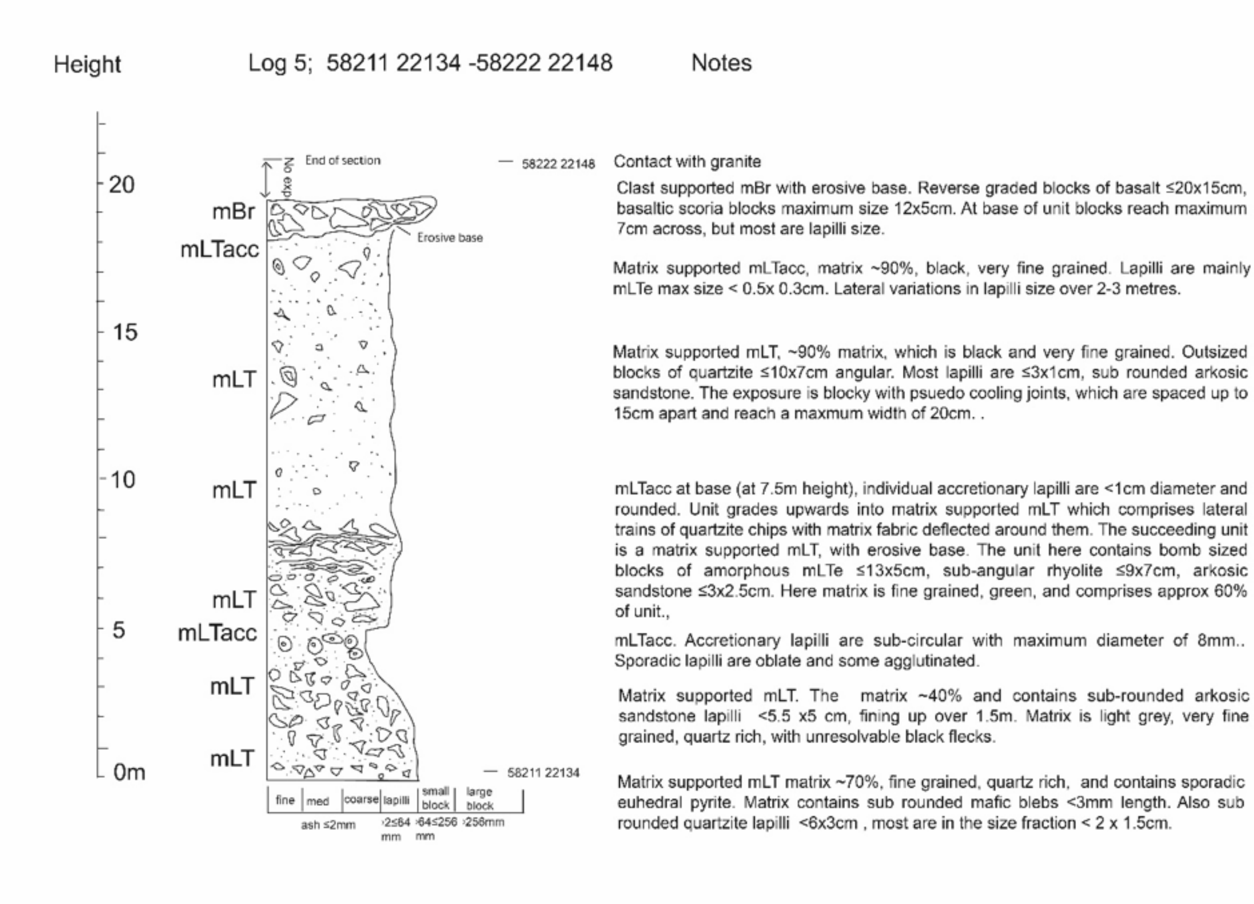
Matrix supported mLTacc, the accretionary lapilliacc comprise approximately 5% of outcrop and are oblate. Their maximum size is 1.4 cm x 5mm. Randomly orientated net veins pervade the exposure. The matrix comprises 40% and is fine grained green, insipient welded fabric is deflected around sub rounded arkosic sandstone lapilli which are < 5x4cm.

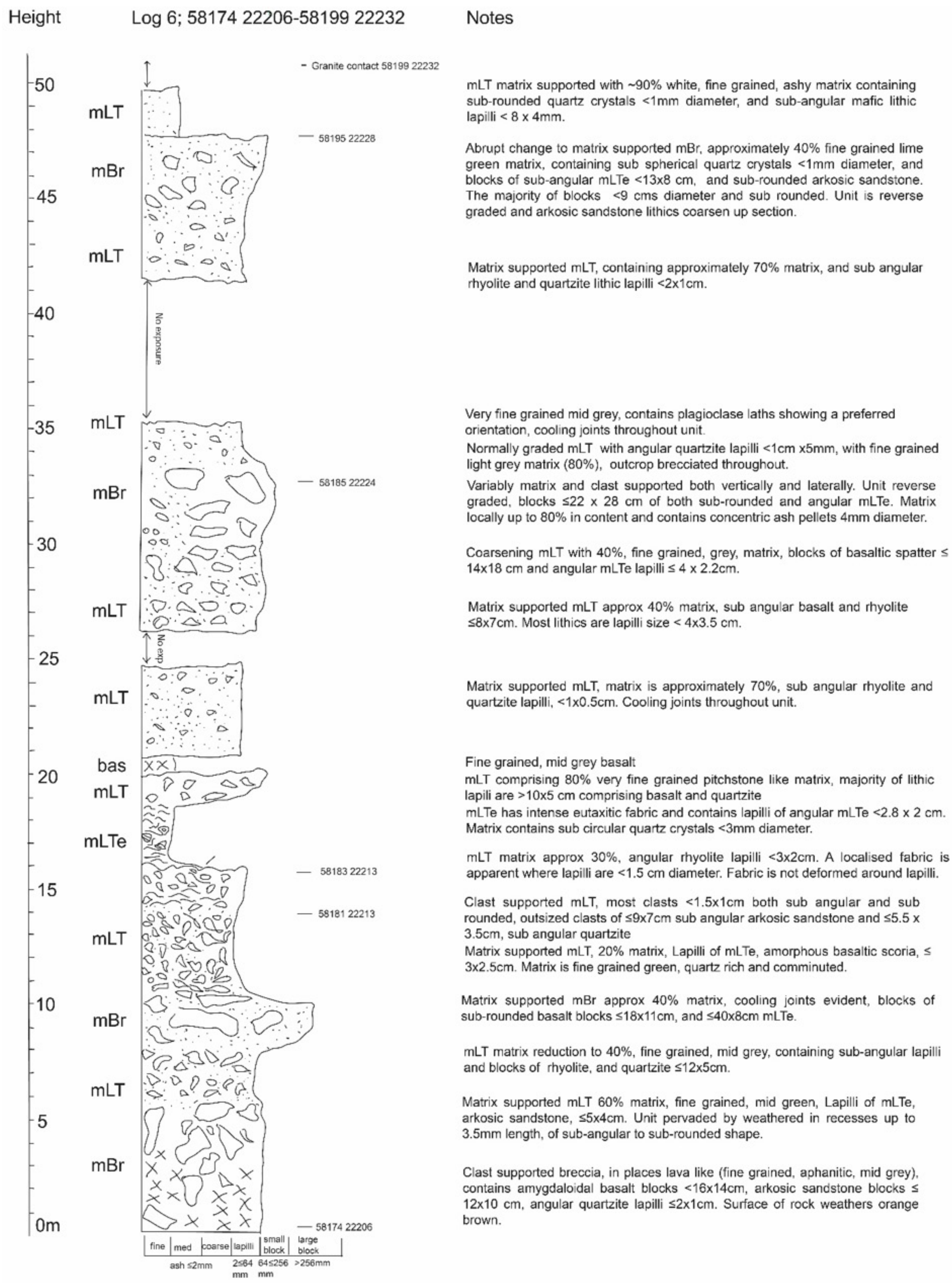
Matrix supported, mLT. Matrix comprises 80% and is very fine grained, green. The dominant lapilli type is quartzite ≤4 x 3 cm.

Matrix supported mLT, approx 30% fine grained green matrix, contains clasts of sub angular mLTe ≤8x5cm, also sub rounded arkosic sandstone ≤1.5 x1cm. Evidence of mechanical fracturing of clasts. Cooling joints average spacing 8-10 cm apart.

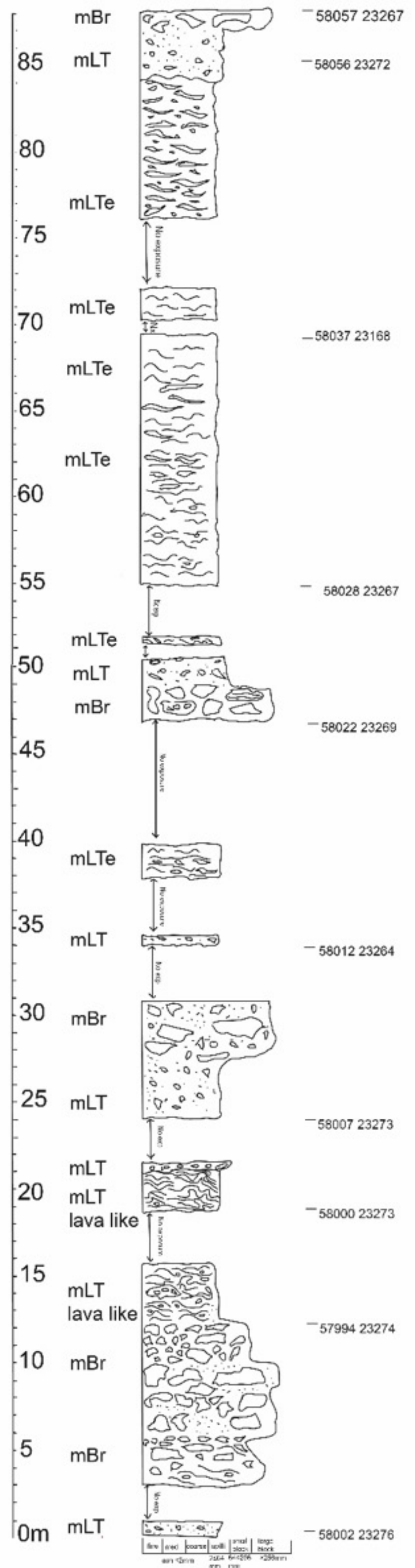
Matrix supported mBr with approximately 40% matrix. Contains blocks of mLTe ≤ 12x10cm sub rounded. Intense fabric but is not deflected around lithics.

Clast supported heterolithic mLT. Contains angular rhyolitic lapilli ≤4x2cm, amygdaloidal basalt ≤4x3 cm together with sub-angular, and sub-rounded arkosic sandstone ≤6x4cm.


Height
Log 5; 58211 22134 -58222 22148
Notes
20
15
10
5
0m
End of section
No exp
58222 22148
mBr
mLTacc
Erosive base
mLT
mLT
mLT
mLTacc
mLT
mLT
58211 22134
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
›2≤64 mm
›64≤256 mm
›256mm
Contact with granite
Clast supported mBr with erosive base. Reverse graded blocks of basalt ≤20x15cm, basaltic scoria blocks maximum size 12x5cm. At base of unit blocks reach maximum 7cm across, but most are lapilli size.
Matrix supported mLTacc, matrix ~90%, black, very fine grained. Lapilli are mainly mLTe max size < 0.5x 0.3cm. Lateral variations in lapilli size over 2-3 metres.
Matrix supported mLT, ~90% matrix, which is black and very fine grained. Outsized blocks of quartzite ≤10x7cm angular. Most lapilli are ≤3x1cm, sub rounded arkosic sandstone. The exposure is blocky with psuedo cooling joints, which are spaced up to 15cm apart and reach a maxmum width of 20cm. .
mLTacc at base (at 7.5m height), individual accretionary lapilli are <1cm diameter and rounded. Unit grades upwards into matrix supported mLT which comprises lateral trains of quartzite chips with matrix fabric deflected around them. The succeeding unit is a matrix supported mLT, with erosive base. The unit here contains bomb sized blocks of amorphous mLTe ≤13x5cm, sub-angular rhyolite ≤9x7cm, arkosic sandstone ≤3x2.5cm. Here matrix is fine grained, green, and comprises approx 60% of unit.,
mLTacc. Accretionary lapilli are sub-circular with maximum diameter of 8mm.. Sporadic lapilli are oblate and some agglutinated.
Matrix supported mLT. The matrix ~40% and contains sub-rounded arkosic sandstone lapilli <5.5 x5 cm, fining up over 1.5m. Matrix is light grey, very fine grained, quartz rich, with unresolvable black flecks.
Matrix supported mLT matrix ~70%, fine grained, quartz rich, and contains sporadic euhedral pyrite. Matrix contains sub rounded mafic blebs <3mm length. Also sub rounded quartzite lapilli <6x3cm , most are in the size fraction < 2 x 1.5cm.


Height
Log 6; 58174 22206-58199 22232
Notes
Granite contact 58199 22232
58195 22228
58185 22224
58183 22213
58181 22213
58174 22206
No exposure
No exp
50
45
40
35
30
25
20
15
10
5
0m
mLT
mBr
mLT
mLT
mBr
mLT
mLT
bas
mLT
mLTe
mLT
mBr
mLT
mBr
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
2≤64 mm
64≤256 mm
>256mm
mLT matrix supported with ~90% white, fine grained, ashy matrix containing sub-rounded quartz crystals <1mm diameter, and sub-angular mafic lithic lapilli < 8 x 4mm.
Abrupt change to matrix supported mBr, approximately 40% fine grained lime green matrix, containing sub spherical quartz crystals <1mm diameter, and blocks of sub-angular mLTe <13x8 cm, and sub-rounded arkosic sandstone. The majority of blocks <9 cms diameter and sub rounded. Unit is reverse graded and arkosic sandstone lithics coarsen up section.
Matrix supported mLT, containing approximately 70% matrix, and sub angular rhyolite and quartzite lithic lapilli <2x1cm.
Very fine grained mid grey, contains plagioclase laths showing a preferred orientation, cooling joints throughout unit.
Normally graded mLT with angular quartzite lapilli <1cm x5mm, with fine grained light grey matrix (80%), outcrop brecciated throughout.
Variably matrix and clast supported both vertically and laterally. Unit reverse graded, blocks ≤22 x 28 cm of both sub-rounded and angular mLTe. Matrix locally up to 80% in content and contains concentric ash pellets 4mm diameter.
Coarsening mLT with 40%, fine grained, grey, matrix, blocks of basaltic spatter ≤ 14x18 cm and angular mLTe lapilli ≤ 4 x 2.2cm.
Matrix supported mLT approx 40% matrix, sub angular basalt and rhyolite ≤8x7cm. Most lithics are lapilli size < 4x3.5 cm.
Matrix supported mLT, matrix is approximately 70%, sub angular rhyolite and quartzite lapilli, <1x0.5cm. Cooling joints throughout unit.
Fine grained, mid grey basalt
mLT comprising 80% very fine grained pitchstone like matrix, majority of lithic lapilli are >10x5 cm comprising basalt and quartzite
mLTe has intense eutaxitic fabric and contains lapilli of angular mLTe <2.8 x 2 cm. Matrix contains sub circular quartz crystals <3mm diameter.
mLT matrix approx 30%, angular rhyolite lapilli <3x2cm. A localised fabric is apparent where lapilli are <1.5 cm diameter. Fabric is not deformed around lapilli.
Clast supported mLT, most clasts <1.5x1cm both sub angular and sub rounded, outsized clasts of ≤9x7cm sub angular arkosic sandstone and ≤5.5 x 3.5cm, sub angular quartzite
Matrix supported mLT, 20% matrix, Lapilli of mLTe, amorphous basaltic scoria, ≤ 3x2.5cm. Matrix is fine grained green, quartz rich and comminuted.
Matrix supported mBr approx 40% matrix, cooling joints evident, blocks of sub-rounded basalt blocks ≤18x11cm, and ≤40x8cm mLTe.
mLT matrix reduction to 40%, fine grained, mid grey, containing sub-angular lapilli and blocks of rhyolite, and quartzite ≤12x5cm.
Matrix supported mLT 60% matrix, fine grained, mid green, Lapilli of mLTe, arkosic sandstone, ≤5x4cm. Unit pervaded by weathered in recesses up to 3.5mm length, of sub-angular to sub-rounded shape.
Clast supported breccia, in places lava like (fine grained, aphanitic, mid grey), contains amygdaloidal basalt blocks <16x14cm, arkosic sandstone blocks ≤ 12x10 cm, angular quartzite lapilli ≤2x1cm. Surface of rock weathers orange brown.

Height Log 7; 5800223276-5805723267 Notes



Clast supported mBr, contains highly angular blocks of mLTe <60x40 cm, angular pitchstone <20x7cm, and angular welded mLTe <12x10cm . Fabric not evident.

Matrix supported mLT matrix approx 80%, fine grained, quartz rich, contains lapilli of angular quartzite <4x3cm, and angular rhyolite <1cm x 0.5mm.

Matrix supported mLTe, matrix is fine grained white, sub circular quartz crystals, <1mm diameter. Lithic lapilli angular pitchstone ≤2x1cm.

mLTe increasing in welding intensity to >30:1

mLTe very similar to underlying unit. Fiamme length to width ratio >20:1

Fiamme coarsening to a maximum size of 8 x 1cm thick, slight decrease in welding intensity

mLTe with approximately 90% fine grained, green, matrix, contains sub rounded arkosic sandstone ≤5x3mm. Within the matrix fiamme have a length to width ratio of >20:1. Welding is less pronounced than lower down in unit.

mLTe with ~80% matrix, contains boudined lapilli of quartzite < 5x3mm. Rock has an intense fabric deformed around lithics.

Matrix supported mLT with ~60%, fine grained, grey matrix containing mafic blebs ≤4x3mm with lobate margins, and sporadic pyrite. Lapilli of mLTe are ≤4x5 cm and angular.

Clast supported block breccia containing angular blocks of arkosic sandstone ≤ 46x20cm, mLTe ≤ 16x14 cm, quartzite ≤ 7x2.7cm, and outsized greccia blocks <27x15cm. Coarsening up.

mLTe with ~80% matrix, contains boudined lapilli of quartzite < 5x3mm. Intense matrix fabric deformed around lithics.

Matrix supported mLT approx 70%, fine grained, friable, light grey, matrix with greenish tinge. Pronounced cooling joints evident throughout outcrop. Lithic lapilli of angular mLTe ≤ 1.5x1cm, and highly angular rhyolite ≤0.8x0.5 cm.

Matrix supported mBr, approximately 50% fine grained matrix, approximately 40% blocks sub-angular mLTe ≤28x14cm, sub angular basalt ≤30x20cm and angular quartzite <2x1cm.

Matrix supported mLT contains lithic lapilli of angular arkosic sandstone ≤4x3cm, and aphanitic basalt ≤4x2cm

Erosive base to overlying matrix supported mLT which has approximately 40%, medium grained matrix, with a strong locally intense folded fabric. Lapilli of mLTe ≤1cm x 5mm.

Fabric banded 3mm thick average bands, cream coloured, containing <1mm thick, laterally discontinuous, purple streaks (former fiamme?). Intense folding at base of welded unit

Very fine grained, contains unresolvable lithics (pitchstone?) <3mm x1.5mm, and amorphous mafic blebs ≤3mm long.

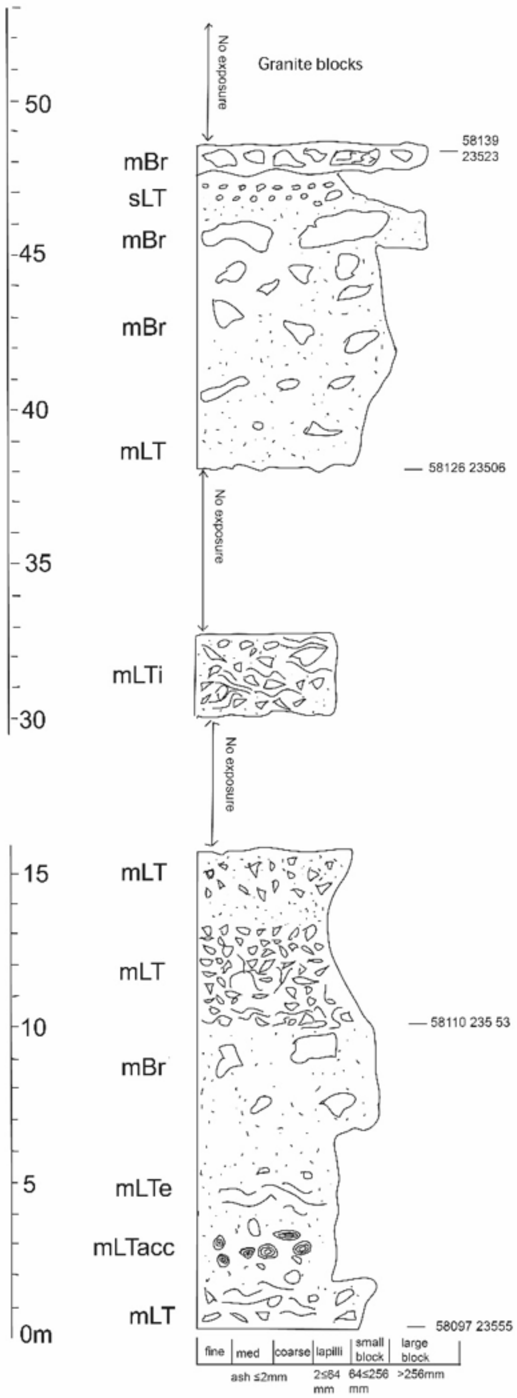
Clast supported breccia containing blocks of angular quartzite <17x12cm. Majority are angular quartzite ≤10x7cm and arkosic sandstone average size >8x4cm.

Clast supported breccia comprising sub rounded arkosic sandstone blocks <38x37cm, basalt <38x29cm and fine grained, sub rounded black tuff ≤9x6cm. Local areas of unit (approx 10%) are ≤60% matrix supported and contain lithic lapilli of angular quartzite ≤ 1cm x 8mm and rhyolite ≤1cm x 5mm.

Clast supported breccia containing sub rounded basalt blocks ≤47x43cm, and sub-rounded arkosic sandstone ≤33x20 cm.

Matrix supported mLT, approx 60% fine grained, green, matrix, which contains sporadic pyrite crystals, sub-angular quartzite lapilli <1.5 x 1cm, and angular rhyolite 5x 3mm .

Height Log 8; 58097 23555- 58139 23523 Notes



Granite contact, end of section

Clast supported block breccia, blocks of mLT lava like ≤ 45x26cm, and highly angular mLT blocks ≤18x12cm. The outcrop is very brecciated.

Stratified lapilli tuff containing 15% mLT lithic lapilli <15x3mm. mLT trails are laterally continuous over several metres.

Matrix supported large block breccia, matrix ~40%, medium grained matrix containing large blocks exclusively of pitchstone ≤ 83x17 cm.

Matrix supported mBr, matrix is approximately 20%, contains outsized blocks of mLTacc ≤12x12cm, sub rounded amygdaloidal basalt ≤8x5 cm and angular pitchstone ≤1.5x1cm maximum diameter.

Matrix supported mLT with approximately 80% matrix, poorly developed cooling joints throughout unit, contains 5% outsized blocks of amygdaloidal basalt ≤17x7cm. Lithic lapilli include sub angular arkosic sandstone ≤5x3 cm and sub rounded basalt ≤6x4 cm maximum.

Matrix supported mLT, matrix is approximately 20%, unit contains outsized blocks of sub angular amygdaloidal basalt ≤17x14cm, majority of clasts are arkosic lapilli ≤ 5cm x 3.5cm. Fabric is locally weakly deformed around lithics.

mLT ~50% mid grey, fine grained, matrix containing lapilli of angular mLTe≤ 8x5cm,angular quartzite ≤4.5x 3.7cm, and sub-rounded arkosic sandstone ≤7x6 cm.

Clast supported mLT, max lithic size 10x6 cm, most are angular rhyolite lapilli <4x3cm .

Matrix supported mLT ~40%, fine grained, green matrix. Lapilli of sub rounded arkosic sandstone ≤5x3cm. Outcrop is pervasively net veined and brecciated

Clast supported breccia containing outsized,sub rounded basaltic blocks, ≤38x18cm, also angular quartzite ≤ 7x4cm and angular mLTe ≤5x4cm. In places the matrix has a laterally discontinuous, weak, planar fabric.

Sharp contact with matrix supported mBr. Matrix comprises ~80%, is fine grained and contains angular blocks of mLT ≤36x26 cm, sub rounded mLT ≤13x7 cm, and sub rounded arkosic sandstone ≤9x6 cm.

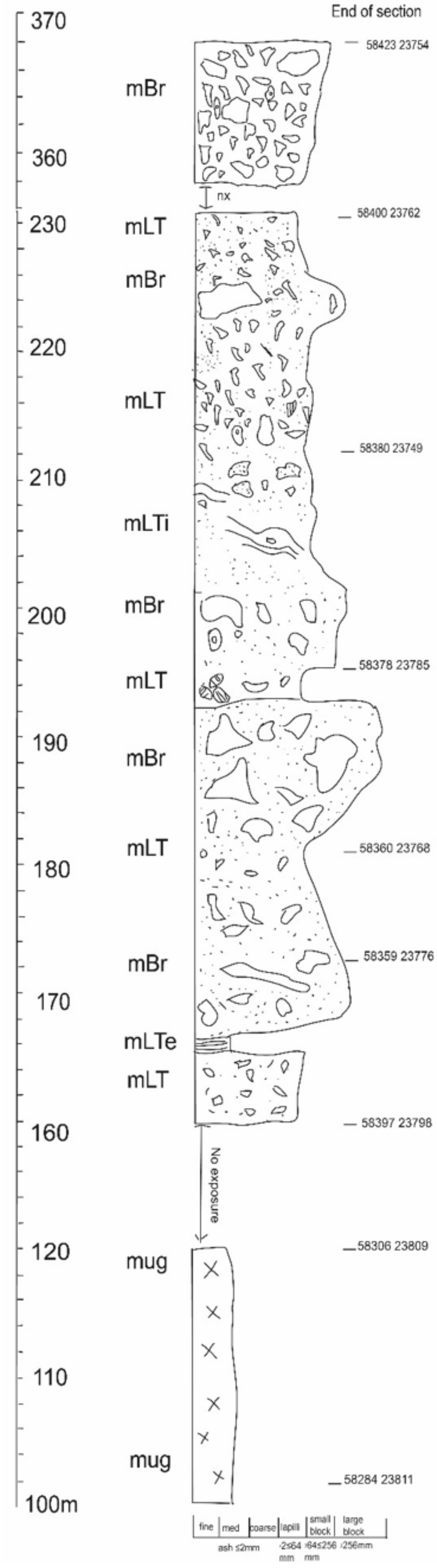
Matrix supported mLTe with >90% matrix. Unit has a sporadic pervasive fabric deformed around angular rhyolite lapilli ≤1cm x 8mm.

mLTacc, very fine grained, matrix supported ~95%, lapilli of angular arkosic sandstone ≤ 5x3cm, sub rounded quartzite <3cm x 1cm. Accretionary lapilli ≤12mm and sub rounded to oblate.

Matrix supported mLT, matrix approx 60%, dark grey, fine grained. Contains blocks of breccia ≤11x10cm, sub angular quartzite ≤8x6cm, and approximately 5% outsized blocks of mLTe ≤28x10cm. In places an insipid fabric is deflected around clasts.

Height

Log 15; 58107 23851- 58423 23754, sheet 2



Notes

granite contact approx 100m away on bearing 150

Clast supported mBr with sporadic lithophysae evident. Blocks of angular porphyritic basalt, quartzite, and basaltic scoria, ≤ 38x20cm. Weakly defined cooling joints spaced approximately 50-70cm apart, and plunging 52→262. Arkosic sandstone blocks are only evident in last 40 m of the section.

Matrix supported mLT, matrix ~65%, dark grey and glassy cooling joints 04→264 pervasive spaced 5-15cms apart. Blocks and lapilli of sub rounded and sub angular porphyritic basalt, arkosic sandstone, mLTe and aphanitic basalt 7x6 cm.

Matrix supported mBr, matrix ~ 60%, pale grey. Outsized sub rounded blocks of arkosic sandstone blocks ≤40x30cm. The majority of blocks are ≤15 x 6 cm.

Matrix supported mLT ~ 70% matrix, fine grained, mid grey. Lithophysae in matrix are ellipsoid ≤ 8x4cm. Lapilli of amygdaloidal basalt ≤4x3cm, angular lapilli of stratified tuff ≤5x4cm.

Matrix supported mLTi ~ 80% matrix. Lapilli of sub angular quartzite ≤3x2cm. Insipid fabric in matrix deformed around clasts. Fabric may be locally pronounced almost eutaxitic.

Matrix supported mBr, clasts form approximately 40% and are dominantly sub rounded basaltic blocks ≤26 x19 cm. Lithophysae in unit are sub rounded ≤4x3 cm. Cooling joints pervade unit and are sub vertical and spaced ≤ 5cm and plunge 76→ 240.

mLT 90% matrix rich with a black, fine grained matrix. Unit has an erosive base. Concentric lapilli of mLTe ≤1.5cm diameter. Evidence of thermal spalling during transportation.

mBr matrix supported, ~50%, pale grey matrix. Matrix contains blocks of amorphous amygdaloidal basalt ≤33x12cm, angular amygdaloidal basalt ≤30x17cm and very fine grained, angular basalt ≤4x3cm ,towards base of unit.

Matrix supported mLT, matrix fine grained, grey approx 80%. Lapilli of both angular quartzite and sub rounded mLTe ≤2x1cm.

Matrix supported mBr, approx 40% blocks of angular quartzite ≤6x8cm, sub rounded amygdaloidal basalt ≤14x9 cm, and angular mLTe ≤2x1cm. Indistinct columnar cooling joints at outcrop, spaced approximately 60cm-1.1m apart, and plunging at 42 →044.

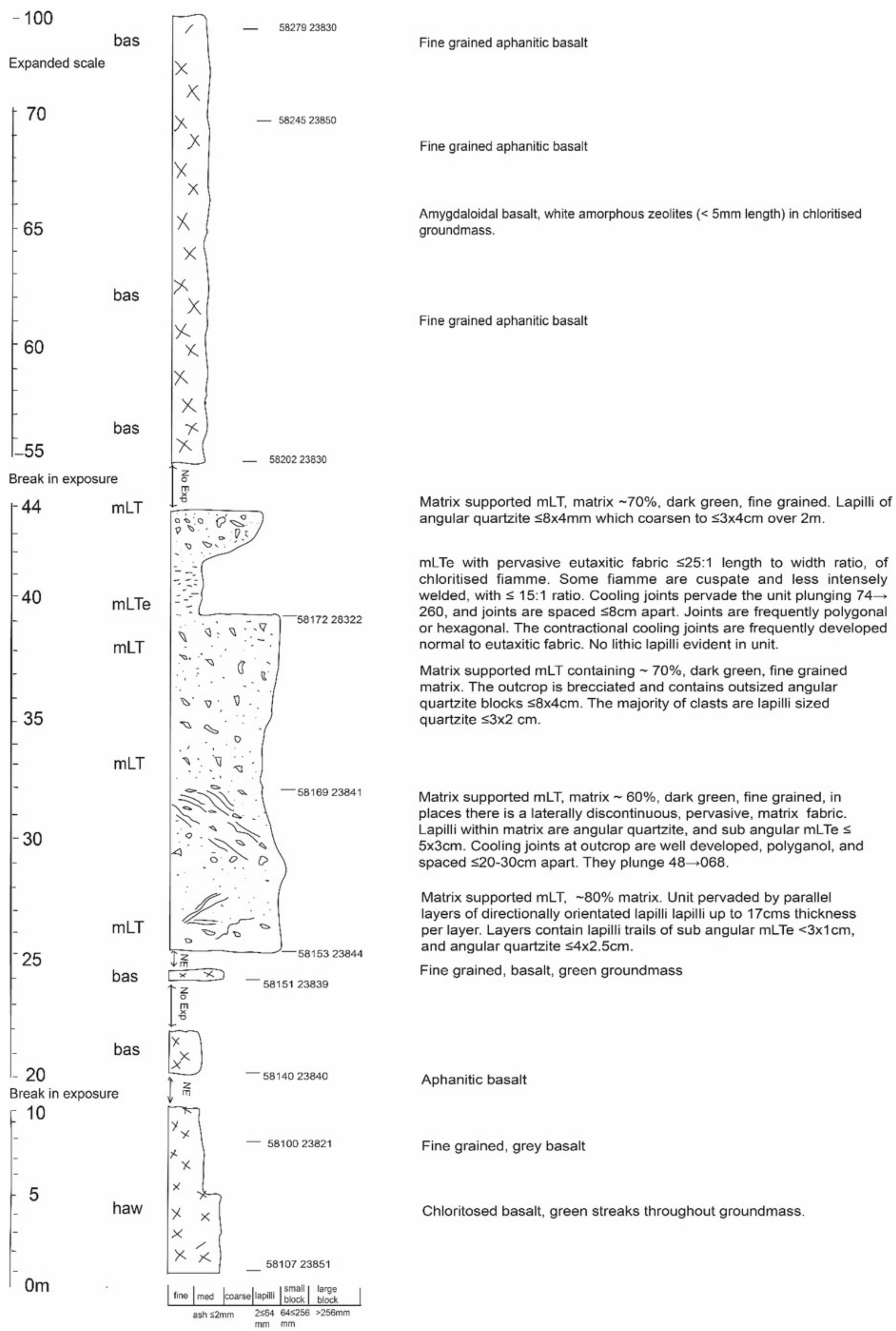
Fine grained mLTe with laminated matrix >90%. Sporadic angular quartzite lapilli ≤ 8x4mm. Sharp contact with underlying mLT

Matrix supported mLT, fine grained ~ 60%, grey, matrix. Lithics of angular quartzite ≤ 6x4 cm.

Pipe amygdales ≤ 1.2cm length by 14 mm stem , indicate flow direction → 050-060

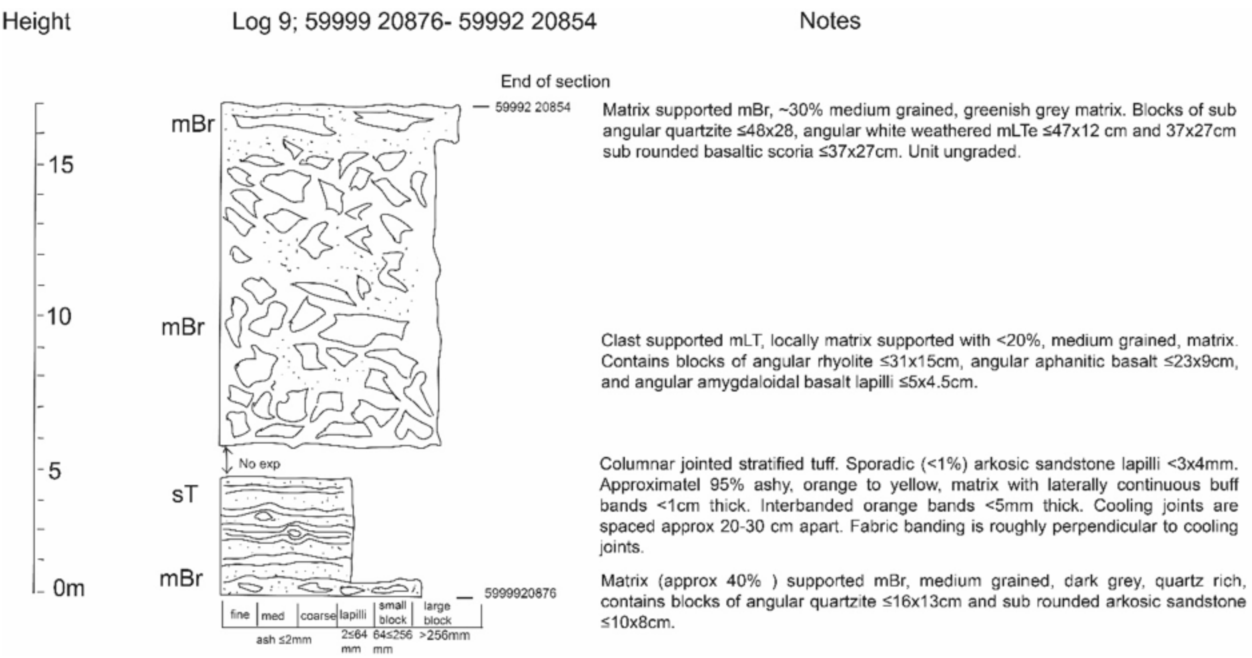
Amygdaloidal Mugearites ,amygdales are sub circular ≤ 1cm diameter.

Log 15: 58107 23851- 58279 23830 Sheet 1

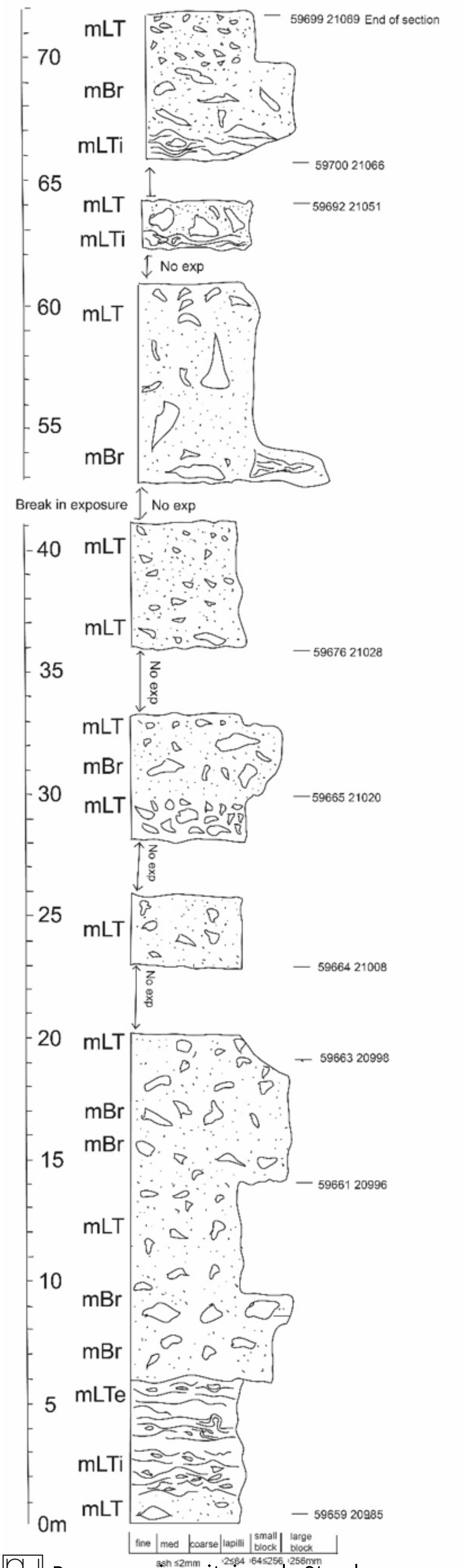


4 Logs B

Kilchrist logs 9–14 and 16–18 South of Beinn na Caillich Centre



Height Log 10; 59659 20985-59669 21067



Notes

Matrix supported mLT ~50%, fine grained matrix. Lithics of angular quartzite <1.5x1cm. Pervasive cooling joints spaced approx 3-7cm.

Matrix supported mLTi ~70% green, fine grained, and glassy locally. Sporadic outsized blocks of angular quartzite ≤19x9cm . Fabric in matrix deformed around lapilli, majority are quartzite and arkose <2x1.5 cm.

Matrix supported mLT ~60% matrix light grey, very fine grained. Outsized blocks of sub rounded rhyolite ≤39x40cm, average clast size ≤7x5 cm, of sub angular mLTe, and sub rounded amygdaloidal basalt. Unit partially welded at base.

Matrix supported mLT, clasts approx 30%, matrix medium grey. Dominant lithic lapilli type is angular quartzite <3.5x2cm.

Matrix supported mBr approx 20% blocks. Outsized angular blocks of mLT, lava like ≤65 x 8cm and amygdaloidal basalt ≤27x21cm. Sporadic cooling joints at outcrop spaced 2-3 cm apart. Cooling joints are evident where lapilli <1.6x1cm. The majority of clasts are block size ≤ 9x6cm.

Matrix supported mLT >90% matrix. Lapilli of angular quartzite and rhyolite ≤ 2x1cm.

Normally graded matrix supported mLT. Lapilli of angular quartzite, mLTe, and sub rounded arkosic sandstone maximum lithic size <6x5 cm. Majority are ≤ 2x1 cm.

Matrix supported (~70%) mLT, matrix is fine grained, lime green. Cooling joints throughout unit are spaced 20-30 cm. Angular quartzite and sub rounded arkosic sandstone ≤6x5 cm. Sporadic quartzite blocks ≤16x8 cm.

Matrix supported mLT ~70%, very fine grained matrix, contains lithics of sub angular quartzite ≤8x6 cm. Majority are lapilli size <1cm x 5mm.

Matrix supported mBr ~ 60%, fine grained, matrix which contains clasts of sub rounded arkosic sandstone ≤20x16cm, and sub angular quartzite <13x8cm. Poorly developed cooling joints throughout unit.

Clast supported mLT, containing outsized blocks of angular rhyolite ≤10x8cm. Majority of lithics (≥80%) are ≤3x2cm and comprise angular quartzite, basalt, and amygdaloidal basalt. Outcrop brecciated and contains cooling joints 20-30cm apart.

Matrix supported ungraded mLT ~ 80%, matrix fine grained, lithic lapilli not evident, cooling joints throughout unit. Joints spaced approximately every 2-5cm. Weathered out recesses of former lapilli (pumices?) approximate to 20% of outcrop. Maximum recess size ≤5x4cm and are sub rounded. The average recess size is <1cmx 3 mm.

Matrix supported mLT matrix ~ 70%, fine grained, dark green matrix. Bi-modal clast size approx 20% of blocks >12x9cm including angular quartzite, whilst 80% of lithics <5x3 cm, angular to sub angular quartzite lapilli.

mBr ~90% matrix supported, coarse grained, grey containing outsized blocks of sub angular quartzite ≤17x10cm and sub angular amygdaloidal basalt lapilli ≤ 3x4cm. Poory developed, sub vertical ontractional cooling joints at outcrop spaced 10-15cm apart.

Matrix supported ungraded mLT, matrix ~90%, fine grained, grey. Lapilli of sub angular quartzite and sub rounded arkosic sandstone ≤4x2cm, most are in size fraction ≤3x2cm.

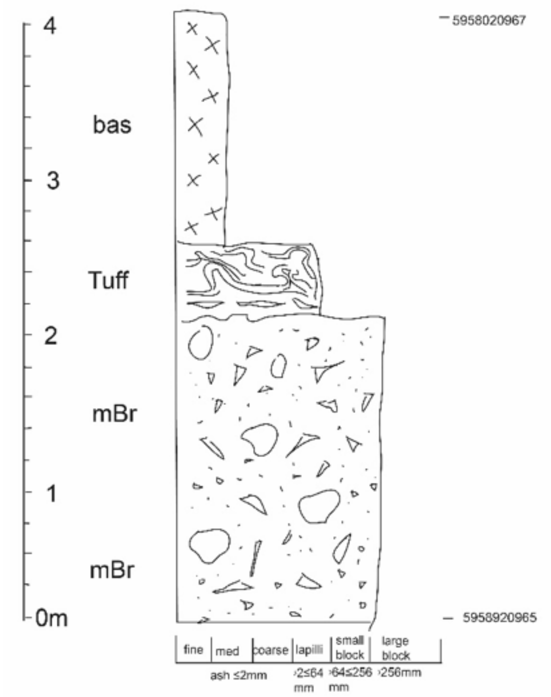
Reverse graded matrix supported mBr, Matrix ~80% is fine grained, grey. Blocks of angular quartzite ≤15x23cm. Unit cut by sub vertical cooling joints spaced 25-35 cm apart.

mLTe ~80% matrix, fine grained, grey. Matrix has pervasive intense welded fabric containing micro ptygmatic folds. Lapilli of sub rounded and sub angular quartzite and arkosic sandstone ≤5x2 mm. Evidence of lapilli rotation.

Matrix supported mLT, ~30% sub rounded to sub angular basaltic lapilli <5x3mm. Laterally discontinous sub parallel fiamme matrix trails are spaced 3-4mm vertically. Lapilli of sub angular quartzite ≤3x2cm.

Matrix supported mLT ~80% fine grained grey matrix. Lithics of angular mLTe ≤ 1cm x 5mm. Outsized sporadic blocks of sub rounded mLTe ≤10x5 cm.

Height | Log 11; 59589 20965- 59580 20967 | Notes



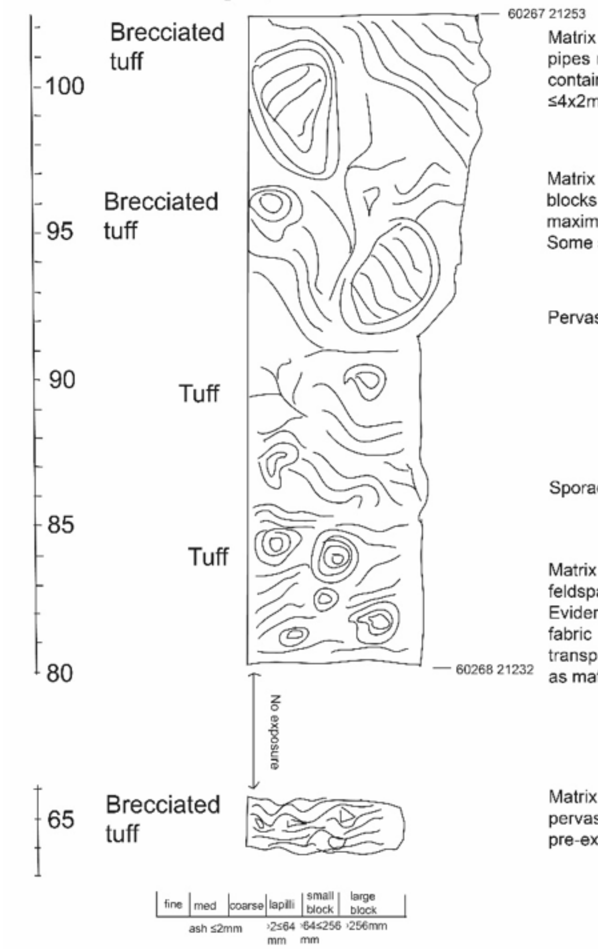
End of section no exposure

Dark grey, aphanitic basaltic dyke, trending 348˚.

Highly vesiculated tuff ≥90% white, very fine grained matrix, aligned quartz streaked crytstals ≤6x1mm, unresolved angular black lithics ≤3x2 mm. Intense refolded folds in fabric on scale (≤ 5mm amplitude). Fold type, closed, intrafolial, recumbant, ptygmatic and sheath on cm scale. Cooling joints pervasive throughout unit. Average spacing of sub vertical cooling joints is 15-30 cm. Chilled margin in overlying basalt at contact with tuff.

Matrix supported mBr, matrix ~ 50% very fine grained, green, containing angular pitchstone fragment ≤2x1mm. Blocks of sub rounded arkosic sandstone ≤15x12cm and angular quartzite ≤5x4mm.

Height | Log 12; 60344 21188- 60267 21253 | Notes



Matrix supported brecciated tuff ~80% matrix cut by sub vertical elutriation pipes. Within pipes randomly orientated quartz and black lithics <3x2mm. Pipes are free of fines and contain sub spherical quartz crystals <2mm diameter, and ellipsoidal chloritised pumice ≤4x2mm. Blocks within matrix are tuff ≤ 45x28cm.

Matrix supported brecciated tuff ~70%, mid grey, medium grained, matrix. Containing blocks of sub rounded tuff and sub angular mLTe. Blocks are reverse graded to a maximum size of 35x16cm. Blocks are mantled by intensely deformed fabric in matrix. Some smaller blocks (≤ 8x6 cm) are faceted.

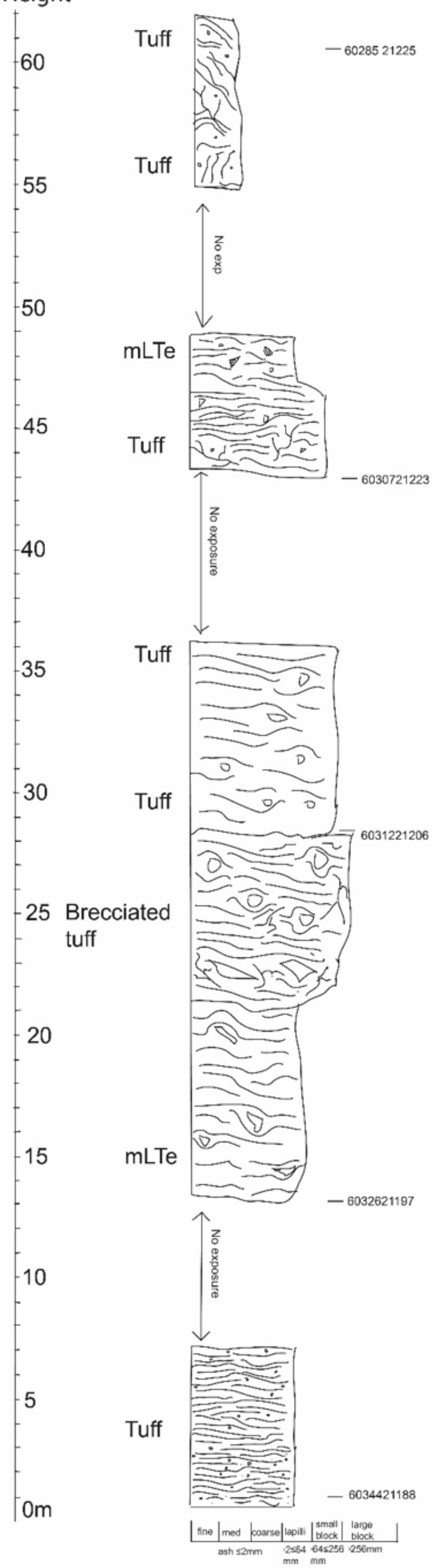
Pervasive planar fabric within tuff orientated approximately normal to cooling joints

Sporadic sub circular lithophysae ≤5x4cm

Matrix supported brecciated lapilli tuff matrix ~90% medium grained, mid grey, quartz and feldspar rich. Lithics of sub rounded mLTe ≤8x6cm, majority of lithics are ≤ 5x3cm. Evidence on weathered outcrop surfaces of weathering in of former pumices?. Intense fabric is deformed around enclosed clasts indicating that clasts have rotated during transportation. Clasts are less competent than matrix and are weathered in, blocks same as matrix.

Matrix supported brecciated tuff, blocks ~20% are sub angular mLTe ≤10x6 cm. A pervasive fabric is deformed around existing blocks and weathered out recesses of pre-existing blocks.

Log 12 Sheet 1 NG 6034421188 - NG60285 21225



Matrix supported ~40% matrix. Matrix contains ≤3x1mm lath like feldspars and <1mm sub spherical quartz crystals, intensely altered (hydrothermally?). Hand specimen green/purple colour and highly friable.

Matrix supported ~90%, high ash content, friable matrix, contains spherules of quartz <1mm diameter, randomly orientated purple veins throughout unit, and sub vertical elutriation pipes. Outcrop weathers orange/buff.

Matrix supported mLTe, clasts of mLTe approx 10% ≤4x3 cm, both sub angular and sub rounded. Clasts are mLTe and possess a strong eutaxitic fabric with a different orientation to pervasive eutaxitic matrix fabric. Clasts are highly friable, soft and are very similar to matrix. Weakly defined cooling joints orientated at a high angle to eutaxitic fabric.

Matrix supported < 5% lithics ≤7.5 x 5cm, sub angular quartzite and ≤5 x 3 cm sub angular arkosic sandstone. Cream coloured fine grained, matrix ~90%, contains sub rounded quartz crystals <1cm, unresolved tabular black crystals ≤8x3 mm orientated parallel to intensely stratified fabric.

Cooling joints 85→084 becoming laterally discontinuous.

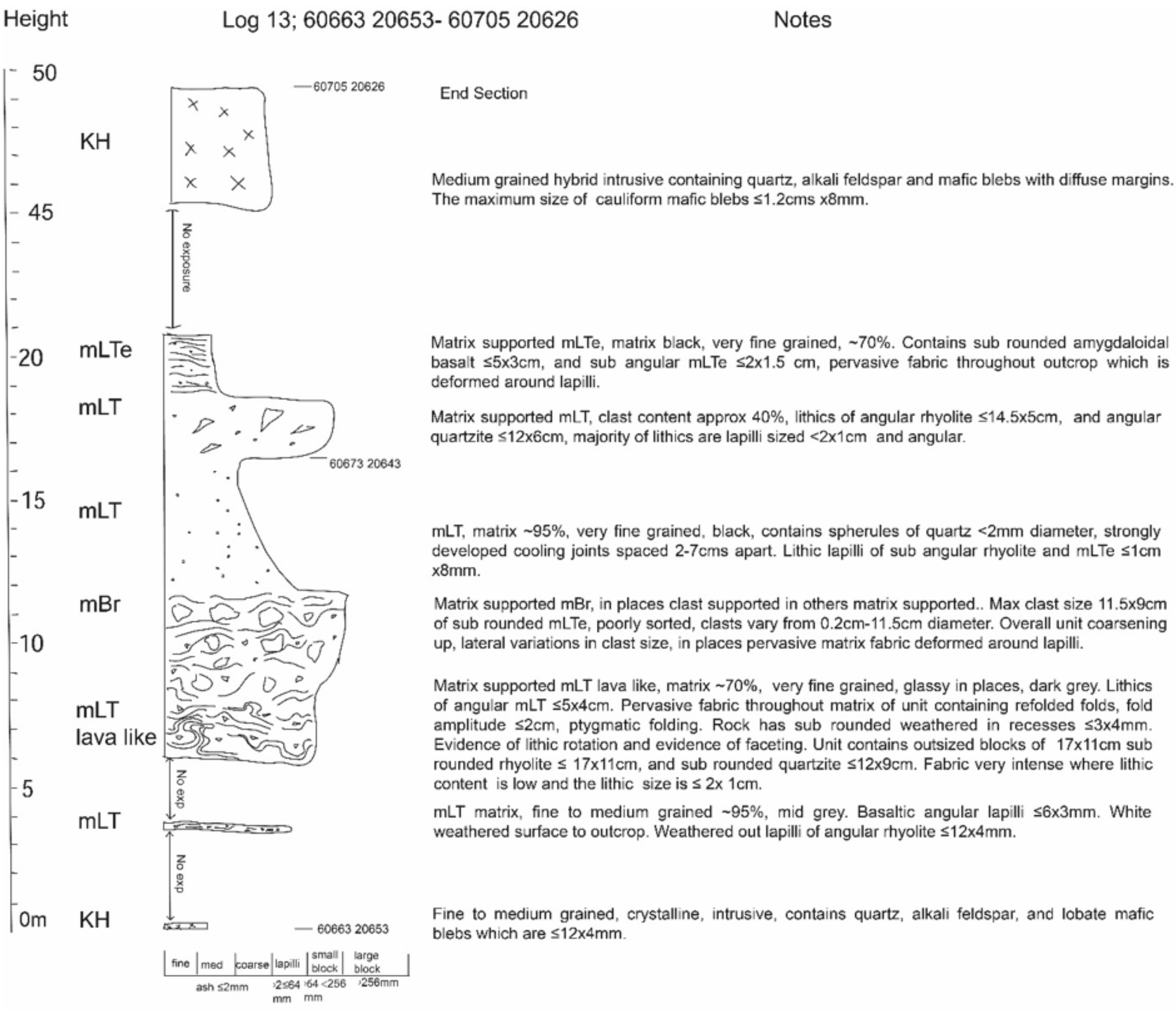
Highly friable with approx 95% matrix. Undulatory, erosive base to unit. Sporadic outsized highly angular quartzite blocks ≤15 x 3cm are orientated parallel to intense welded fabric, which itself is deformed around blocks. The matrix contains ~ 50% chloritised pumice clasts ≤8 x4 mm and randomly orientated purple veins pervade unit. Columnar jointing is orientated parallel to some veins.

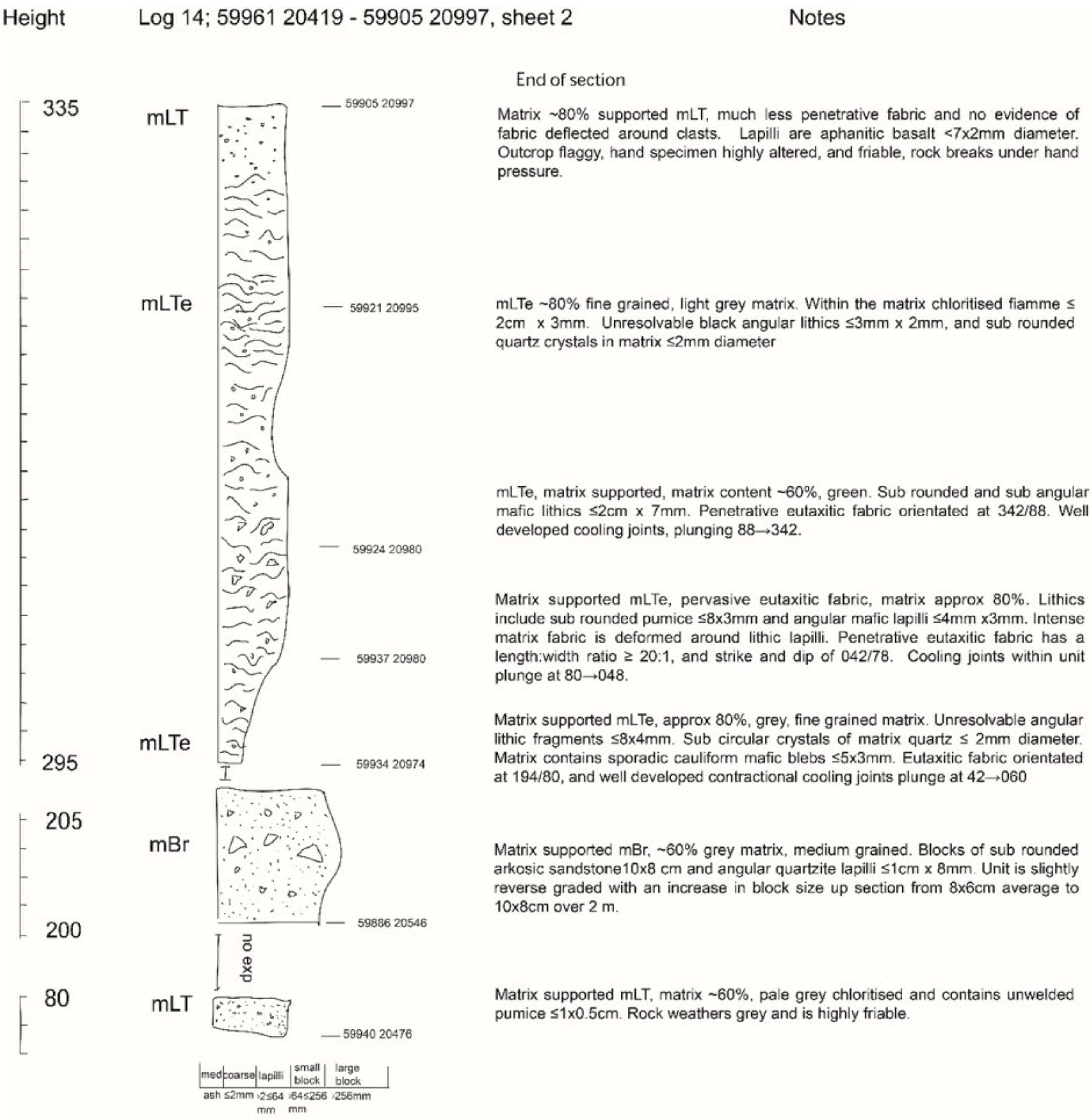
Matrix supported brecciated tuff approx 95% matrix, Fabric deflected around blocks. Prominant cooling joints at outcrop spaced 15-30 cms apart.

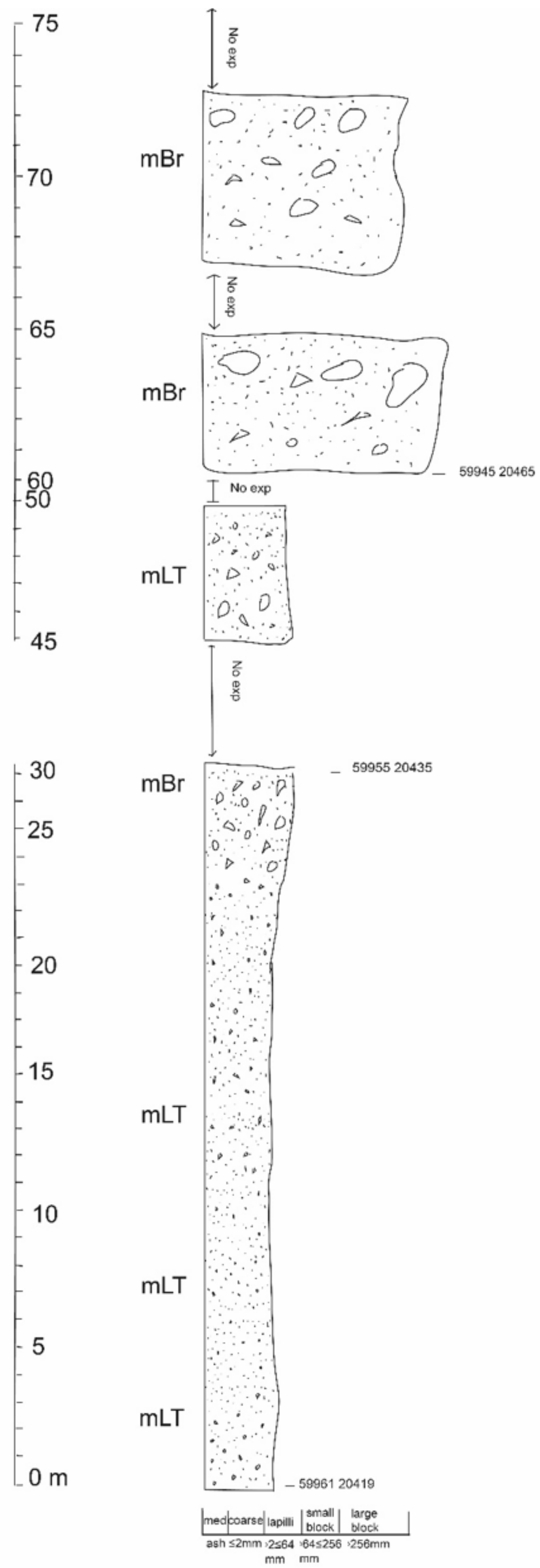
Erosive base cutting down into underlying mLTe

Matrix supported mLTe, matrix approx 90%. Matrix has intense fabric, containing sporadic sub angular quartzite lithic lapilli ≤5.3x 2.2cm. Fabric is deformed around lithic lapilli.

Matrix ~ 60% medium grained, cream coloured, ash rich. The matrix contains weathered orange sub rounded pumice ≤3x4 mm, and sub circular quartz crystals <1mm diameter. Randomly orientated purple elutrutriaton pipes contain angular quartz lithics ≤2x1mm and no fines. A pervasive matrix fabric is not deformed around lithics. Outcrop weathers to a white colour. Outcrop is cut by intense cooling joints spaced 15-20cm apart throughout.


Height
Log 13; 60663 20653- 60705 20626
Notes
50
45
20
15
10
5
0m
KH
mLTe
mLT
mLT
mBr
mLT
lava like
mLT
KH
60705 20626
No exposure
60673 20643
No exp
No exp
60663 20653
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
›2≤64 mm
›64 <256 mm
›256mm
End Section
Medium grained hybrid intrusive containing quartz, alkali feldspar and mafic blebs with diffuse margins. The maximum size of cauliform mafic blebs ≤1.2cms x8mm.
Matrix supported mLTe, matrix black, very fine grained, ~70%. Contains sub rounded amygdaloidal basalt ≤5x3cm, and sub angular mLTe ≤2x1.5 cm, pervasive fabric throughout outcrop which is deformed around lapilli.
Matrix supported mLT, clast content approx 40%, lithics of angular rhyolite ≤14.5x5cm, and angular quartzite ≤12x6cm, majority of lithics are lapilli sized <2x1cm and angular.
mLT, matrix ~95%, very fine grained, black, contains spherules of quartz <2mm diameter, strongly developed cooling joints spaced 2-7cms apart. Lithic lapilli of sub angular rhyolite and mLTe ≤1cm x8mm.
Matrix supported mBr, in places clast supported in others matrix supported.. Max clast size 11.5x9cm of sub rounded mLTe, poorly sorted, clasts vary from 0.2cm-11.5cm diameter. Overall unit coarsening up, lateral variations in clast size, in places pervasive matrix fabric deformed around lapilli.
Matrix supported mLT lava like, matrix ~70%, very fine grained, glassy in places, dark grey. Lithics of angular mLT ≤5x4cm. Pervasive fabric throughout matrix of unit containing refolded folds, fold amplitude ≤2cm, ptygmatic folding. Rock has sub rounded weathered in recesses ≤3x4mm. Evidence of lithic rotation and evidence of faceting. Unit contains outsized blocks of 17x11cm sub rounded rhyolite ≤ 17x11cm, and sub rounded quartzite ≤12x9cm. Fabric very intense where lithic content is low and the lithic size is ≤ 2x 1cm.
mLT matrix, fine to medium grained ~95%, mid grey. Basaltic angular lapilli ≤6x3mm. White weathered surface to outcrop. Weathered out lapilli of angular rhyolite ≤12x4mm.
Fine to medium grained, crystalline, intrusive, contains quartz, alkali feldspar, and lobate mafic blebs which are ≤12x4mm.


Height
Log 14; 59961 20419 - 59905 20997, sheet 2
Notes
End of section
335
mLT
59905 20997
Matrix ~80% supported mLT, much less penetrative fabric and no evidence of fabric deflected around clasts. Lapilli are aphanitic basalt <7x2mm diameter. Outcrop flaggy, hand specimen highly altered, and friable, rock breaks under hand pressure.
mLTe
59921 20995
mLTe ~80% fine grained, light grey matrix. Within the matrix chloritised fiamme ≤ 2cm x 3mm. Unresolvable black angular lithics ≤3mm x 2mm, and sub rounded quartz crystals in matrix ≤2mm diameter
mLTe, matrix supported, matrix content ~60%, green. Sub rounded and sub angular mafic lithics ≤2cm x 7mm. Penetrative eutaxitic fabric orientated at 342/88. Well developed cooling joints, plunging 88→342.
59924 20980
Matrix supported mLTe, pervasive eutaxitic fabric, matrix approx 80%. Lithics include sub rounded pumice ≤8x3mm and angular mafic lapilli ≤4mm x3mm. Intense matrix fabric is deformed around lithic lapilli. Penetrative eutaxitic fabric has a length:width ratio ≥ 20:1, and strike and dip of 042/78. Cooling joints within unit plunge at 80→048.
59937 20980
Matrix supported mLTe, approx 80%, grey, fine grained matrix. Unresolvable angular lithic fragments ≤8x4mm. Sub circular crystals of matrix quartz ≤ 2mm diameter. Matrix contains sporadic cauliform mafic blebs ≤5x3mm. Eutaxitic fabric orientated at 194/80, and well developed contractional cooling joints plunge at 42→060
mLTe
295
59934 20974
205
mBr
Matrix supported mBr, ~60% grey matrix, medium grained. Blocks of sub rounded arkosic sandstone10x8 cm and angular quartzite lapilli ≤1cm x 8mm. Unit is slightly reverse graded with an increase in block size up section from 8x6cm average to 10x8cm over 2 m.
200
59886 20546
no exp
80
mLT
Matrix supported mLT, matrix ~60%, pale grey chloritised and contains unwelded pumice ≤1x0.5cm. Rock weathers grey and is highly friable.
59940 20476
med ash ≤2mm
coarse
lapilli ›2≤64 mm
small block ›64≤256 mm
large block ›256mm



mBr breccia, matrix content 60%, medium grained, dark grey. Blocks of arkosic sandstone and laminated arkosic sandstone. Both varieties are sub rounded ≤ 5x9cm diameter.

Matrix supported mBr, matrix content approximately 70%, medium grained, grey. Contains blocks of sub angular amygdaloidal basalt ≤3x2 cm, and arkosic sandstone blocks ≤15 x 9cm diameter in top 20cm of unit. Reverse graded.

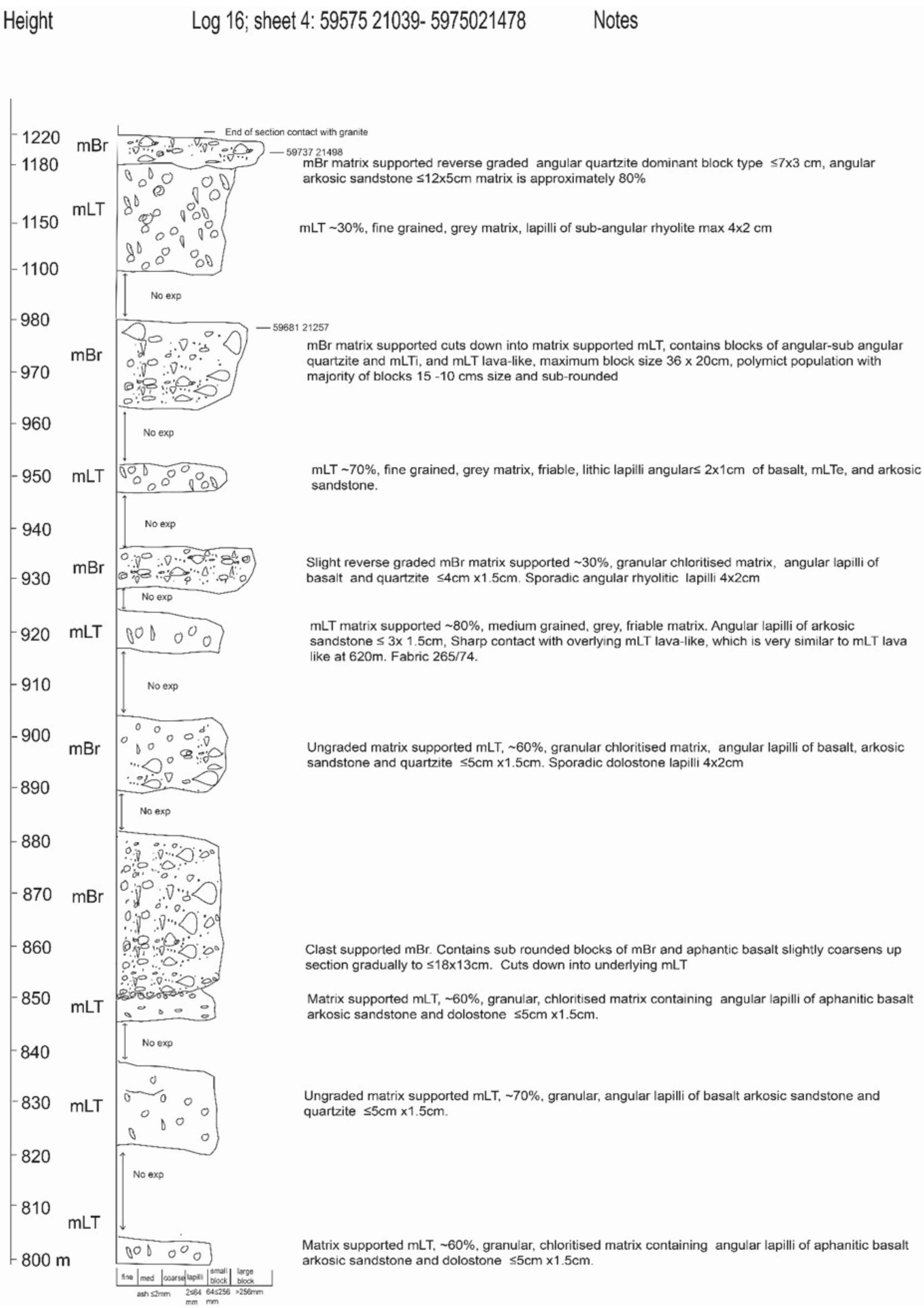
Matrix supported mLT, ~ 70 %, fine grained, grey matrix. Clast population in two size fractions ≤10x8cm arkosic sandstone and aphanitic basalt (majority are ≤1cm x 8mm).

Matrix supported mBr coarsening up, reduced matrix content to ~ 50%. Contains sub rounded blocks of porphyritic basalt ≤12x9 cm,and sub rounded arkosic sandstone ≤10x8cm.

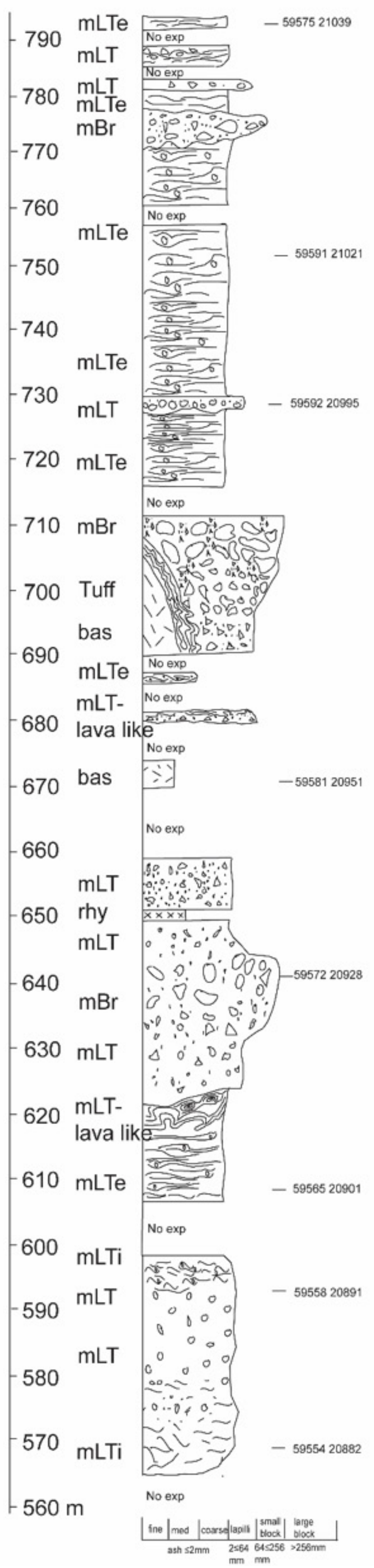
Matrix supported mLT, ~ 70%, fine to medium grained, grey, containing lithics of angular arkosic sandstone ≤1.2 cm x 8mm.

Matrix supported mLT, fining slightly, increased matrix content to 85%. Lapilli of sub angular arkosic sandstone ≤1cm x 8mm.

Matrix supported mLT~ 80%, medium grained, grey, matrix. Contains lithic lapilli of angular arkosic sandstone ≤3cm x4mm diameter.


Height
Log 16; sheet 4: 59575 21039- 5975021478
Notes
1220
1180
1150
1100
980
970
960
950
940
930
920
910
900
890
880
870
860
850
840
830
820
810
800 m
mBr
mLT
mBr
mLT
mBr
mLT
mBr
mBr
mLT
mLT
mLT
End of section contact with granite
59737 21498
mBr matrix supported reverse graded angular quartzite dominant block type ≤7x3 cm, angular arkosic sandstone ≤12x5cm matrix is approximately 80%
mLT ~30%, fine grained, grey matrix, lapilli of sub-angular rhyolite max 4x2 cm
No exp
59681 21257
mBr matrix supported cuts down into matrix supported mLT, contains blocks of angular-sub angular quartzite and mLTi, and mLT lava-like, maximum block size 36 x 20cm, polymict population with majority of blocks 15 -10 cms size and sub-rounded
No exp
mLT ~70%, fine grained, grey matrix, friable, lithic lapilli angular≤ 2x1cm of basalt, mLTe, and arkosic sandstone.
No exp
Slight reverse graded mBr matrix supported ~30%, granular chloritised matrix, angular lapilli of basalt and quartzite ≤4cm x1.5cm. Sporadic angular rhyolitic lapilli 4x2cm
No exp
mLT matrix supported ~80%, medium grained, grey, friable matrix. Angular lapilli of arkosic sandstone ≤ 3x 1.5cm, Sharp contact with overlying mLT lava-like, which is very similar to mLT lava like at 620m. Fabric 265/74.
No exp
Ungraded matrix supported mLT, ~60%, granular chloritised matrix, angular lapilli of basalt, arkosic sandstone and quartzite ≤5cm x1.5cm. Sporadic dolostone lapilli 4x2cm
No exp
Clast supported mBr. Contains sub rounded blocks of mBr and aphantic basalt slightly coarsens up section gradually to ≤18x13cm. Cuts down into underlying mLT
Matrix supported mLT, ~60%, granular, chloritised matrix containing angular lapilli of aphanitic basalt arkosic sandstone and dolostone ≤5cm x1.5cm.
No exp
Ungraded matrix supported mLT, ~70%, granular, angular lapilli of basalt arkosic sandstone and quartzite ≤5cm x1.5cm.
No exp
Matrix supported mLT, ~60%, granular, chloritised matrix containing angular lapilli of aphanitic basalt arkosic sandstone and dolostone ≤5cm x1.5cm.
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
2≤64 mm
64≤256 mm
>256mm

Height Log 16; sheet 3 59554 20882 -59575 21039 Notes



Matrix supported mLTe ≥80 %, fine grained,mid grey matrix, chloritised fiamme length; width ratio ≥ 30:1, sporadic mafic blebs ≤1cm x 8mm, Sub rounded quartz crystals ≤2mm diameter.

mLT ~70%, fine grained, grey matrix, friable, lithic lapilli angular≤ 2x1cm of basalt, mLTe, and arkosic sandstone.

Clast supported mBr. Contains sub rounded blocks of mBr and aphantic basalt coarsen up section gradually to ≤18x13cms.

Matrix supported mLTe, ≥80 % , very fine grained, grey, matrix containing chloritised fiamme with a length: width ratio ≥25:1. Sporadic mafic blebs ≤8mm across together with angular mafic lapilli ≤8x3mm and sporadic arkosic sandstone.

mLTe matrix supported, ≥80 %, fine grained, mid grey matrix containing chloritised fiamme with length; width ratio ≥30:1. Fabric in matrix 342/85. Exposure cut by sheet like fractures. Sporadic matrix mafic blebs and common sub-rounded quartz crystals ≤2mm. Slight increase in welding intensity up section from 735-750m. Cooling joints are poorly developed and plunge 20→035.

Matrix supported mLT~60%, fine grained matrix which contains angular lapilli of aphanitic basalt and mLTi ≤ 4 x 1.5cm. Ungraded and no fabric evident

Matrix supported mLTe, ≥90% fine grained, grey matrix containing chloritised fiamme with length: width ratio ≥30:1. Matrix contains sporadic, lobate, mafic blebs ≤1.5cm x6mm. Poorly developed columnar cooling joints which plunge 3→058.

Sharp contact with matrix supported mBr. Matrix grey, granular and friable.Contains blocks of arkosic sandstone, aphanitic basalt and mLTi that coarsen from 7cm to ≤19x15cms from 700-710m.

Tuff, matrix ≥ 90%, white, intensely deformed into microfolds. Sheath folds on rock surface are sporadic and elliptical ≤4x1cm. Matrix fabric is deformed around sheathfolds. Sporadic mafic angular lapilli ≤5x2mm in matrix. Evidence of loading with overlying mBr as some tuff is present as flame like structures ≤10cm in the base of the overlying mBr.

Aphanitic basalt dyke, trend 320º.

Matrix supported mLTe ≥90%, fine grained, grey matrix containing chloritised fiamme length: width ratio ≥30:1, and fabric trend 238/68 . Mafic blebs <2x1mm, sporadic.

mLT matrix supported ~80%, medium grained, grey, friable matrix. Angular lapilli of arkosic sandstone ≤ 3x 1.5cm, Sharp contact with overlying mLT lava-like, which is very similar to mLT lava like at 620m.

Aphanitic basalt dyke, trend 320º, no contact relationships.

Matrix supported mLT,~60% fine to medim grained, friable, matrix. Contains angular aphanitic basalt and mLTi lapilli ≤ 2.5 x 1cm. Ungraded and no matrix fabric evident.

Silicic dyke 30 cm thick, orange, trend →276˚

Matrix supported mLT, ~80%, medium grained, green, friable, normally graded matrix. Contains angular mLTi and basalt lapilli ≤ 2cm x 8mm.

Clast supported mBr with rounded blocks of arkosic sandstone and aphantic basalt ≤ 15x10cm.

Matrix supported mLT, ~80%, granular, chloritised matrix containing angular lapilli of aphanitic basalt and arkosic sandstone ≤3cm x1.5cm. Sporadic mafic clots with lobate margins comprise ≤2% of matrix. Contact with underlying mLTlava like is sharp and undulatory.

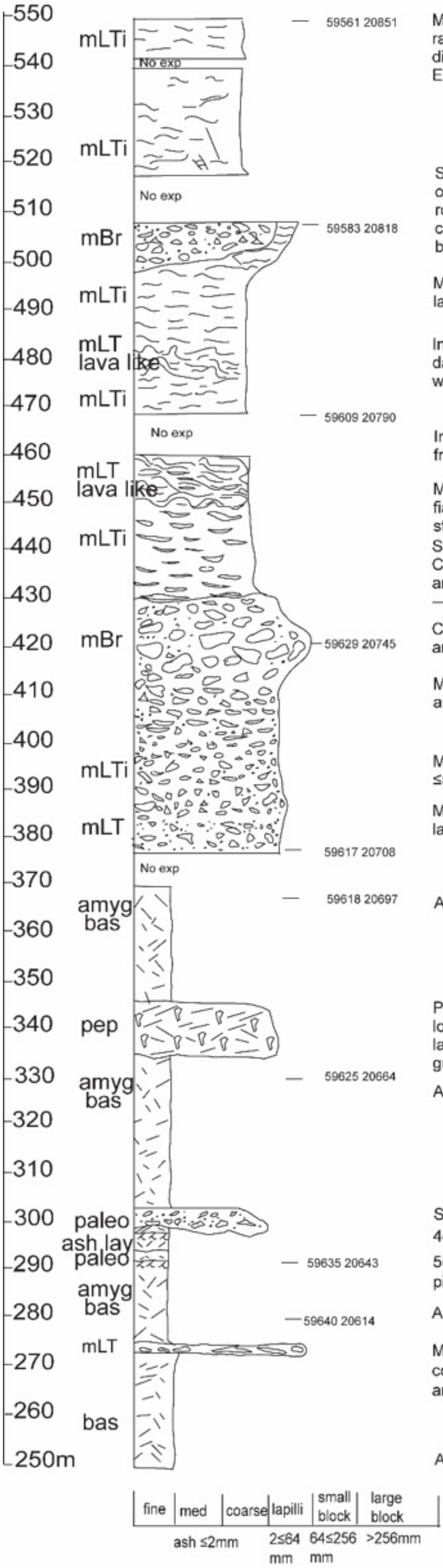
mLT lava like, matrix ≥90%, fine grained, intensely welded domains of lilac and grey laterally discontinuous layers. Matrix strongly deformed around sporadic sub rounded, matrix pumice ≤ 1.5cm x 8mm. Pytgmatic and tight folds with fold wavelength of ≤5cm. Laterally discontinuous planar fabric, frequently changes to intensely folded over a distance of < 0.5m.

Matrix supported mLTe, ≥90%, fine grained, grey matrix containing chloritised fiamme with a length; width ratio of ≥30:1. Sporadic swallow tailed fiamme ≤4cm x 8mm and aphanitic basalt lapilli ≤8mm x 4mm. Fabric deformed strongly around lapilli. Fabric largely planar and orientated 082/52.

Matrix supported mLTi, glassy, mid-grey ≥80% matrix containing chloritised fiamme (length : width ratio ~10:1). Lapilli of basalt ≤1.2 cmx5mm and quartzite ≤8mmx4mm. Rock incompetent intensely altered.

Matrix supported mLT, ~ 60% granular, grey matrix. Angular to sub angular aphanitic basalt, mLTi and arkosic sandstone ≤5x4 cm. Towards top of unit sporadic chloritised mafic blebs evident in matrix, ≤ 1.5cm x 6mm with lobate margins.

Matrix supported, mLTi,~ 80% matrix containing chloritised fiamme with a length : width ratio ~10:1. Matrix contains angular lapilli of aphanitic basalt ≤1cm x 5mm. Unit cut by sub horizontal sheets trending 040/70 and ≤ 10cm thick.



Matrix supported mLTi, matrix ~ 60%, contains insipient streaked chloritised pumice ≤5:1 length : width ratio. Angular lithic lapilli of amygdaloidal basalt ≤ 8mmx 6mm, sub rounded quartz crystals ≤2mm diameter, and ubiquitous mafic blebs ≤1cm x 1.4cm with cauliform margins. Fabric orientated 336/80. Exposure pervaded by contractional joints which plunge 03→070.

Sharp contact with matrix supported mBr containing ~70%, medium grained, grey, friable, matrix. Blocks of sub rounded arkose and sub angular mLTi (≤18cm x10cm) at base of waterfall. Blocks of sub rounded arkose and mLTi fine to ≤10x8cm at top of waterfall. mLTi next to mBr has sub horizontal cooling joints orientated 02→260. Angular fragments of fault gouge ≤2cm x1 cm form a 10cm thick layer between mBr and adjacent mLTi. Faulted contact.

Matrix supported mLTi, matrix ~ 60%, streaked chloritised pumice ≤5:1 length to width ratio, angular lapilli amygdaloidal basalt ≤ 1.5cm x8mm diameter. Cooling joints, plunge of columns 32→255.

Intensely folded mLT lava like, matrix ≥90%, lithic lapilli not evident. Unit is banded on a mm scale into darker and lighter bands, frequent micro folding, ptygmatic, recumbant and intra folial folds with fold wavelength of ≤5cm,

Intensely folded mLT lava like, matrix ≥90%. Banded on a mm scale into darker and lighter bands, frequent micro folding in matrix. Sporadic pumice lapilli with streaked out tube walls ≤2x1cm.

Matrix supported mLTi, matrix ≥80%, fiamme ≤20 x 4cm wide with a mafic coloured interior. Such large fiamme are sporadic, most are ≤5 cm long with length: width ratio ≤15:1. Columns are sub horizontal in stream floor and plunge 04→350

Sharp, erosive, contact with overlying mLTi, matrix supported ~80%, very fine grained, chloritised. Contains fiamme ≤ 20:1, and chloritised sub angular lithic lapilli ≤ 8x 6mm basalt . Matrix fabric is deflected around fiamme and lapilli. Lobate mafic blebs ≤8mm across. Matrix fabric 350/12, cooling joints plunge 15 →270.

Coarsening matrix supported mBr. Matrix 40%, green, medium grained friable. Contains sub rounded amygdaloidal basalt ≤20 x15cm to mLTi, arkosic sandstone and mBr blocks ≤ 30 x 20cm diameter.

Matrix supported mBr, with ~ 50% green, medium grained matrix. Contains sub rounded blocks of amygdaloidal basalt and arkosic sandstone ≤ 12 x7cm diameter.

Matrix supported mLTi, ~ 60%, medium grained, grey matrix, fabric 300/78. Insipient welded pumice ≤5:1 length to width ratio. Angular lithic lapilli of amygdaloidal basalt and arkosic sandstone ≤6x4cm.

Matrix supported mLT ~ 70% greenish grey, fine grained matrix. Sub angular arkosic sandstone lapilli ≤5x 2.5cm.

Amygdaloidal basalt, dark green, chloritised.

Peperite. Friable, granular matrix, ash rich ~70%, containing highly lobate mafic clots. Numerous lobes are completely isolated within sediment and some display a jigsaw type fit with neighbouring lapilli. Sporadic amygdales present within some of the blebs. Layer is 20cm thick, slight normal grading of clots.

Amygdaloidal basalt, dark green, chloritised.

Similar to lower paleosol, reddish, fissile, 2cm thick, diffuse margin with underlying basalt.

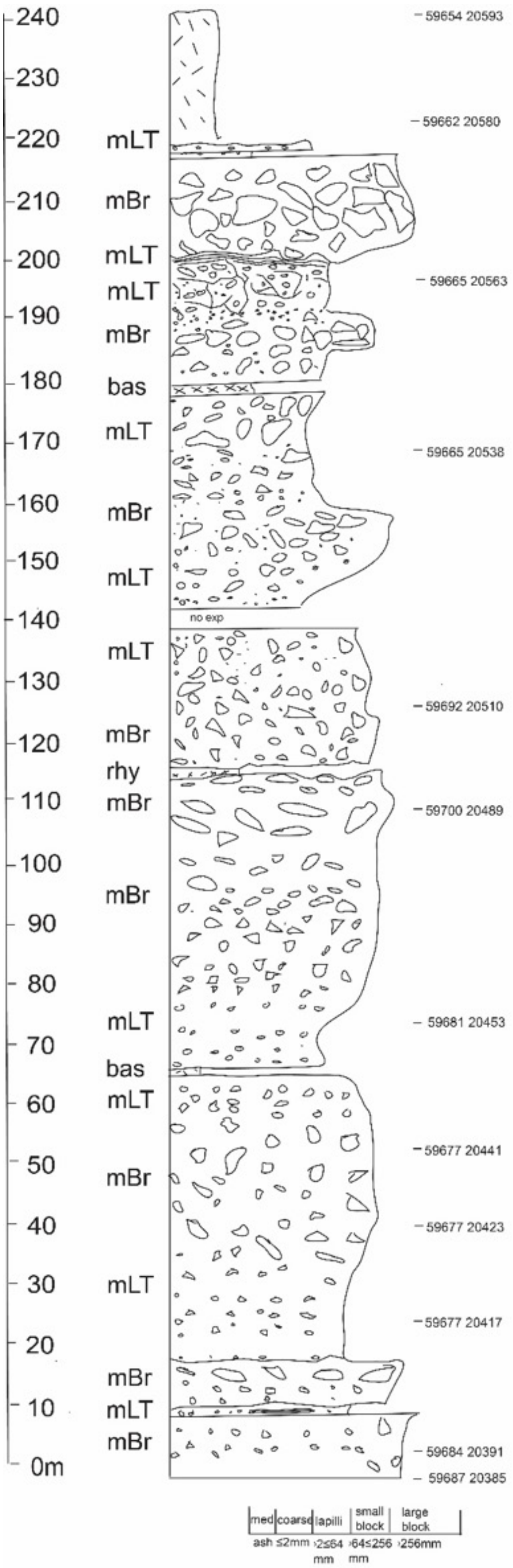
4cm thick red ash layer, sharp planar contact with underlying basalt, green crystals of augite.

5cm thick paleosol, red oxidised, diffuse contact with underlying amygdaloidal basalt. Paleosol gets pinker in colour down to ~20cm depth within underlying top of basalt.

Amygdaloidal basalt, dark green, chloritised, pronounced increase in size and % of amygdales.

Matrix supported mLT, ~ 80% matrix,medium grained, grey, matrix. Unit has an erosive base. Matrix contains arkosic sandstone lapilli sub rounded, majority are ≤ 5.2x 3 cm. Unit contains outsized, angular, aphanitic basaltic blocks ≤10x5 cm.

Amygdaloidal basalt, dark green, chloritised.



Chloritosed basalt, contains amorphous white amygdales ≤1cm length, randomly orientated laths of plagioclase. Contact with underlying mLT not discernable.

30cm thick silicic dyke trending 294°.

Clast supported mBr containing blocks of sub rounded amygdaloidal basalt, mLTi and arkosic sandstone ≤30x40cm. Localised matrix deformed into open folds with a fold wavelength of ~3m.

Stratified mLT, ~80%, fine grained, grey matrix, with pronounced laterally persistant fabric 270/70. Angular lapilli of aphanitic basalt and sandstone. Imbrication of some lapilli yielding a paleocurrent direction ~ 345°

Clast supported mBr but locally matrix supported <40%, medium grained, rounded arkosic blocks ≤ 23x 20cm, some are thermally spalled.

Chloritosed basalt, with amorphous white amygdales ≤1cm length. Highly fractured amygdaloidal basalt flow top. Plagioclases dip at ~20° which is roughly the dip of the stream. Amygdaloidal basalt lava 40cm thick capped by red ash layer ≤5mm. Sharp contact with underlying basalt.

Matrix supported mLT, fabric 120/57, and cooling joints spaced ~7cm apart. Slight reverse grading of lithic lapilli at top of unit. Sporadic outsized, angular, arkosic sandstone blocks ≤ 25x 13cm.

Clast supported mBr , highly brecciated, blocks of highly angular, mBr and arkosic sandstone ≤35x20cm.

Matrix supported mLT, ~80% matrix, medium grained, grey. Angular lithic lapilli ≤ 6x5 cm of arkosic sandstone, amygdaloidal basalt, and mLTi,

Matrix supported mLT, matrix fine grained, ~ 70%. Sub rounded lithic lapilli of aphanitic basalt, fluvial sandstone and quartzite ≤5x4cm.

Variably clast to matrix supported mBr. At base ~70% matrix supported mBr, containing angular blocks of dolostone and arkosic sandstone ≤8x 6cm. Erosive base to upper mBr which cuts down into silicic intrusion.

silicic intrusion 40cm thick, weathers white, laterally sinuous

Clast supported mBr, sub rounded to sub angular blocks of arkosic sandstone, aphanitic basalt, and dolostone ≤ 12x8cm

Matrix supported mLT, normally graded. Matrix is ~70%, medium grained, and contains lapilli of sub rounded arkosic sandstone and basalt, which fine from 7x5cm to 3 x2 cm over 3 metres vertically.

Aphanitic basalt.

Matrix supported mLT ~30% matrix, contains sub angular to sub rounded lapilli ≤ 6x5cm of dolostone, arkosic sandstone and rhyolite.

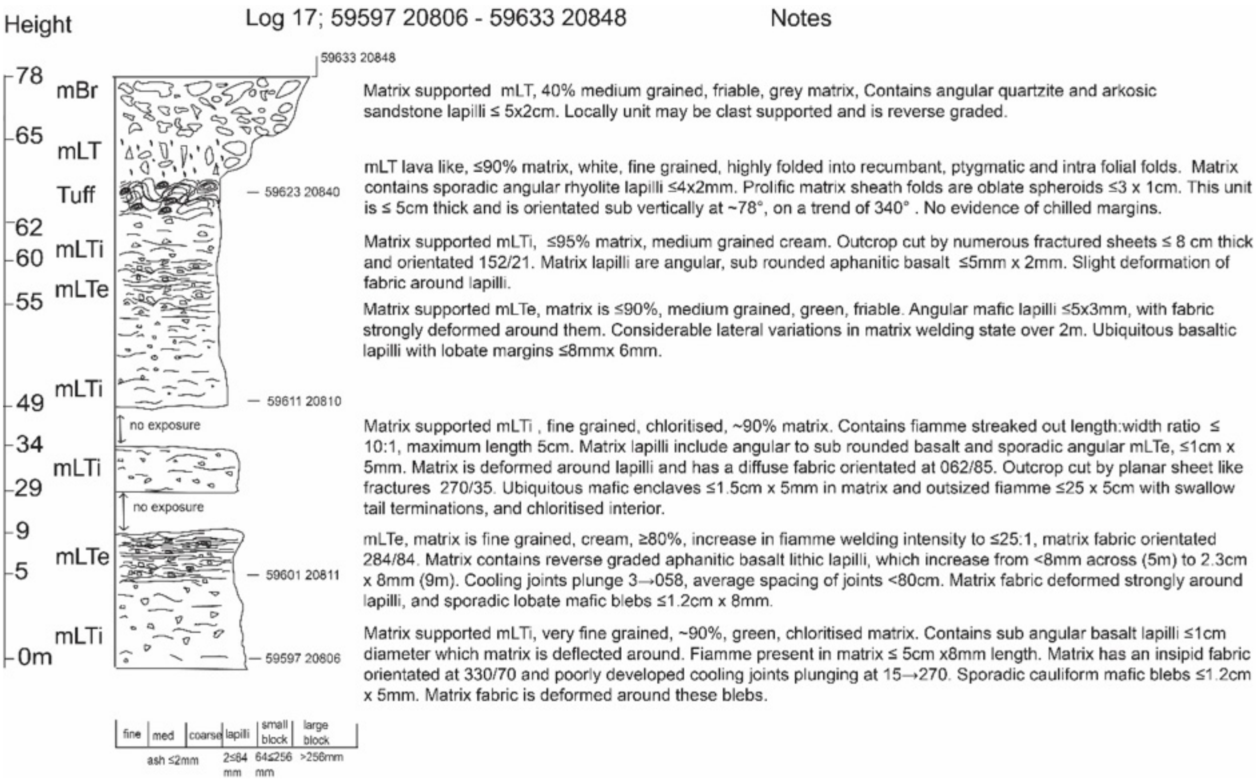
Matrix supported mBr, matrix content is ~45%, medium grained and green. Blocks of sub rounded to sub angular arkosic sandstone, basalt and quartzite (all ≤ 15x8cm) are aligned into a crude stratification (326/50). Glacial striations on surface of exposure.

Matrix supported mLT. Matrix is ~50%, medium grained, grey containing lithics of aphanitic basalt ≤8x4cm, weathered pumiceous blocks ≤12x8cm, angular quartzite ≤ 5x3cm.

mBr, matrix supported, ~80% medium grained ,friable, grey matrix. Contains angular mBr blocks ≤ 40x20cm and sub rounded arkosic sandstone ≤ 15x12 cm. Unit has a crude stratification orientated 286/50 and an erosive base into underlying mLT.

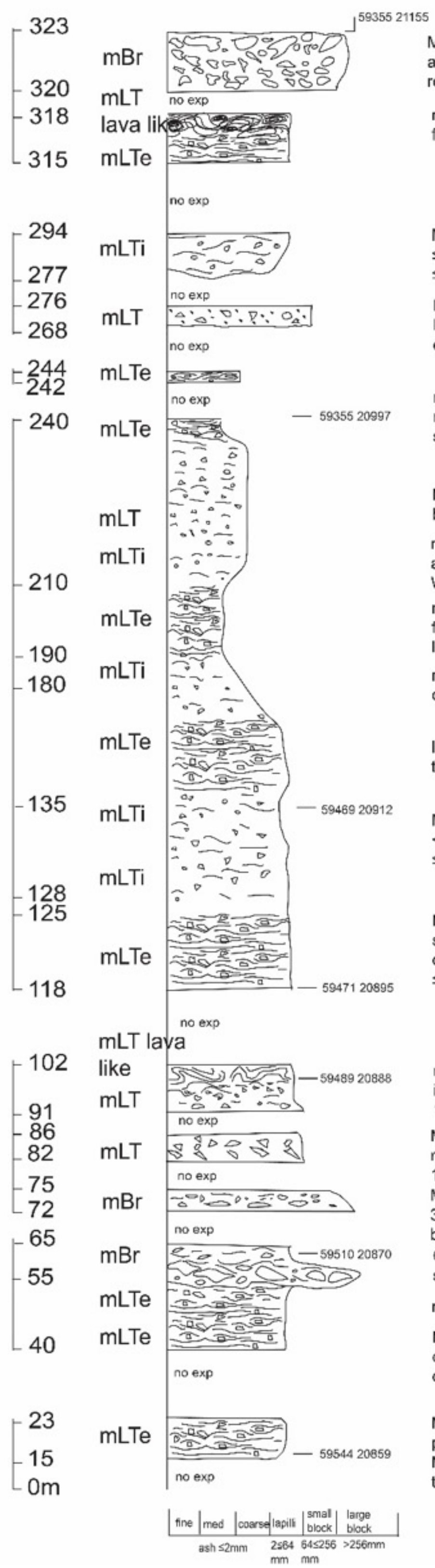
mLT ~ 80% matrix supported. Contains angular dolostone lapilli ≤3x4cm, and angular, outsized blocks of calcareous sandstone ≤70x20cm.

mBr ~ 55%, coarse grained matrix containing angular arkose, and calcareous sandstone blocks ≤ 23cm x 9cm.



Height
Log 17; 59597 20806 - 59633 20848
Notes
59633 20848
78
mBr
65
mLT
Tuff
59623 20840
62
mLTi
60
mLTe
55
mLTi
49
59611 20810
no exposure
34
mLTi
29
no exposure
9
mLTe
5
59601 20811
mLTi
0m
59597 20806
fine
med
coarse
lapilli
small block
large block
ash ≤2mm
2≤64 mm
64≤256 mm
>256mm
Matrix supported mLT, 40% medium grained, friable, grey matrix, Contains angular quartzite and arkosic sandstone lapilli ≤ 5x2cm. Locally unit may be clast supported and is reverse graded.
mLT lava like, ≤90% matrix, white, fine grained, highly folded into recumbant, ptygmatic and intra folial folds. Matrix contains sporadic angular rhyolite lapilli ≤4x2mm. Prolific matrix sheath folds are oblate spheroids ≤3 x 1cm. This unit is ≤ 5cm thick and is orientated sub vertically at ~78°, on a trend of 340° . No evidence of chilled margins.
Matrix supported mLTi, ≤95% matrix, medium grained cream. Outcrop cut by numerous fractured sheets ≤ 8 cm thick and orientated 152/21. Matrix lapilli are angular, sub rounded aphanitic basalt ≤5mm x 2mm. Slight deformation of fabric around lapilli.
Matrix supported mLTe, matrix is ≤90%, medium grained, green, friable. Angular mafic lapilli ≤5x3mm, with fabric strongly deformed around them. Considerable lateral variations in matrix welding state over 2m. Ubiquitous basaltic lapilli with lobate margins ≤8mmx 6mm.
Matrix supported mLTi , fine grained, chloritised, ~90% matrix. Contains fiamme streaked out length:width ratio ≤ 10:1, maximum length 5cm. Matrix lapilli include angular to sub rounded basalt and sporadic angular mLTe, ≤1cm x 5mm. Matrix is deformed around lapilli and has a diffuse fabric orientated at 062/85. Outcrop cut by planar sheet like fractures 270/35. Ubiquitous mafic enclaves ≤1.5cm x 5mm in matrix and outsized fiamme ≤25 x 5cm with swallow tail terminations, and chloritised interior.
mLTe, matrix is fine grained, cream, ≥80%, increase in fiamme welding intensity to ≤25:1, matrix fabric orientated 284/84. Matrix contains reverse graded aphanitic basalt lithic lapilli, which increase from <8mm across (5m) to 2.3cm x 8mm (9m). Cooling joints plunge 3→058, average spacing of joints <80cm. Matrix fabric deformed strongly around lapilli, and sporadic lobate mafic blebs ≤1.2cm x 8mm.
Matrix supported mLTi, very fine grained, ~90%, green, chloritised matrix. Contains sub angular basalt lapilli ≤1cm diameter which matrix is deflected around. Fiamme present in matrix ≤ 5cm x8mm length. Matrix has an insipid fabric orientated at 330/70 and poorly developed cooling joints plunging at 15→270. Sporadic cauliform mafic blebs ≤1.2cm x 5mm. Matrix fabric is deformed around these blebs.

Height Log 18; 59544 20859 - 59355 21155 Notes



Matrix supported mBr ~70%, granular, chloritised matrix containing blocks of sub angular to sub rounded arkosic sandstone, aphanitic basalt and quartzite ≤18x9cm. Weathering in on surface of exposire of sub rounded recesses ≤ 12 x 7cm. Slight coarsening up section to block size ≤24 x14 cm at 323 m.

mLT lava like, ≥ 95% matrix, very fine grained, intense folding of cuspate shards into tight and recumbant folds with fold wavelength 3cm. Sheath folds on rock surface are oblate spheroid ≤3 x 1cm.

Matrix supported mLTi, ≥80% fine grained, mid grey, matrix containing angular arkose and quartzite lapilli ≤3x1.5 cm. Insipid welded fabric in matrix orientated 102/80. Matrix contains sub rounded quartz crystals ≤ 2mm diameter. Rock friable and highly altered.

Matrix supported mLT, medium grained ~80% matrix containing chloritised pumice and angular basalt lapilli ≤ 5cm x 2cm. Lapilli form diffuse, sub linear trails locally 242/59. Matrix contains sporadic mafic enclaves ≤ 1cm x 7mm with cauliform margins.

mLTe increase in matrix welding intensity to ≤25:1 length : width ratio in chloritised fiamme. Matrix is ≥85%, medium grained, highly altered, pumiceous, grey and has an intense fabric orientated 288/85. Contains sporadic basaltic lapilli ≤ 5x3mm. Sporadic, chloritised, mafic enclaves ≤8x4mm are evident in the matrix.

Matrix supported mLT, ~80%, medium grained, chloritised matrix containing chloritised pumice and black angular basalt lapilli ≤ 3x 2cm. Diffuse fabric of sub linear lapilli trails 142/30.

mLTi, matrix ≥80%, fine grained, mid-grey with slight coarsening upwards. Contains lapilli of angular arkosic sandstone and aphanitic basalt ≤1.2 cm x 8mm, and sub rounded quartz crystals ≤ 2mm diameter. Welded fabric in matrix orientated at 342/80,

mLTe, matrix supported. Increase in welding intensity to ≤25:1 and laterally discontinous black pumiceous fiamme streaks. Locally folding of cuspate shards into tight and recumbant folds, which change to a laterally continuous planar fabric over 0.5m. Matrix fabric is fabric orientated 320/78.

mLTi decrease in welding intensity over 2m to ≤15:1. Matrix supported ≥90%, fine grained, grey. Matrix contains angular basalt lapilli ≤1cm x8mm and has a eutaxitic fabric locally orientated at 320/78.

Increase in welding intensity to ≤ 25:1, highly streaked former pumice fiamme with occasional swallow tails.

Matrix supported mLTi, ≥ 80%, mid grey, medium grained matrix containing angular, basaltic lapilli <5mm across and sporadic, lobate, mafic blebs ≤5x3mm. Former pumiceous chloritised fiamme have ≤10:1 length to width ratio.

Matrix supported mLTe, ≥ 80%, medium grained, mid grey matrix containing lapilli of mLTi and arkosic sandstone ≤ 1.2cm x 6mm, and sporadic sub rounded quartz crystals ≤ 2mm. Matrix eutaxitic fabric is orientated at 164/79 and deformed strongly around lapilli. Sporadic mafic blebs in matrix with lobate margins ≤1.2 cm x 5mm

mLT lava like, ≥95%, fine grained, orange, matrix containing angular basaltic lapilli ≤8x4mm. Matrix has intense planar fabric deformed into recumbant, ptygmatic, sheath and tight folds with fold wavelengths ≤ 10 cm.

Matrix supported mLT, ~60% medium grained matrix, friable containing angular lapilli of aphanitic basalt and mLTi ≤ 3cm x 1.5cm. Weak matrix fabric evident orientated at 330/88 with chloritised sub-rounded pumices ≤ 1.2 cm diameter.

Matrix supported mBr, ~60%, granular, chloritised matrix. In places matrix has insipid fabric orientated at 350/82 and sub linear highly diffuse trails of pumices and angular arkose ≤ 15x8cm. Sporadic matrix, mafic blebs with lobate margins ≤1cm x 4 mm.

Clast supported mBr containing angular blocks of rhyolite lava and mLTe ≤10cm x8cm. Breccia coarsening up section to ≤14 x10cm at 56m height. Contact with underlying mLTe is undulatory and erosive.

mLTe with reduction in welding intensity length:width ratio of fiamme ≤15:1

Matrix supported mLTe, ≥80%, medium grained, grey matrix containing sporadic sub rounded quartz crystals ≤ 2mm diameter, and lapilli of aphanitic basalt ≤ 8x 6mm. Eutaxitic fabric orientated at 154/78 and deformed strongly around lapilli. Sporadic euhedral matrix pyrite.

Matrix supported mLTe, ≥90%, fine grained, mid grey matrix containing sporadic, sub rounded, chloritised, pumice and aphanitic basalt lapilli ≤6mm x 4mm. Eutaxitic fabric is deformed strongly around these lapilli. Matrix fabric largely planar and orientated 054/59. The unit slightly coarsens up with increase in lithic lapilli to ≤1.5cm diameter at 22m height.

5 Methodology U/Pb Zircon dating for Allt nan Suidheachan mLTi (NIGL facility, British Geological Survey, Keyworth, Nottingham, UK)

U/Pb dating of samples was conducted at the NIGL facility, British Geological Survey, Keyworth. Nottingham UK. Zircons were isolated using conventional mineral separation techniques. Prior to isotope dilution thermal ionization mass spectrometry (ID-TIMS) analyses zircons were subject to a modified version of the chemical abrasion technique (Mattinson, 2005). U-Pb ID-TIMS analyses herein utilized the EARTHTIME ^{205}Pb-^{233}U-^{235}U (ET535) tracer solution. Measurements at the NERC Isotope Geosciences Laboratory were performed on a Thermo Triton TIMS. Pb analyses were measured in dynamic mode on a MassCom SEM detector and corrected for 0.14 ± 0.04 %/u. mass fractionation. Linearity and dead-time corrections on the SEM were monitored using repeated analyses of NBS 981 and U500. Uranium was measured in static Faraday mode on 10^{11} ohm resistors or for signal intensities <15 mV, in dynamic mode on the SEM detector. Uranium was run as the oxide and corrected for isobaric interferences with an ^{18}O/^{16}O composition of 0.00205 (IUPAC value and determined through direct measurement at NIGL). Single analysis U-Pb dates and uncertainties were calculated using the algorithms of Schmitz and Schoene [2007].

6 Geochemical data

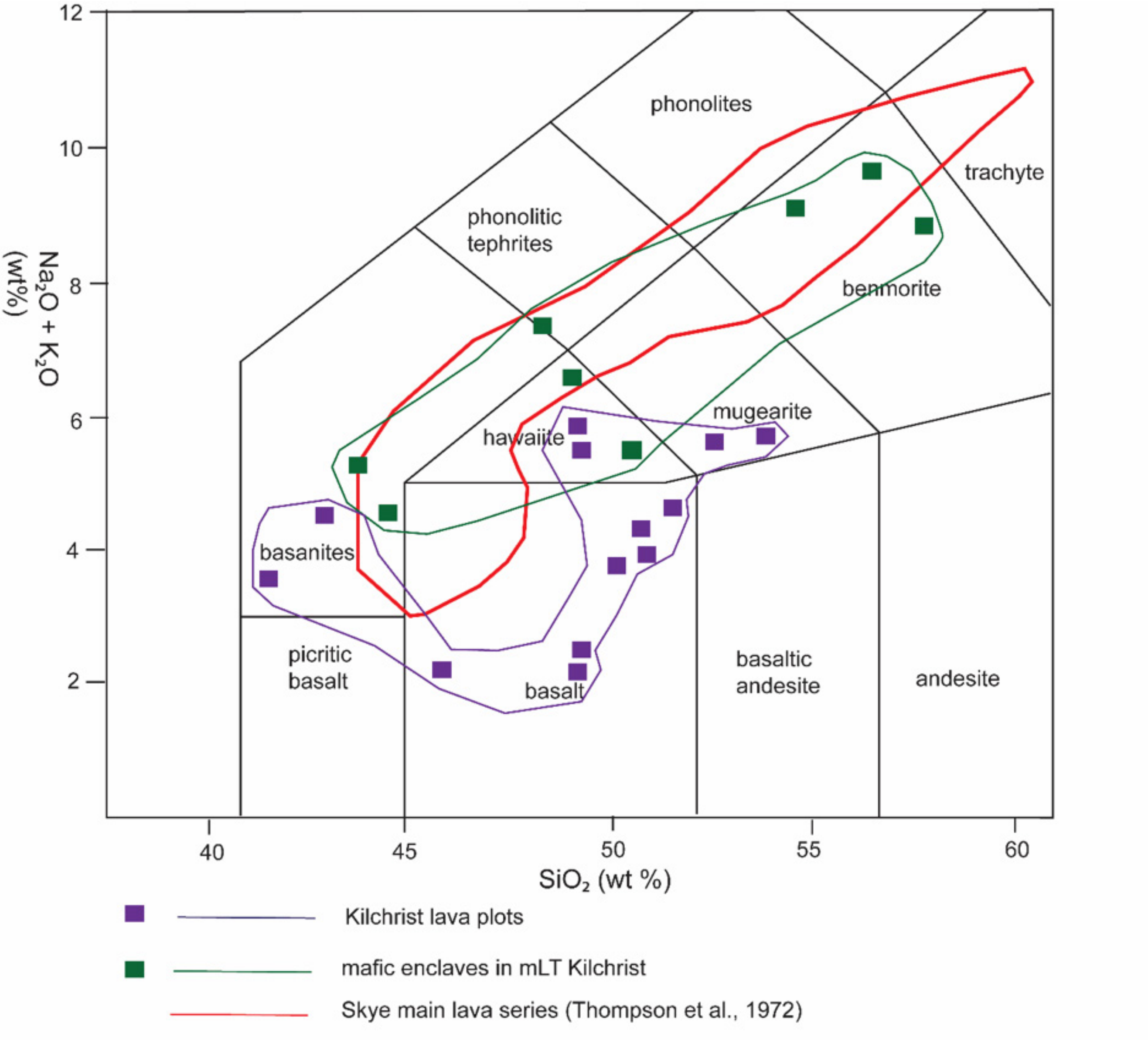


Figure S11: Total alkali versus silica diagram for Kilchrist basalts and mafic enclaves within mLT matrix. Modified from Emeleus and Bell [2005].

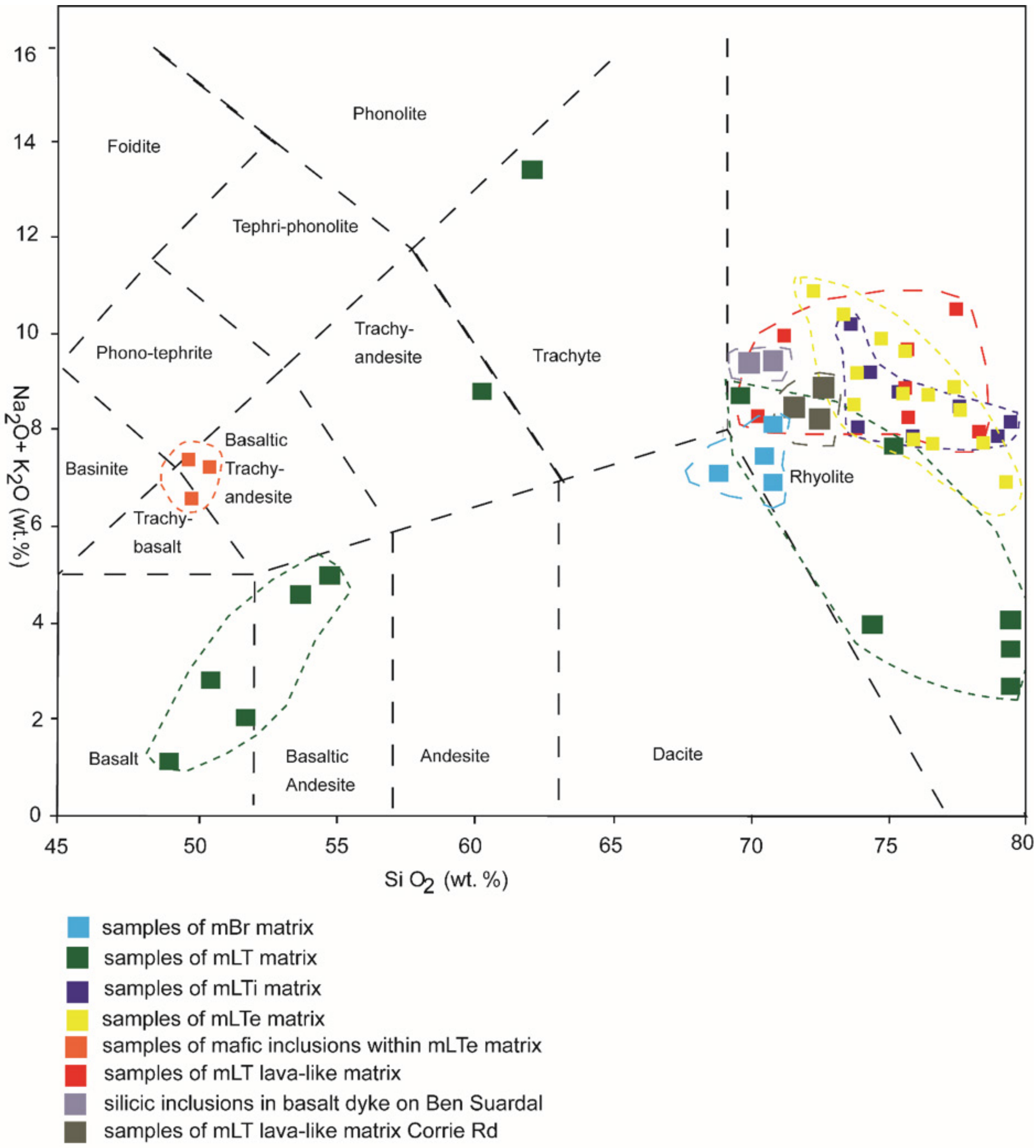


Figure S12: Compositional plots of representative mBr, mLT, mLTi, mLTe and mLT lava-like area matrix scans together with samples of mafic enclaves within mLTe matrix, and granitic xenoliths from within a basaltic dyke on Ben Suardal.

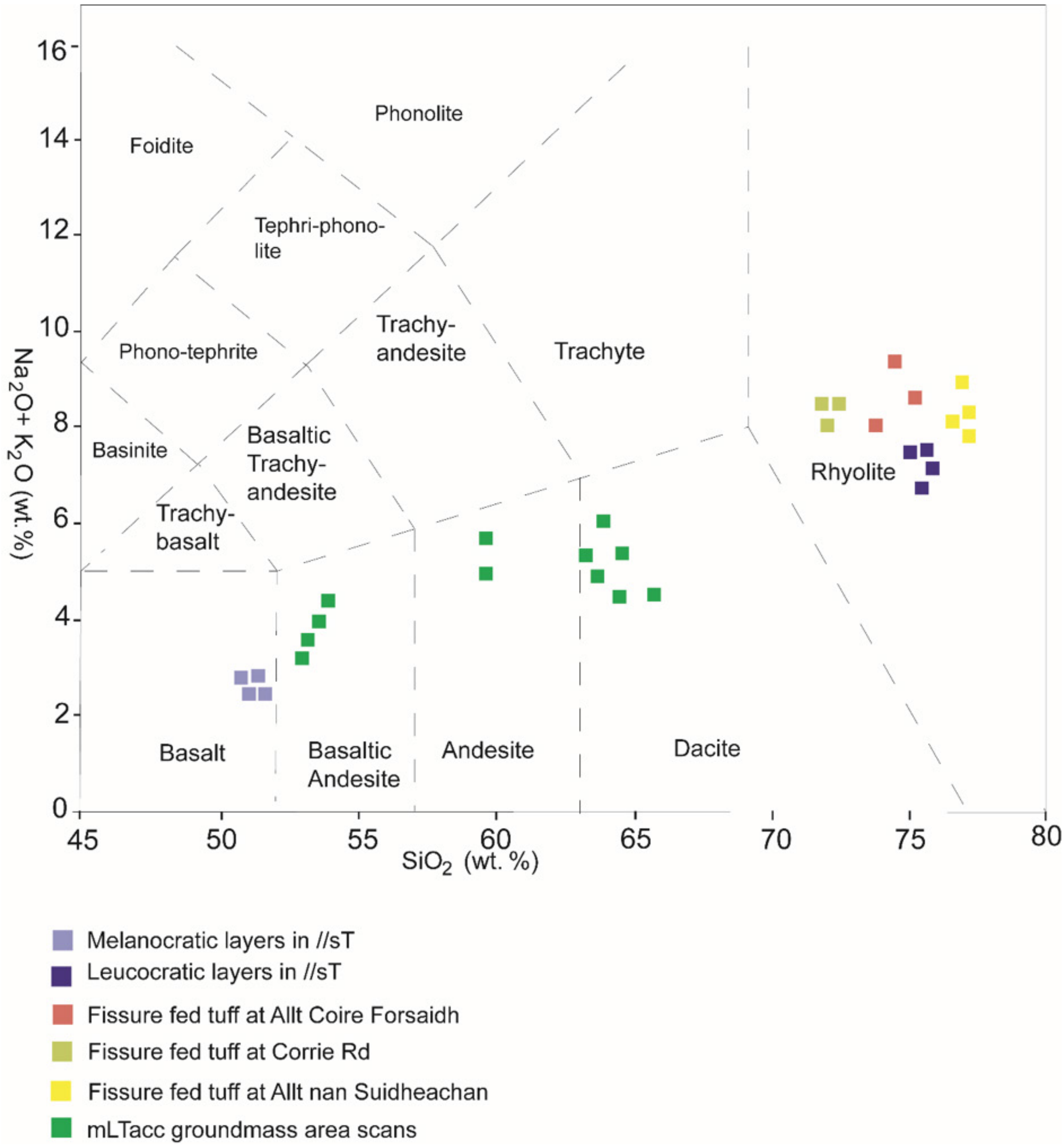


Figure S13: Compositional plots of representative fissure fed tuff, stratified tuff (//sT) and accretionary lapilli bearing massive lapilli tuff (mLTacc).

Table S4: CA-ID-TIMS data for analysed zircons.

Sample*		Compositional Parameters					
		Th/U†	^{206}Pb* ($\times 10^{-13}$ mol)‡	^{206}Pb* (mol%)‡	Pb*/Pbc	Pbc (pg)‡	^{206}Pb/^{204}Pb§
SD-BS-01	z1	0.8	0.0262	90.00	2.9	0.24	180
	z2	0.85	0.0251	88.90	2.7	0.26	163
	z3	0.87	0.0436	92.50	4.1	0.29	243
	z4	0.87	0.0299	87.60	2.4	0.35	146
	z5	0.87	0.0327	90.50	3.2	0.28	190
SD-ANS-01	z1	0.99	0.1777	84.80	1.9	2.63	119
	z2	0.83	0.1758	85.30	1.9	2.52	123
	z4	0.85	0.0858	87.20	2.3	1.04	142

Sample*		Radiogenic Isotope Ratios							
		^{208}Pb/^{206}Pb¶	^{207}Pb/^{206}Pb¶	% err**	^{207}Pb/^{235}U¶	% err**	^{206}Pb/^{238}U	% err**	corr. coef.
SD-BS-01	z1	0.261	0.04813	6	0.058388	6.4	0.008798	0.7	0.59
	z2	0.285	0.04939	6.7	0.060007	7.1	0.008812	0.7	0.6
	z3	0.282	0.04771	4.3	0.057659	4.6	0.008765	0.5	0.65
	z4	0.29	0.04897	7.5	0.05945	7.9	0.008805	0.7	0.69
	z5	0.286	0.04824	5.6	0.058331	6	0.008771	0.6	0.65
SD-ANS-01	z1	0.319	0.04758	9.2	0.057278	9.8	0.008731	0.6	0.93
	z2	0.268	0.04772	8.9	0.057368	9.5	0.008719	0.6	0.9
	z4	0.276	0.04791	7.6	0.057811	8.1	0.008751	0.6	0.88

Sample*		Isotopic Ages					
		^{207}Pb/^{206}Pb⁂	±**	^{207}Pb/^{235}U⁂	±**	^{206}Pb/^{238}U⁂	±**
SD-BS-01	z1	102.4	141.8	57.6	3.6	56.5	0.4
	z2	163.1	156.2	59.2	4.1	56.6	0.4
	z3	81.8	102.1	56.9	2.5	56.3	0.3
	z4	143.3	175	58.6	4.5	56.6	0.4
	z5	107.6	132.8	57.6	3.4	56.4	0.3
SD-ANS-01	z1	75.2	219.6	56.6	5.4	56.1	0.3
	z2	82.2	211.9	56.6	5.2	56	0.4
	z4	91.7	180.5	57.1	4.5	56.2	0.3

* z1, z2 etc. are labels for fractions composed of single zircon grains or fragments; all fractions annealed and chemically abraded after Mattinson [2005].

† Model Th/U ratio calculated from radiogenic ^{208}Pb/^{206}Pb ratio;

‡ Pb* and Pbc represent radiogenic and common Pb, respectively; mol % ^{206}Pb* with respect to radiogenic, blank and initial common Pb.

§ Measured ratio corrected for spike and fractionation only. Daly analyses, based on analysis of NBS-981 and NBS- 982.

¶ Corrected for fractionation, spike, and common Pb; up to 1 pg of common Pb was assumed to be procedural blank: ^{206}Pb/^{204}Pb = 18.60 ± 0.80 %; ^{207}Pb/^{204}Pb = 15.69 ± 0.32 %; ^{208}Pb/^{204}Pb = 38.51 ± 0.74 % (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb.

** Errors are 2-sigma, propagated using the algorithms of Schmitz and Schoene [2007].

⁂ Calculations are based on the decay constants of Jaffey et al. [1971].

Table S5: CO_2 flux calculations resulting from decarbonation reactions and direct melting of dolostone country rock.

Aerial extent of dolostone outcrop (pre-volcanic episode) is ~31 km^2 (Figure 2 main text)
Cumulative thickness of Strath Suardal Formation = 530 m Ben Suardal Member (BSIL) ~170 m thick Dark grey dolostone (SSIL) ~85 m thick. This unit is recorded as having up to three repetitions [BGS 2005] Mid- dark grey dolostone Kilchrist Member (KiLI) ~35 m thick Pale grey, well bedded, Lonachan Member (LonL) 140 m thick Total thickness estimated to include 3× SSIL repetitions.
To convert volume of limestone (proxy for dolostone) in to mass (kg)
1 m^3 of limestone = 2711 kg 1000 m^3 (km^3) = 2711000 kg
Percentage estimates volume of dolostone assimilated during KVF episode and resultant CO_2 mass flux
30 % consumption: 31 000 000 m^2 × 159 m = 4.9 × 10^9 m^3=4.9 × 10^6 km^3 50 % consumption: 31 000 000 m^2 × 265 m = 8.2 × 10^9 m^3=8.2 × 10^6 km^3 80 % consumption: 31 000 000 m^2 × 424 m = 1.31 × 10^{10} m^3 = 1.33 × 10^7 km^3
Converted volume of dolostone to total mass
30 %: 4.9 × 10^6 km^3 × 2711000 = 1.34 × 10^{13} kg 50 %: 8.2 × 10^6 km^3 × 2711000 = 2.23 × 10^{13} kg 80 %: 1.33 × 10^7 km^3 × 2711000 = 3.56 × 10^{13} kg
Range of calculated CO_2 flux measured in Giga tons (Gt) for different percentages of assimilated dolostone consumed during KVF producing eruptions. 1 kg of limestone produces 239 g CO_2 [Ganino et al. 2013]
30 %: 1.34 × 10^{13} kg × 0.239 = 3.19 × 10^{12} kg of CO_2 = (3.19 × 10^9 mt) = 3.9 Gt 50 %: 2.23 × 10^{13} kg × 0.239 = 5.32 × 10^{12} kg of CO_2 = (5.32 × 10^9 mt) = 5.32 Gt 80 %: 3.56 × 10^{13} kg × 0.239 = 8.52 × 10^{12} kg of CO_2 = (8.52 × 10^9 mt) = 8.52 Gt

Table S6: CH_4 flux calculations resulting from contact metamorphism and dehydration of organic rich Lower Jurassic Shale

50 % of total thickness of Pabay Shales and Broadford Beds ~200 m Total area of above which surrounds composite sills and other intrusions = 18 km^2 (18 000 000 m^2), Total volume of shale = 18000000 × 200 = 3.6×10^9 m^3 (Figure 2 main text)
Total volume of shale = m^3
(100 %) 200 × 18000000 = 7.2×10^9 m^3 (80 %) 160 × 18000000 = 5.8×10^9 m^3 (50 %) 80 × 18000000 = 3.6×10^9 m^3 (30 %) 60 × 18000000 = 2.16×10^9 m^3
1 m^3 of shale = 2675 kg
1000 m^3 (km^3) = 2675000 kg 100 kg CH_4 = per kg m^{-3}
Total mass of shale kg
(100 %) = (7×10^9 m^3) × 2675000 = 1.93×10^{16} kg (80 %) = (5.6×10^9 m^3) × 2675000= 1.54×10^{16} kg (50 %) = (3.5×10^9 m^3) × 2675000 = 9.33×10^{15} kg (30 %) = (2.1×10^9 m^3) × 2675000 = 5.78×10^{15} kg
130 CH_4 (kg) driven off per kg m^{-3}.
(100 %) = (1.93×10^{16} kg) / 130 = 1.48×10^{14} kg (80 %) = (1.54×10^{16} kg) / 130 = 1.19×10^{14} kg (50 %) = (9.33×10^{15} kg) / 130 = 7.41×10^{13} kg (30 %) = (5.78×10^{15} kg) / 130 = 4.44×10^{13} kg
As Gt (1Kg = 1.0 × 10-12 Gt) – CH_4 driven off one side of intrusive sheet following contact metamorphism and dehydration
(100 %) = 1.48×10^{14} kg = 148 Gt (80 %) = 1.19×10^{14} kg = 119 Gt (50 %) = 9.32×10^{13} kg = 74.1 Gt (30 %) = 5.62×10^{13} kg = 44.4 Gt
CH_4 driven off both sides of intrusive sheet following contact metamorphism and dehydration
(100 %) = 296 Gt (80 %) = 237 Gt (50 %) = 148 Gt (30 %) = 88.9 Gt

7 Additional text on Paleocene geology of Skye

The Cuillin Central Complex has been sub-divided, in age of emplacement from oldest to youngest, into the Cuillin Centre, the Srath na Creitheach Centre, the Western Red Hills (WRH) Centre, and the Eastern Red Hills (ERH) Centre [Emeleus and Bell 2005]. The Cuillin Centre is typically gabbroic, and comprises plutonic bodies, with minor intrusions including arcuate 'cone-sheets'. Pegmatitic veins in Cuillin Centre gabbro have been dated at 58.91± 0.08 Ma [Hamilton et al. 1998]. The Coire Uaigneich Granite [59.3 ± 0.7 Ma, Dickin 1981], crops out adjacent to the SE Cullin Centre margin. The Srath na Creithach Centre comprises granitic intrusions and volcaniclastic rocks. The Western Red Hills Centre typically comprises granitic plutons and mixed magma intrusions, with the Loch Ainort Granite having been dated at 58.58 ± 0.13 Ma [Chambers and Pringle 2001]. The Eastern Red Hills Centre typically comprises granitic intrusions, although gabbroic units are also present [Bell 1966; 1976; Emeleus and Bell 2005]. The Eastern Red Hills Centre has been sub-divided into two suites: 1) the older Outer Granite comprising granite intrusions forming the hills of Glas Beinn Mhor, Beinn na Cro, Beinn an Dubhaich, and east of Beinn na Caillich to Creag Strollamus, together with the Beinn na Cro and Broadford gabbros and; 2) the younger Inner Granite comprising the granite intrusions forming Beinn na Caillich, Beinn Dearg Mhor and Beinn Dearg Bheag (Figure 2). The Beinn an Dubhaich Granite has been dated at 55.89 ± 0.15 Ma [M. A. Hamilton, in Emeleus and Bell 2005], whilst a pitchstone dyke cross-cutting the Beinn na Caillich Granite has been dated at 55.7 ± 0.1 Ma [M. A. Hamilton, in Emeleus and Bell 2005]. Emplacement of the Beinn an Dubhaich Granite formed a well-developed contact aureole in surrounding Cambro-Ordovician country rock [Holness 1992].

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