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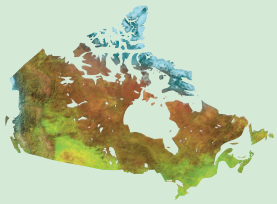

The volcanic stratigraphy of Kima'Kho Mountain: a Pleistocene tuya, northwestern British Columbia

C. Ryane, B.R. Edwards, and J.K. Russell

Geological Survey of Canada

Current Research 2011-14

2011

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ISSN 1701-4387
Catalogue No. M44-2011/14E-PDF
ISBN 978-1-100-19303-8
doi: 10.4095/289196

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Toll-free (Canada and U.S.A.): 1-888-252-4301

Recommended citation

Ryane, C., Edwards, B.R., and Russell, J.K., 2011. The volcanic stratigraphy of Kima'Kho Mountain: a Pleistocene tuya, northwestern British Columbia; Geological Survey of Canada, Current Research 2011-14, 12 p. doi:10.4095/289196

Critical review
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Abstract: The results of fieldwork completed during 2009 and 2010 at Kima'Kho Mountain, northwestern British Columbia, comprising a geological map and complementary stratigraphic and petrological data are presented herein. The geological map shows the distribution of three distinct basaltic lithofacies. The lithofacies are denoted as volcaniclastic, coherent intrusive dykes and sills, and extrusive massive and pillow lava and they record a transitional sequence from explosive subaqueous and subaerial to effusive subaerial volcanism. On the basis of these lithofacies and their stratigraphic relationships, the authors deduce that Kima'Kho is a volcanic edifice resulting from explosive and effusive eruption beneath and within a Pleistocene Cordilleran ice sheet.

Résumé : Cet article présente les résultats de travaux de terrain réalisés en 2009 et 2010 sur le mont Kima'Kho, dans le nord-ouest de la Colombie-Britannique, soit une carte géologique et des données stratigraphiques et pétrologiques complémentaires. La carte géologique montre la répartition des trois groupes de lithofaciès basaltiques distincts : dépôts volcanoclastiques, roches intrusives cohérentes (filons-couches et dykes), et roches extrusives cohérentes (laves coussinées et massives). Ces lithofaciès dénotent une séquence de transition allant du volcanisme subaquatique et subaérien explosif au volcanisme subaérien effusif. Sur la base de ces lithofaciès et de leurs relations stratigraphiques, nous déduisons que le mont Kima'Kho est un édifice volcanique formé au Pléistocène par éruption explosive et effusive en dessous et à l'intérieur des glaces de l'Inlandsis de la Cordillère.

INTRODUCTION

Tuyas are flat-topped volcanic landforms formed when volcanoes erupt beneath and within ice (Mathews, 1947). In Iceland, the same landforms are termed 'stapar' (Kjartansson, 1943). These volcanic edifices are described as comprising pillows and associated volcaniclastic deposits capped by flat-lying sheets of lava; it is a lithostratigraphy that is interpreted to result from explosive to effusive eruption into glacial lakes.

The Tuya-Kawdy region of the northern Cordillera volcanic province (Edwards and Russell, 1999, 2000) hosts more than 30 volcanic centres that are thought to be less than 2 Ma old (Fig. 1; Edwards et al. (2010)). The region

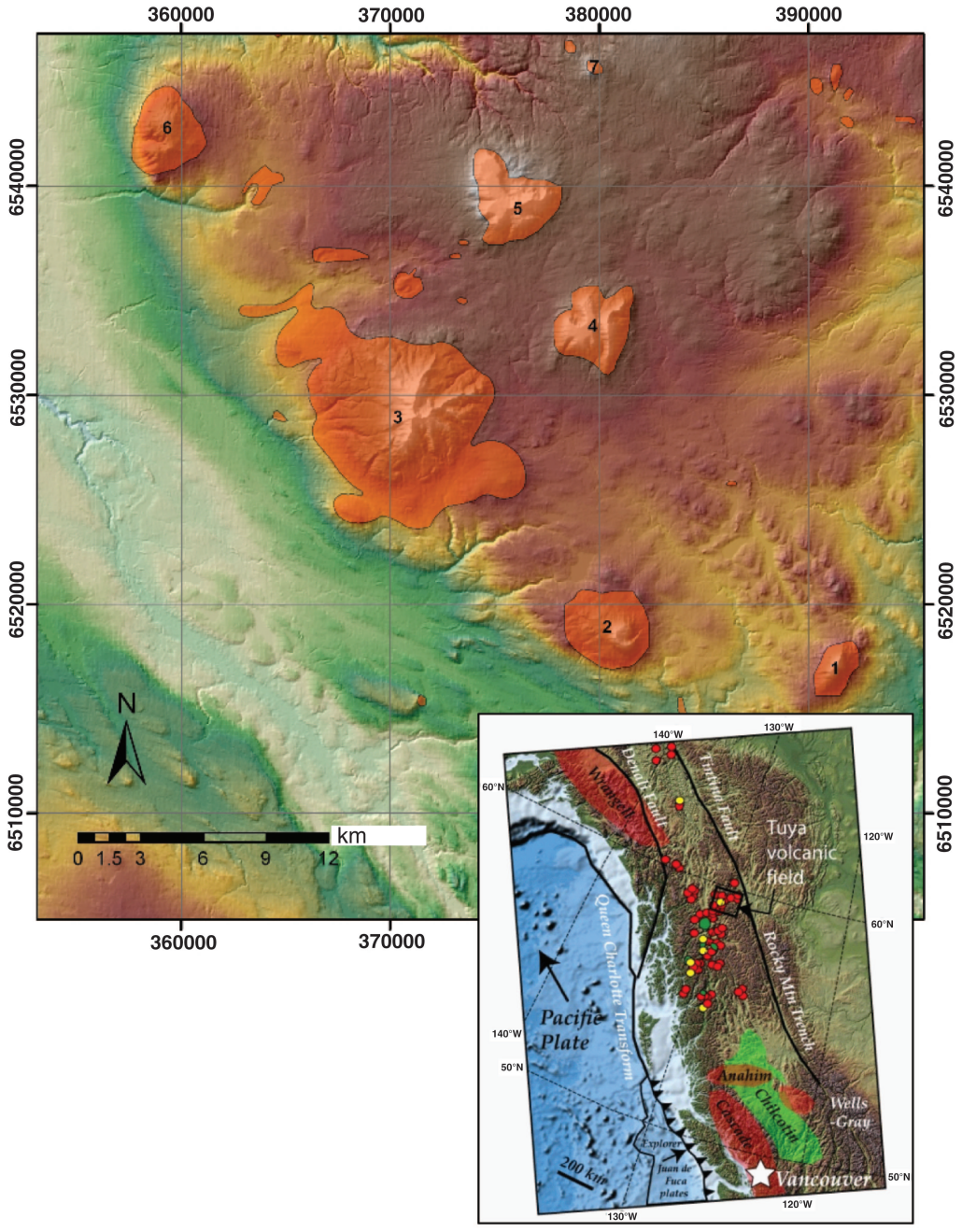

Figure 1. Location of Kima'Kho Mountain (5) within the Tuya-Kawdy volcanic field shown on a topographic map. Warmer colours indicate higher relief. Other Kawdy Plateau volcanic rocks include Tutsingale (1), Nuthinaw (2), Kawdy (3), Horseshoe (4), Meehaz (6), and Badman Point (7). Inset shows location of Kima'Kho in the northern Cordillera volcanic province (Edwards and Russell, 1999, 2000), British Columbia.

is host to many of the flat-topped and steep-sided volcanoes described as tuyas by Mathews (1947; Allen et al., 1982; Edwards et al., 2010, 2011).

Watson and Mathews (1944) designated the Pleistocene volcanic units across the area as the Tuya Formation. That stratigraphic designation was utilized in the Jennings River (Gabrielse, 1970), Dease Lake (Gabrielse, 1980), and Cry Lake (Gabrielse, 1990) 1:250 000 map sheets.

Kima'Kho Mountain (58°52′48″N, 131°13′48″W; Fig. 1) is the highest mountain of the southern Kawdy Plateau and is located 89 km northwest of Dease Lake, northern British Columbia. It was first described by Watson and Mathews (1944) who originally named the feature Kawdy Mountain and described it as an eroded volcanic edifice built upon the peneplain surface of the Kawdy Plateau; however, through cartographic error on NTS map sheet 104 (1952), the name Kawdy Mountain was assigned to a slightly lower relief edifice approximately 11 km to the southwest. For clarity, the highest mountain on the southern Kawdy Plateau is now renamed Kima'Kho Mountain (a Tahltan phrase meaning, 'Two Grizzlies'). Kima'Kho was first interpreted by Mathews (1947) as a volcano that had erupted under ice forming a large fragmental cone several hundred metres in height on top of a lava plateau.

Kima'Kho covers a surface area of approximately 28 km^2 and rises 460 m from its base to an elevation of 1936 m a.s.l. The basement surface outcrops at 1470 m a.s.l. on the north side of the volcano, and comprises sedimentary, volcanic, and metamorphic rocks of the Mesozoic Cache Creek Complex Kedahda Formation (Gabrielse, 1970, 1998).

The present mapping program of Kima'Kho began at a reconnaissance level in 2007 and was followed by an abbreviated field program (three days) in 2009 (Edwards et al., 2010; Ryane et al., 2010). The 2010 summer field program comprised five weeks of mapping. The field area was accessed by helicopter from Dease Lake and mapping was conducted on foot at a 1:5000 scale. Here the present authors report the volcanic stratigraphy for Kima'Kho and present a map and graphic logs (*see* Fig. 3, *see also* Fig. 6). Representative samples were prepared into thin sections for detailed petrographic analysis. This allows the present authors to elucidate the volcanic history and evolution of the Kima'Kho edifice.

KIMA'KHO MOUNTAIN

Kima'Kho Mountain is a single volcano that has two major structural elements (Fig. 2): 1) a central vent (southeast) that is dominated by lapilli tuff and basaltic intrusions, and 2) a small plateau (northwest) comprising beds of dipping pillow basaltic tuff breccia that are capped with subaerial lava flows. These two features are physically connected and stratigraphically continuous as the lapilli tuff of the central vent underlies the basaltic tuff breccia and lava

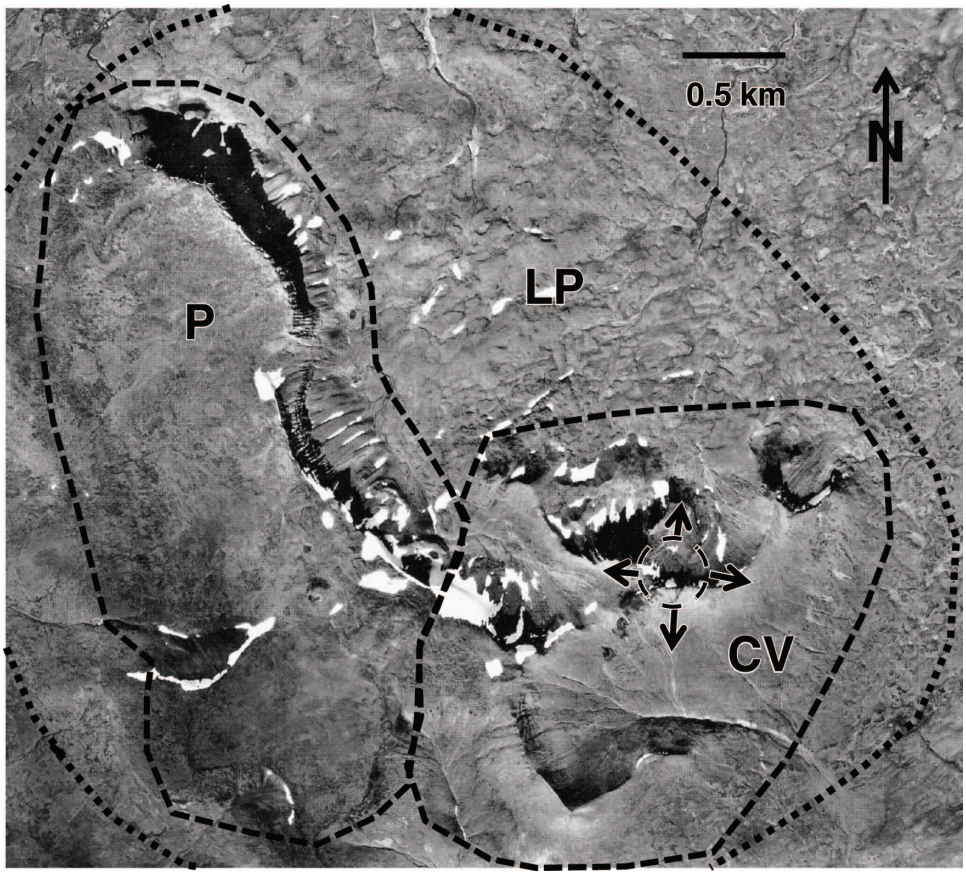

Figure 2. Aerial photograph showing main physiographic elements at Kima'Kho. LP = the areal limits to the dissected primary volcanic edifice, CV = the central vent deposits; circle denotes approximate location of main vent, P = highstanding plateau underlain by lava.

cap that define the plateau. A sample of pillow basalt from within the basaltic tuff-breccia sequence has a preliminary $^{40}Ar/^{39}Ar$ age of 1.82 ± 40 ka (Fig. 3; B.S. Singer, pers. comm., 2008). Kima'Kho and the surrounding landscape have been extensively glacially modified (Dunnington et al., 2010). Two distinct glacial features can be found on the northern flank of the volcano, one of which is interpreted to be a Little Ice Age moraine, indicating the past existence of a small cirque glacier (*see* Appendix). Gravitational collapse producing landslides has occurred predominately on the northeast flank of the volcano.

The Kima'Kho volcanic edifice comprises three lithofacies spanning volcaniclastic, coherent intrusive and coherent extrusive rock types (Table 1; Fig. 4, 5). The volcaniclastic lithofacies include: massive to coarsely bedded lapilli tuff; finely bedded to laminated lapilli tuff; lapilli tephra; weakly stratified basaltic tuff breccia; and massive to bedded basaltic tuff breccia to lapilli tuff. The coherent rocks comprise intrusive dykes and sills and extrusive lavas, both massive and pillowed.

Volcaniclastic facies

The dominant lithofacies exposed at Kima'Kho are volcaniclastic deposits spanning the full areal extent of the volcano and underlying the subaerial lava plateau (Fig. 3).

Massive to coarsely bedded lapilli tuff (lithofacies V_1)

The eastern half of Kima'Kho above about 1840 m a.s.l., including the summit, comprises poorly sorted lapilli tuff, the componentry of which is dominated by juvenile angular, scoriaceous, lapilli clasts in a matrix of palagonitized fine ash (Fig. 4a; Table 1). The lithofacies is massive to coarsely bedded with beds dipping up to 30°, occasionally crossbedded, and interbedded with about 10 cm thick units of tuff breccia (Fig. 5d, e). Some clasts approach block size. Armoured lapilli up to several centimetres in diameter are common, concentrated along centimetre-scale bedding planes and within massive lapilli-tuff beds (Fig. 5a, b). The eastern flank of the lapilli-tuff deposits is crosscut by sills and steeply dipping dykes, typically 1–5 m thick (lithofacies D).

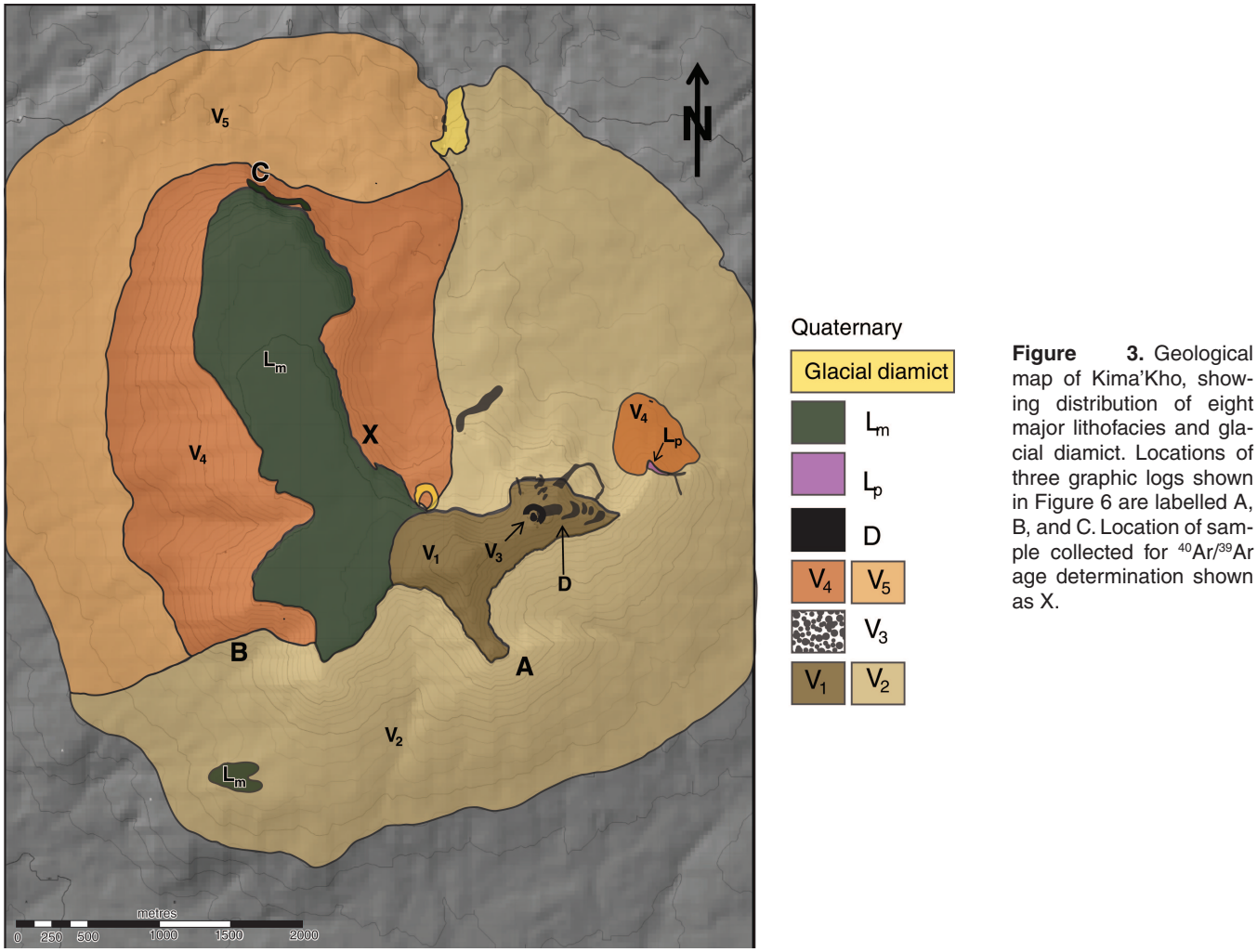

Figure 3. Geological map of Kima'Kho, showing distribution of eight major lithofacies and glacial diamict. Locations of three graphic logs shown in Figure 6 are labelled A, B, and C. Location of sample collected for $^{40}Ar/^{39}Ar$ age determination shown as X.

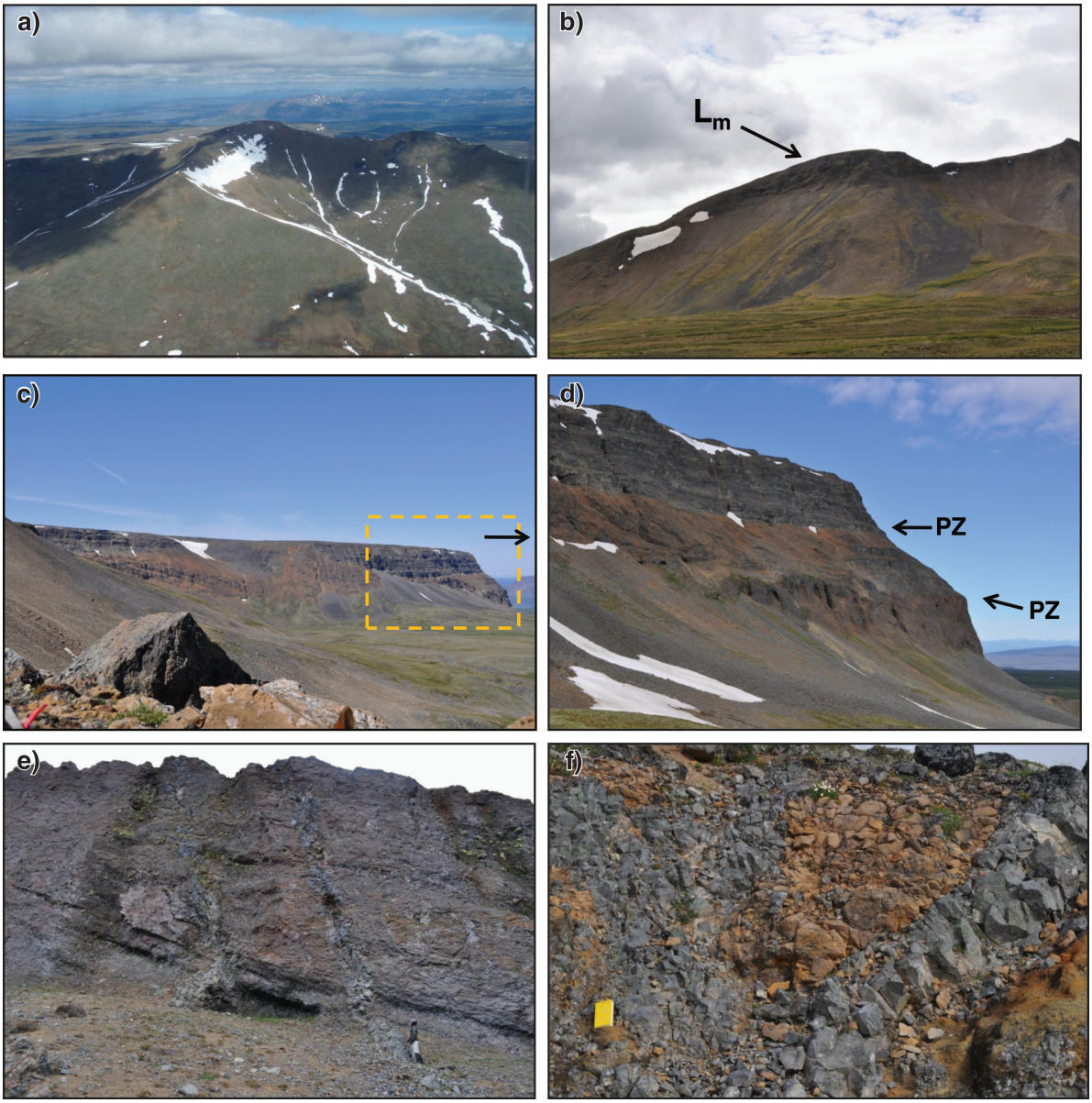

Figure 4. Field photographs depicting nature of deposits at Kima'Kho. **a)** Aerial view looking northeast at the tallest edifice and central vent of Kima'Kho, rising 460 m from its base to an elevation of 1936 m a.s.l. Field of view is 2.5 km. Photograph by B. Edwards. 2011-087. **b)** View of the eastern flank of Kima'Kho looking south. The ridge is composed of lithofacies L_m (Table 1), which directly overlies lithofacies L_p and V_4. Field of view is 1.5 km. Photograph by C. Ryane. 2011-095. **c)** View to the northwest of the Kima'Kho plateau, comprising dipping basaltic tuff breccia (lithofacies V_4), capped by subaerial lava flows (lithofacies L_m). The plateau has an approximate elevation of 1800±20 m and surface area of about 3 km^2. Detail of the dashed box seen in Figure 3d. Field of view is 2.4 km. Photograph by C. Ryane. 2011-089. **d)** Detailed view of the northeast flank of the Kima'Kho plateau, showing lower basaltic tuff breccia (lithofacies V_4) overlain by capping massive lava (lithofacies L_m). A second massive lava deposit is found within the basaltic tuff-breccia unit. Lower and upper passage zones indicated by arrows. Field of view is 0.75 km. Photograph by C. Ryane. 2011-088. **e)** View of two near-vertical dykes (lithofacies D) intruding basaltic tuff breccia (lithofacies V_4) on the northeast flank of the Kima'Kho plateau. Note person for scale. Photograph by C. Ryane. 2011-096. **f)** Detailed view of dykes (lithofacies D) crosscutting bedded lapilli tuff (lithofacies V_2) on northeast lowlands of Kima'Kho at approximately 1550 m a.s.l. Yellow notebook for scale is 12 cm by 19 cm. Photograph by C. Ryane. 2011-097.

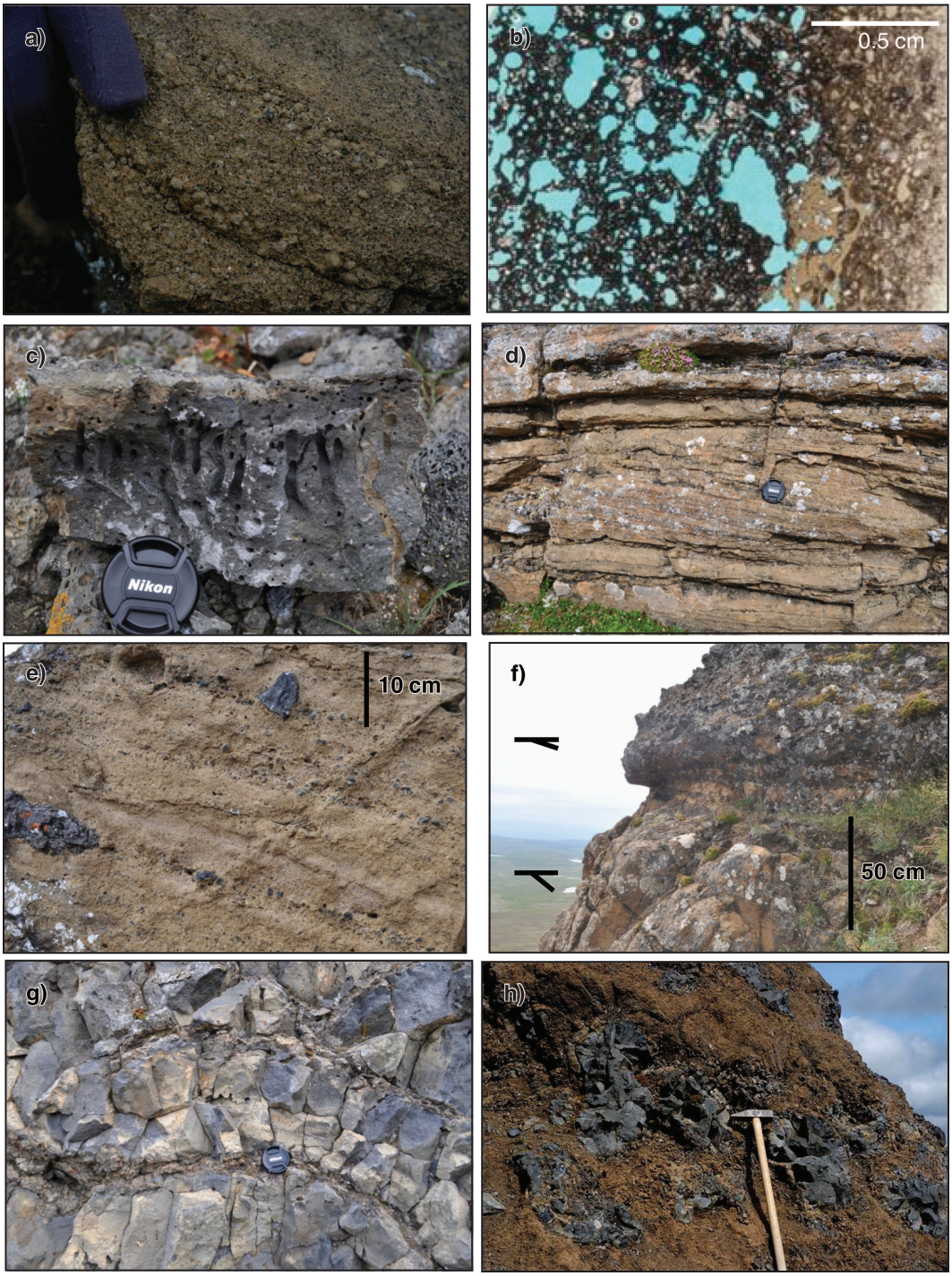

Figure 5. Various volcanic features and deposits at Kima'Kho. **a)** Detail of armoured lapilli found near the summit of Kima'Kho (lithofacies V_1). Field of view is approximately 15 cm. 2011-092. **b)** Enlarged portion of scanned thin section showing armoured lapillus found near summit of Kima'Kho (lithofacies V_1), comprising a central vesicular pyroclast (left) surrounded by accreted ash particles (right). Note: blue stain shows vesicularity. 2011-085. **c)** Tube vesicles from within a lower subaerial massive lava flow (lithofacies L_m) on the northeast flank of Kima'Kho. Lens cap for scale is 6.5 cm. 2011-098. **d)** Detailed view of crossbedding within lapilli tuff (lithofacies V_1) near the summit of Kima'Kho. Lens cap (6.5 cm) sits on crossbed forsets. 2011-093. **e)** Massive to coarsely bedded lapilli-tuff deposit (lithofacies V_1) near the summit of Kima'Kho. Note large basaltic pyroclasts. 2011-091. **f)** View of the sharp contact between bedded lapilli tuff (lithofacies V_2) and pillow basaltic tuff breccia (lithofacies V_4) on the western flank of Kima'Kho (*see* graphic log; Fig. 5). Approximate dips of units indicated on left of image. 2011-090. **g)** Detailed view of pillow lava (lithofacies L_p) found on the eastern flank of Kima'Kho at approximately 1740 m a.s.l. Lens cap for is scale 6.5 cm. 2011-086. **h)** View of intact pillow basalt within lithofacies V_4. Hammer head for scale is 21 cm long. 2011-094. All photographs in Figure 5 by C. Ryane.

Lithofacies V_1 is interpreted to be the product of explosive volcanism, as indicated by the abundance of juvenile scoriaceous pyroclasts. The deposits are interpreted to be the depositional products of multiple wet, dilute, pyroclastic surge events of varying energy into an englacial lake of unknown depth. Pyroclastic surges have a high rate of deposition and sedimentation and can deposit on surfaces steeper than 10° (Sparks and Walker, 1973). The resulting deposits are well stratified and may contain low-angle crosslaminations and bedding, with nonuniform bedding thicknesses, sorting (poor to well), and grain-size (ash to block) characteristics (Moore, 1967; Crowe and Fisher, 1973; Sparks et al., 1973; Sparks 1976). Surge deposits contain some combination of juvenile, accessory, and accidental clasts (Wohletz and Sheridan, 1979). Armoured and accretionary lapilli may be present when airfall layers are incorporated into the sequence (Waters and Fisher, 1971). All of these typical pyroclastic surge features can be observed within lithofacies V_1. Additionally, the angular nature of the clasts indicates minimal reworking of the primary pyroclastic material.

Table 1. List of the major lithofacies present at Kima'Kho Mountain.

Lithofacies	Map unit	Description	Interpretation
Coherent (extrusive)	L_m	Massive lava; dark grey to black, poorly (<1%, <1 mm) to moderately vesicular (~30%, <3 cm, rounded to elongate vesicles) aphyric to moderately olivine-plagioclase-phyric aphanitic basalt; rarely pepperitic at base, columnar jointed (typically 10–50 cm spacing); always overlies lithofacies V_2, V_4, and L_p.	Effusive volcanism; subaerial lava that occasionally covered wet sediments.
	L_p	Pillow lava; dark grey to black, 95% coherent pillows about 0.5–1 m in diameter, dense to moderately vesiculated (~30% millimetre- to centimetre-scale round and centimetre-scale tube vesicles), glassy selvages up to 2 cm thick; 5% interpillow matrix of ash to lapilli-sized glass fragments.	Effusive volcanism; subaerial lava entering standing body of water.
Coherent (intrusive)	D	Dykes and sills; dark grey, commonly 1–5 m wide, poorly to moderately vesicular, basalt with less than 5% phenocrysts of olivine and plagioclase; dykes frequently pepperitic at margins; intrudes lithofacies V_1, V_2, V_4, and V_5.	Intrusion into either consolidated or wet, unconsolidated volcanic deposits.
Volcaniclastic	V_5	Massive to bedded basaltic tuff breccia to lapilli tuff; orange and black; massive to bedded, monolithic, poorly sorted, matrix-supported, 60% matrix of ash to lapilli-sized unaltered and palagonitized glassy basalt fragments, dense to poorly vesicular; 40% clasts of 1–50 cm angular to bulbous and wedge-shaped basalt fragments with rare glassy rims up to 1 cm, fresh to altered; palagonitized, dipping 20–40°, strike depends on map location (*see* Fig. 1b); underlies lithofacies L_m.	Effusive volcanism; subaqueous lava-fed delta, distal syndepositional facies of V_4; bulbous clasts originating from the disaggregation of pillow lavas.
	V_4	Weakly stratified basaltic tuff breccia; orange and black, massive to weakly stratified, monolithic, poorly sorted, matrix-supported, 60% matrix of ash to lapilli-sized, poorly (<1% <1 mm) to moderately (30% up to 3 mm) vesiculated glassy basalt fragments; clasts comprise varying proportions of intact pillow basalt, 0.5–2 m in size, dense to moderately (40% up to 1 cm) vesiculated, and angular pillow fragments oriented parallel to bedding; palagonitized, dipping 20–40°. Sometimes crosscut by intrusive pillow basalt; directly overlies V_2, (refer to graphic log in Fig. 5).	Effusive volcanism; subaqueous lava-fed delta, proximal facies. Some pillows may be intrusive to lithofacies V_4.
	V_3	Lapilli-tephra; black, scoriaceous with round to elongate vesicles, monolithic, aphyric, unconsolidated; patchy distribution on southeast Kima'Kho summit directly overlying V_2.	Explosive volcanism; scoria cone.
	V_2	Finely bedded to laminated lapilli tuff; beige to light orange, massive to laminated, occasional normal grading, monolithic, moderately sorted, matrix- to clast-supported, matrix of ash-sized blocky glass particles, clasts of lapilli-sized dense to vesicular glassy basaltic pyroclasts, unaltered to palagonitized, dipping 5–20°; stratigraphically underlies lithofacies V_3, V_4, V_5, L_m, and L_p.	Reworked explosive volcanic deposits; distal syndepositional facies of V_1; deposition into standing water, i.e. possible ice-marginal or englacial lake.
	V_1	Massive to coarsely bedded lapilli tuff; beige to light orange, massive to bedded, occasionally crosslaminated and crossbedded, monolithic, poorly sorted, matrix-supported, matrix of ash-sized blocky glass particles, containing up to block- and bomb-sized dense to vesicular glassy basaltic pyroclasts and armoured lapilli, interbedded with about 10 cm thick interbeds of tuff breccia (Fig. 4e), unaltered to palagonitized, dipping 0–30°; lowermost lithofacies unit below lithofacies V_3, V_4, V_5, L_m, and L_p.	Explosive volcanism; pyroclastic surge deposits.

Finely bedded to laminated lapilli tuff (lithofacies V_2)

Below an elevation of about 1840 m a.s.l., the eastern half of Kima'Kho comprises lapilli tuff that is characteristically finely bedded to laminated (Fig. 5f; Table 1). The deposit is moderately sorted, ranging from matrix- to clast-supported, and locally normally graded in contrast to the massive to coarsely bedded lapilli tuff found above 1840 m a.s.l. The matrix comprises ash-sized glass particles and clasts that are typically lapilli-sized, angular to subrounded, dense to vesicular pyroclasts. Similar to lithofacies V_1, the unit is crosscut by dykes on the east and northeast flanks of the volcano. The contact between units V_1 and V_2 is gradational.

Lithofacies V_2 is interpreted to be the syndepositional distal facies of the massive to coarsely bedded lapilli tuff (V_1). The unit is differentiated from lithofacies V_1 by the following: the presence of subrounded clasts; the clast-supported, well sorted nature of this deposit; and the absence of armoured lapilli. These features indicate that lithofacies V_2 deposit has been reworked by water, such as an ice-marginal or englacial lake.

Lapilli tephra (lithofacies V_3)

The deposit of black lapilli tephra is found near the summit of Kima'Kho and is observed to overlie lithofacies V_1 deposits (Table 1). The deposit is monolithological, unconsolidated, and has a patchy distribution across the southeast summit of the edifice (*see* V_3 in Fig. 3). The clasts are aphyric and scoriaceous; vesicles are generally round to slightly elongate.

The lapilli-tephra deposit is interpreted to have formed by explosive subaerial fire-fountaining activity, following the formation of the underlying pyroclastic surge deposits (*see* Fig. 7c).

Weakly stratified basaltic tuff breccia (lithofacies V_4)

The western half of Kima'Kho comprises weakly stratified basaltic tuff breccia that is overlain by subaerial lava flows (Fig. 4c, d, 5h; Table 1). The basaltic tuff breccia is orange due to pervasive palagonitization. The deposit is poorly sorted and clasts are supported by a matrix of ash to lapilli-sized glassy basaltic fragments. The block-sized clasts comprise predominately dense to highly vesiculated (25% ≤1 cm vesicles) intact pillow basalt units up to 2 m in size and angular pillow fragments. The pillow basalt units are typically parallel to crude bedding surfaces though some crosscut bedding. Dykes less than 5 m in thickness crosscut the basaltic tuff breccia locally. An example of these dykes is well exposed on the northeast flank of Kima'Kho (Fig. 4e). The basaltic tuff breccia can be observed to overly lithofacies V_2 with a sharp contact (Fig. 5f, 6b) at location "B" on the geological map (Fig. 3).

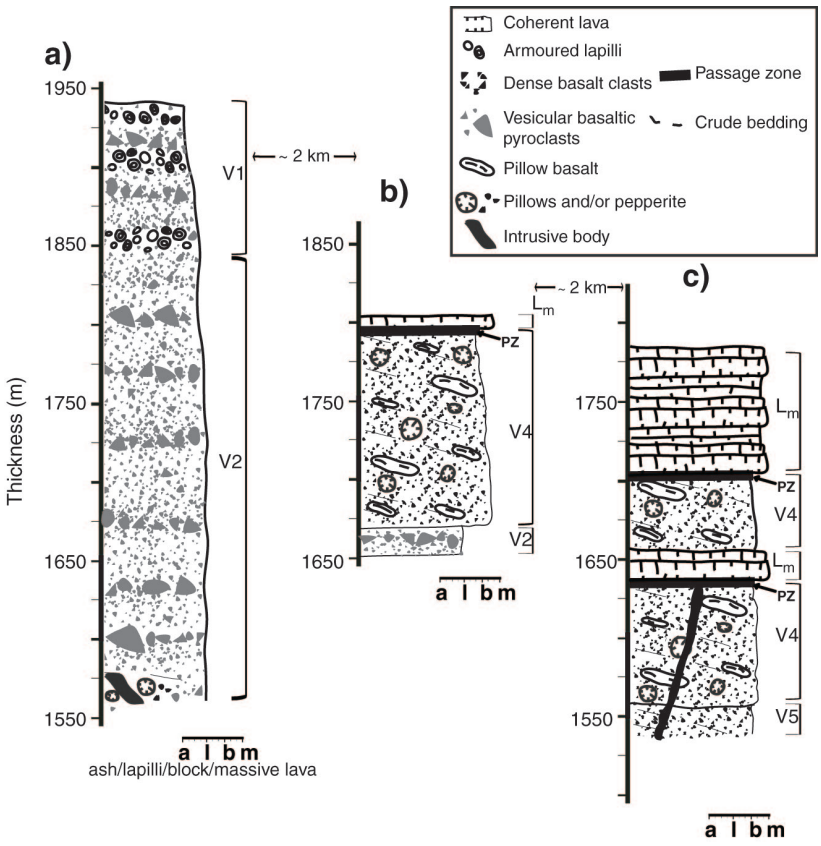

Figure 6. Graphic logs through three different stratigraphic sequences at Kima'Kho (refer to map in Fig. 3 for locations): **a)** southeast edifice, dominated by massive to coarsely bedded lapilli tuff (lithofacies V_1) and finely bedded to laminated lapilli tuff (lithofacies V_2), with armoured lapilli near the summit; **b)** southwest plateau, where the sharp contact between finely bedded to laminated lapilli tuff (lithofacies V_2) and overlying weakly stratified basaltic tuff breccia (lithofacies V_4) is exposed, all capped by subaerial lavas; and **c)** north plateau, where massive to bedded basaltic tuff breccia (lithofacies V_5) is present at the base of the sequence, and weakly stratified basaltic tuff breccia (lithofacies V_4) is interbedded with a subaerial lava flow, indicating a double passage zone.

The weakly stratified basaltic tuff-breccia deposits are interpreted to be a subaqueous lava delta that formed during effusive volcanism (Fig. 7c). Subaerial lava flows entered water, pillowed, and the pillows were subsequently deposited downslope as the delta prograded (Skilling, 2002). The majority of the matrix supporting the pillows and pillow fragments is interpreted to have formed due to the disaggregation of pillows and spalling of glassy pillow rinds; however, the pillow lavas that crosscut apparent bedding planes may be intrusive.

Massive to bedded basaltic tuff breccia to lapilli tuff (lithofacies V_5)

Massive to bedded basaltic tuff breccia is located on the north portion of Kima'Kho, below elevations of approximately 1560 m a.s.l. (Fig. 3; Table 1). The deposit is massive to bedded, matrix supported, poorly sorted, and interbedded with finer grained lapilli tuff. The clasts are dense to poorly vesicular, bulbous to wedge-shaped basalt fragments up to 50 cm in size, with rare glassy rims. The matrix comprises palagonitized ash to lapilli-sized glassy basalt fragments. The contact between lithofacies V_4 and V_5 is gradational.

This unit is interpreted to be the syndepositional distal facies of the weakly stratified basaltic tuff breccia comprising broken pillow basalt (lithofacies V_4). The combination of the lack of intact pillows and the presence of pillow fragments and bedding indicate reworking by water in the distal regions of the prograding delta.

Coherent intrusive deposits (lithofacies D)

Dykes and sills found crosscutting lapilli tuff (lithofacies V_1 and V_2) and basaltic tuff breccia (lithofacies V_4 and V_5) units are distributed across all regions of Kima'Kho except the south (Table 1). The dykes are typically 1–5 m in width and comprise olivine and plagioclase-phyric, poorly to moderately vesicular basalt (Fig. 4e, f). Pepperite and pillowed glassy dyke margins 1–2 cm thick are common.

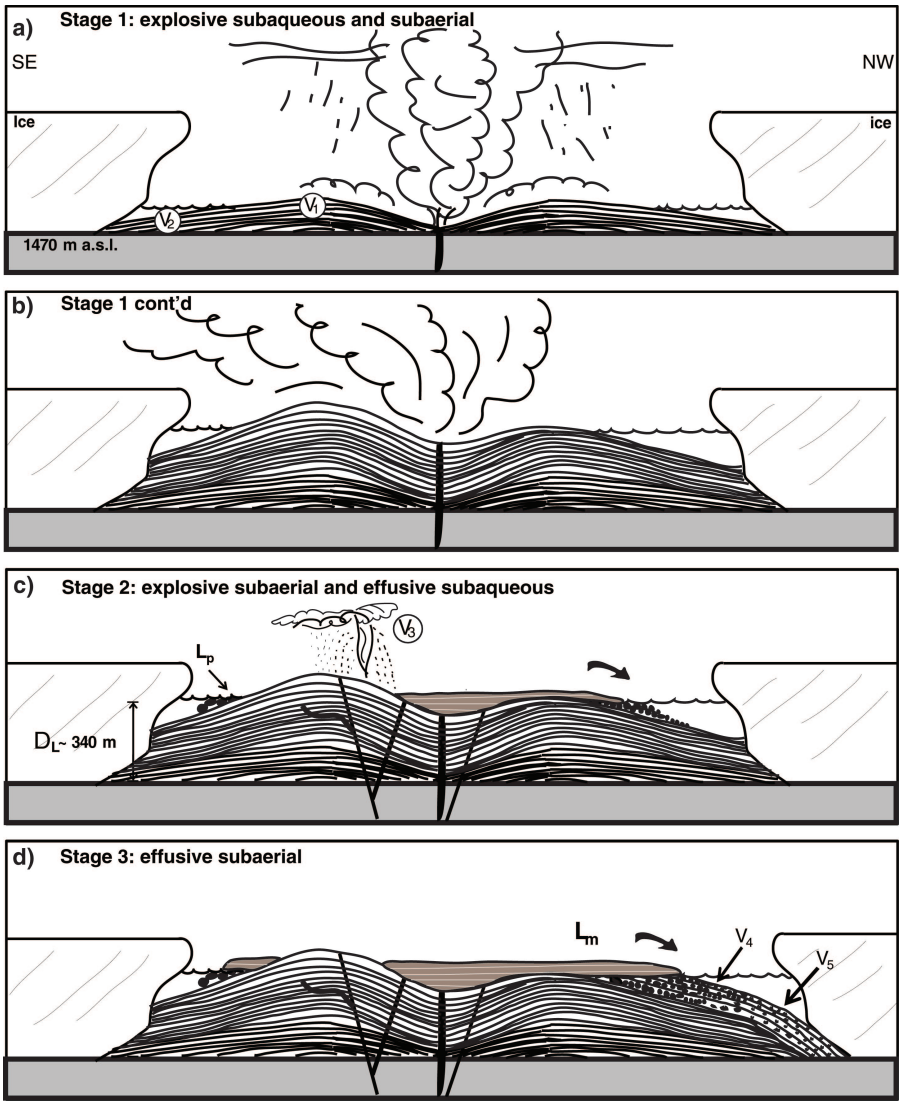

Figure 7. Schematic cross-section from south (left) to north (right) showing the progressive growth of Kima'Kho. The plateau surface on which the volcano sits has an elevation of 1470 m a.s.l. Initially, an ice sheet of unknown thickness covered the vent. The initial stage of the eruption melted through the ice, creating an intraglacial lake. The four main stages are: **a)** the explosive subaqueous and/or subaerial phase, where initially lithofacies V_1 is deposited with the syndeposition of reworked lithofacies V_2; **b)** the continuation of the explosive subaerial stage with progressive growth of the volcano; **c)** subaerial explosive fire-fountaining activity depositing V_3, and effusive subaqueous stage where L_m and L_p are deposited. Intrusions (lithfacies D) crosscut deposits formed during the explosive subaqueous phase. Arrow denotes transport direction of subaerial lava toward subaqueous deposition; and **d)** the effusive subaerial stage, where multiple subaerial lava flows (L_m) blanket earlier deposits, forming the northwest plateau, and lithofacies V_4 and V_5 are deposited. The depth of the reconstructed intraglacial lake at the time of the explosive stage is estimated at about 340 m, but likely fluctuated over the course of the eruption.

These intrusions have been emplaced into both dry and wet, unconsolidated sediments, as seen by pepperite along many of the dyke margins. Some of the dykes may have fed the subaerial lava flows that cap the north plateau (lithofacies L_m).

Coherent extrusive deposits

Massive lava (lithofacies L_m)

The flat-topped plateau comprises multiple subaerial lava flows on the northern half of Kima'Kho in addition to an isolated deposit on the east flank (Table 1; Fig. 3, 4b, c). Exposed on the north flank of Kima'Kho are two dominant flow successions, the 'lower' and the 'upper' (Fig. 4d). The lower flows are sandwiched between two sequences of weakly stratified basaltic tuff breccia and consist of at least five discrete flow units. The lowest elevation of subaerial lava occurs at 1620 m a.s.l. The upper sequence, which defines the Kima'Kho plateau consists of a minimum of 11 separate lava flows. The lavas comprise olivine and plagioclase-phyric basalt flows that are poorly to highly vesicular containing round, elongate, and pipe vesicles (Fig. 5c), commonly exhibiting columnar jointing. The surface morphology is dominated by pahoehoe flow tops, and metre-scale cavities interpreted to be explosion pits occur at the base of some lava-flow units.

Both upper and lower lava-flow sequences are interpreted to have formed by flow advance over the subaqueous lava-fed delta, originating from a central vent (Fig. 7). Occasionally, the underlying deposits were wet and unconsolidated at the time of lava emplacement, as seen by pepperitic bases of some of the flows. The origin of the isolated subaerial lava on the east flank is currently unknown as significant erosion has taken place and the unit is isolated from any potential source (Fig. 3).

An additional outcrop of massive lava is located stratigraphically above the lapilli-tuff deposits (lithofacies V_2) on the southwest side of Kima'Kho, much lower in elevation than the main lava cap (Fig. 3). In hand sample, the lava resembles the capping lava on the northwest plateau; however, similar flat-lying flows can be found nearby on the Kawdy Plateau. Two possibilities for the origin of this lava include: it is sourced from the Kima'Kho vent that flowed down on top of lithofacies V_2 deposits after the lake drained, or it is a younger flow from another volcano. Geochemical studies are underway to test these hypotheses.

Pillow lava (lithofacies L_p)

One pillow lava unit, approximately 10 m wide by 10 m high, is exposed at 1740 m a.s.l. on the eastern ridge of Kima'Kho (Table 1; Fig. 3). The pillow lava is located stratigraphically between lithofacies V_2 and L_m. The pillow lava comprises 95% elongate, intact pillows that are dense to highly vesiculated (Fig. 5g). The pillows have glassy selvages up to 2 cm thick and 5% interstitial matrix comprising ash- to lapilli-sized glass fragments.

The pillow lava is interpreted to have formed during effusive activity where subaerial lava entered a standing body of water, but was not transported a significant distance from the source.

The basaltic tuff-breccia units are capped by massive lavas (described above); the contact between the breccia and the lava is mapped as the 'passage zone' (Jones, 1968) and demarcates the transition from a subaqueous to subaerial regime (Fig. 6). On the north end of the volcano, the basaltic tuff breccia contains an interval of lavas at a lower elevation. These lavas are capped by basaltic tuff breccia which is sandwiched below the above subaerial lava. The repetition of this subaqueous to subaerial sequence is referred to as a 'double passage zone' (Fig. 4d, 6c).

PRELIMINARY PETROGRAPHY

Eleven samples from Kima'Kho have been examined in thin section, including three pyroclastic and eight coherent samples. A single sample of lapilli tuff (lithofacies V_1) is dominated by moderately to highly vesicular palagonitized blocky glass fragments, up to 1 mm. A minor amount of the lapilli tuff comprises subrounded glassy pyroclasts that are up to 3 mm. Some of the ash particles contain elongate vesicles and equant broken olivine grains less than 1 mm. The lapilli tuff contains less than 5% isotropic cement and carbonate. Two armoured lapilli (lithfacies V_1) each have cores comprising a single highly vesicular glassy pyroclast (2 cm and 3.5 cm in diameter). The cores contain round, elongate to irregular vesicles up to 2.5 mm and minor amounts of olivine up to 0.5 mm. Both armoured lapilli cores are coated with a partially palagonitized concentric shell of moderately to highly vesicular blocky and cuspate vitric fragments up to 1.5 mm. The coatings also contain finer subrounded pyroclasts similar to the core of the lapilli that are 0.5 mm and broken olivine crystals up to 0.5 mm.

Three extrusive samples from the subaerial lava cap (lithofacies L_m) and four intrusive samples (lithofacies D) are all holocrystalline and olivine porphyritic (15%, up to 2 mm), with a groundmass mineralogy of plagioclase (20–40%, up to 1 mm), olivine (20%, up to 0.1 mm), titanaugite (20–30%, up to 0.25 mm), and opaque minerals (2–15%, up to 0.1 mm). Two of the intrusive samples contain 10–20% plagioclase phenocrysts, up to 5 mm. Based on mineralogy, six of the coherent samples are alkali olivine basalt, but one dyke sample may be mugearite or hawaiite in composition based on the high plagioclase content (40%). The extrusive samples typically contain approximately 5% rounded to elongate vesicles up to 1 mm. The intrusive samples range from non- to poorly vesicular (2%) with rounded vesicles up to 0.75 mm. A single sample of hyalocrystalline pillow lava (lithofacies V_4) is olivine porphyritic (10%, up

to 0.5 mm), with plagioclase (30%, up to 0.5 mm), opaque minerals (25%, up to 0.25 mm), titanaugite (10%, up to 0.1 mm), olivine (10% up to 0.1 mm), and glass (10%) in the groundmass. The pillow lava contains 1% round vesicles that are up to 0.25 mm and is either an alkali olivine basalt or hawaiite.

IMPLICATIONS AND CONCLUSIONS

Kima'Kho Mountain records a history of volcano-ice interaction. The presence of multiple passage zones on the north flank indicate a dynamic glacial lake environment, with the highest lake level occurring at 1810 m a.s.l. (i.e. lake depth of about 340 m). The continuous stratigraphy of lapilli tuff and pillow breccia (Fig. 6b) indicate an explosive onset of eruption followed by a transition to effusive activity (Fig. 7). The presence of young glacial deposits on Kima'Kho indicates that the edifice has been overrun by glaciers after the eruption.

ACKNOWLEDGMENTS

Funding and support for this research was provided by the National Science Foundation (Research grant EAR-0910712; B. Edwards), the Natural Science and Engineering Research Council (Discovery Grant, J.K. Russell; PGSD3 Postgraduate Scholarship, C. Ryane), and the Indian and Northern Affairs Canada Northern Scientific Training Program (Research Grant; C. Ryane). The authors thank S. Kolzenburg, B. Parker, R. Jansen, G. Dunnington, and E. Lasher for help with logistics and assistance in the field and M. Kelman for a review of this manuscript. The authors also thank J. and S. Reed from Pacific Western Helicopters, and C. Price from B.C. Parks in Dease Lake, British Columbia. The paper benefitted from critical discussions with L. Porritt.

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APPENDIX

Three major diamict deposits have been found at Kima'Kho. These include:

1. Clast-supported glacial moraine ((?)Little Ice Age) formed by small cirque glacier on northeast flank (Fig. 3).
2. Massive to normally graded, less than 1 cm to 50 cm clasts, 5–10 cm dominated, subangular to rounded, grey silt/ clay matrix supported, 50–60% matrix, unconsolidated to lithified, granitic and basaltic clast dominated ground moraine on north flank, possibly deposited by Cordilleran ice (Fig. 3).
3. Large-scale landslide deposit on east flank.