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Preliminary results of field mapping, petrography, and GIS spatial analysis of the West Tuya lava field, northwestern British Columbia

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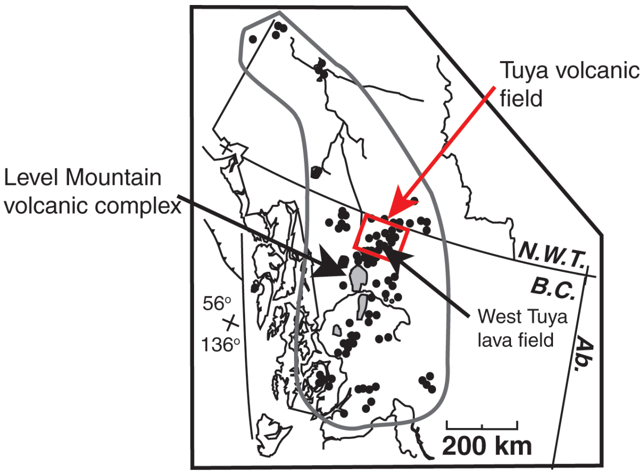
Abstract: An overview and summary of fieldwork, GIS spatial analysis, and preliminary petrographic analysis conducted between July 2003 and August 2004 is presented for the West Tuya lava field, which is part of the northern Cordilleran volcanic province, in the south-central part of the Jennings River (NTS 104-O) map area, northwestern British Columbia. The most important preliminary results include the following: a) identification of three subaerial shield volcanoes, which, based on mineralogy, probably range in composition from alkaline basalt to nephelinite and/or mafic phonolite, b) confirmation that mantle-derived peridotite inclusions ranging from 1 to 4 cm in size are present at two of the volcanoes, and c) interpretation of the subaerial lava flows as predating the Holocene. Using the 3D Analyst extension of ArcGIS 8.3, the minimum and maximum volumes of material erupted can be constrained to 10.36 km^3 and 23.42 km^3, respectively.

Résumé : Nous présentons un aperçu et un sommaire des travaux sur le terrain, de l'analyse spatiale sur SIG et de l'analyse pétrographique préliminaire effectués entre juillet 2003 et août 2004 pour le champ de lave de West Tuya de la province volcanique de la Cordillère du Nord, qui occupe le centre sud de la région cartographique de Jennings River (SNRC 104-O), dans le nord-ouest de la Colombie-Britannique. Parmi les résultats préliminaires les plus importants, mentionnons : a) l'identification de trois volcans-boucliers subaériens dont la composition, telle que déterminée d'après les données minéralogiques, varie probablement du basalte alcalin à la néphélinite ou à la phonolite mafique, b) la confirmation du fait que des inclusions de péridotite dérivées du manteau, d'une taille variant de 1 à 4 cm, sont présentes dans deux des volcans et c) une interprétation situant la mise en place des coulées de lave subaériennes avant l'Holocène. À l'aide de l'extension 3D Analyst du logiciel ArcGIS v. 8.3, on peut établir les limites minimale et maximale du volume des matériaux éruptifs à 10,36 km^3 et 23,42 km^3, respectivement.

INTRODUCTION

The West Tuya lava field (NTS 104-O; centre UTM 390000E/6555000N; base at 1450 m above sea level) is at the western edge of the Tuya volcanic field, within the south-central part of the Jennings River 1:250 000-scale map area (Gabrielse, 1969; Fig. 1). The West Tuya lava field is located approximately 95 km north-northwest of Dease Lake, British Columbia. The volcanic field comprises three discrete topographic high points, partly bounded by plateaus.



The rocks in the lava field were previously mapped as part of the Tuya Formation, which encompasses a large number of basaltic volcanic vents in areas covered by the Dease Lake, Cry Lake, and Jennings River map sheets (Watson and Mathews, 1944; Gabrielse, 1969, 1998). The Tuya Formation is mapped across an area covering three map sheets (Dease Lake, Jennings River, and Cry Lake) and comprises more than thirty individual volcanic features at a scale of 1:250 000, including the Level Mountain volcanic complex (Hamilton, 1981), the Tuya volcanic field, and the West Tuya lava field.

Previous work on the Tuya volcanic field includes regional mapping by Watson and Mathews (1944) and Gabrielse (1969), and detailed stratigraphic analysis of specific volcanic centers (Mathews, 1947; Allen et al., 1982; Moore et al., 1995; Simpson, 1996; Dixon et al., 2002). Watson and Mathews (1944) first mapped several flat-topped, steep-sided volcanoes in the Tuya-Teslin area; the majority of the flat-topped volcanoes, or tuyas, were composed of basaltic lava, tuff, and agglomerate. Mathews (1947) proposed that the formation of the tuyas was related to the eruption of lava under a large Pleistocene ice sheet. Gabrielse (1969) supported Watson and Mathews' findings and concluded that volcanism was interspersed with glaciation. Other studies conducted in the area have focused on the glaciovolcanic deposits to the east of the West Tulya lava field (Mathews, 1947; Allen et al., 1982; Moore et al., 1995; Simpson, 1996; Dixon et al., 2002). Of particular interest to this study was the description by Watson and Mathews (1944) of rocks from two hills approximately

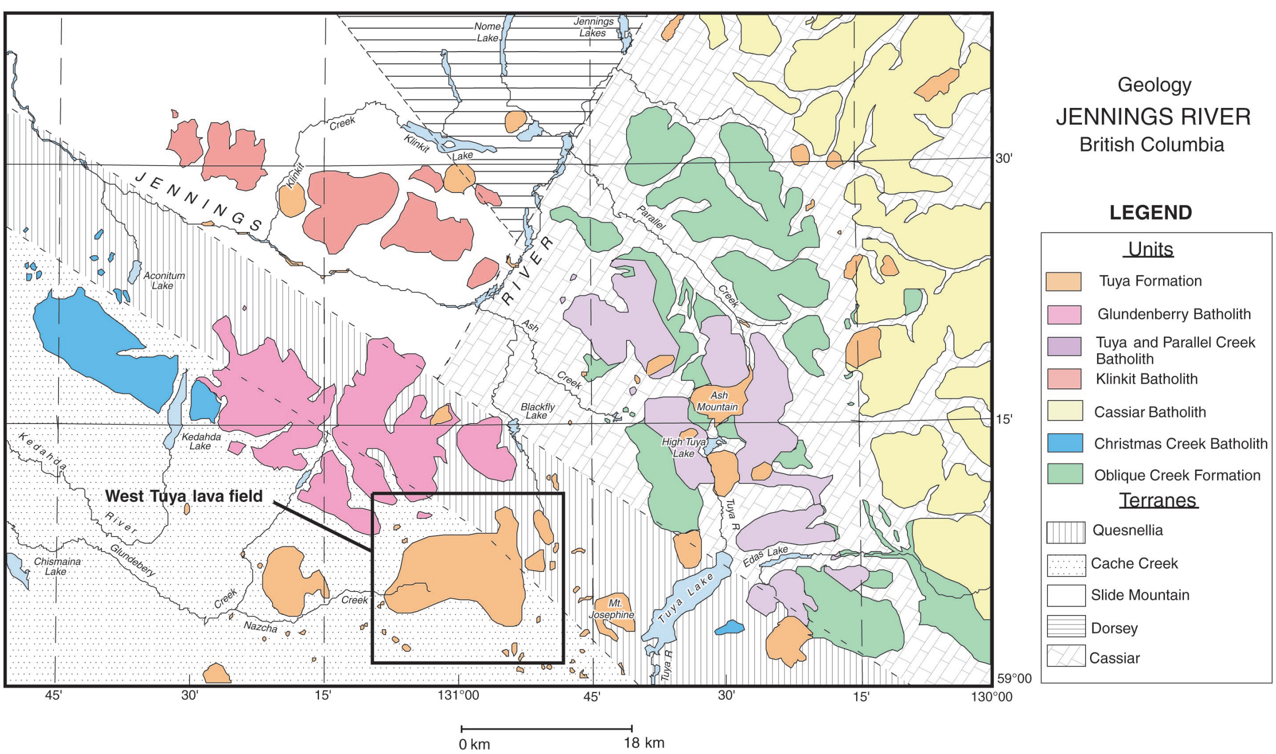


Figure 1. Northern Cordilleran volcanic province inset and regional map. Grey outline shows the extent of the northern Cordilleran volcanic province, black circles denote individual volcanic centres.

13 km northwest of Mount Josephine (Fig. 1) as light grey trachyte containing olivine-rich inclusions. The West Tuya lava field, the area that comprises the southwestern portion of the Tuya volcanic field, appears to be dominated by flat-lying geographic features, rather than the subglacial mounds previously mapped elsewhere throughout the region.

During August 2003, 7 days were spent in the lava field mapping at 1:20 000 scale, describing volcanic units, and collecting samples for petrographic and geochemical analysis. Field maps and sample locations were transferred to ArcGIS 8.3 and used for quantitative spatial analysis. The main goal of the study was to confirm earlier reports of the occurrence of trachytic lava flows and olivine-rich inclusions described by Watson and Mathews (1944). Current work is to complete a detailed study of the volcanic rocks in this area using transmitted-light microscopy, energy-dispersive spectrometry (EDS), and X-ray fluorescence spectrometry (XRF). This report presents field descriptions and maps, results from GIS spatial analysis, and preliminary results from detailed petrographic and SEM-EDS analysis of lava samples.

FIELD MAPPING AND UNIT DESCRIPTIONS

Overview

Three possible vent areas were identified from mapping, herein informally referred to as 'Volcano' vent, 'Grizzly Butte' vent, and 'West' vent (Fig. 2). Volcano vent, West vent, and Grizzly Butte vent stand in relief above the surrounding area north and east of the headwaters of Nazcha Creek and comprise the West Tuya lava field (Fig. 2).

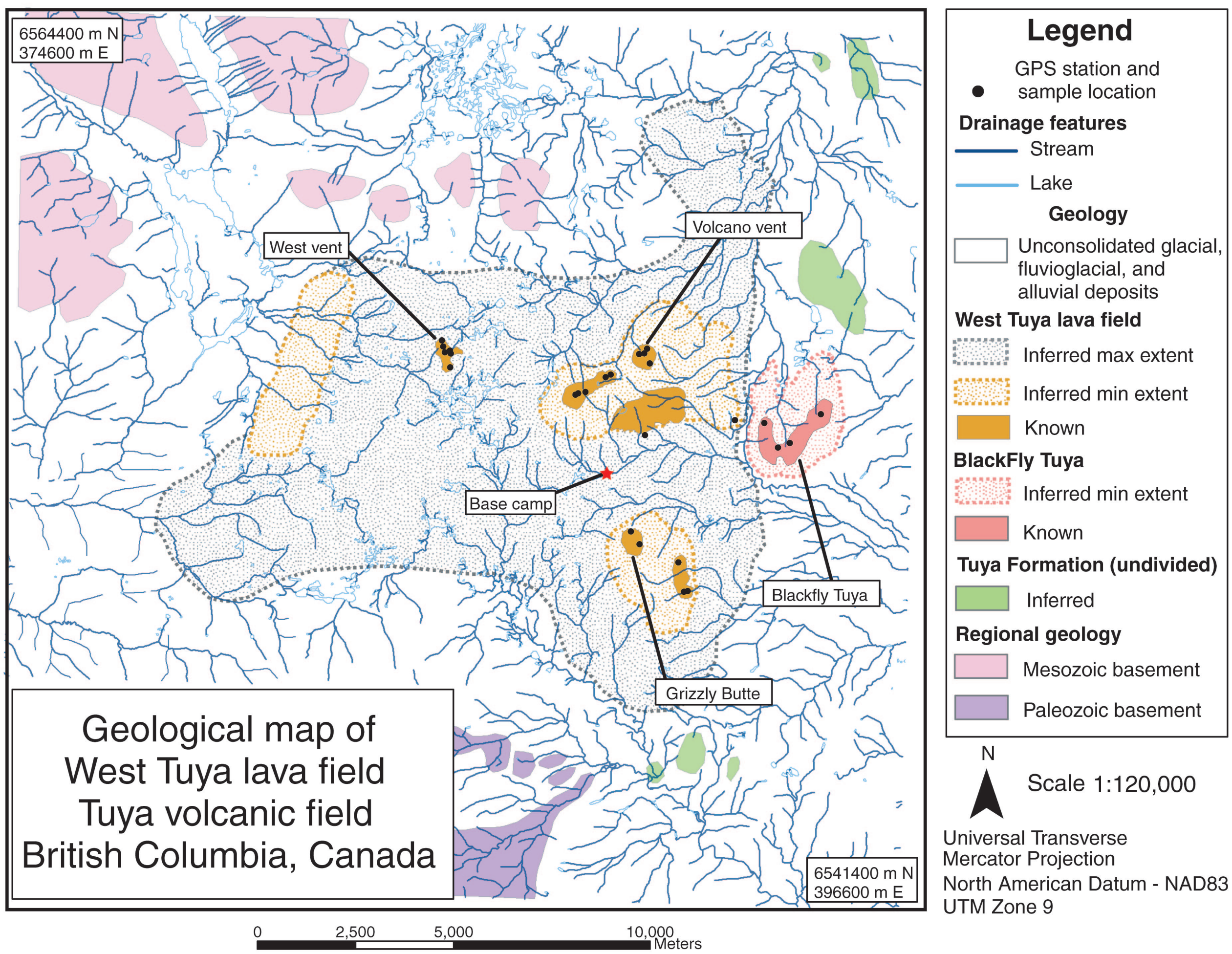
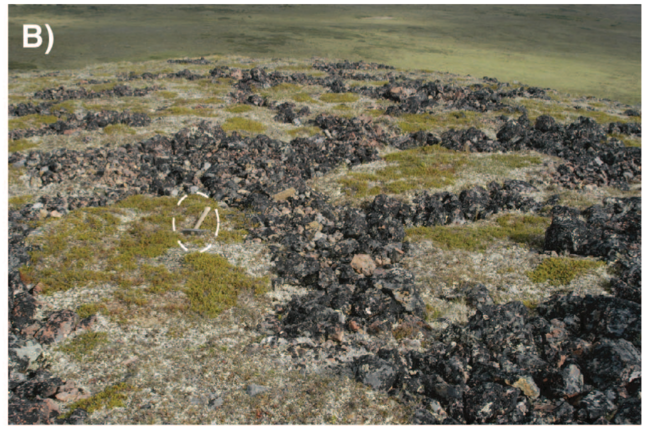


Figure 2. *Geological map of West Tuya lava field, Tuya volcanic field. Boundaries and details of Paleozoic basement, Mesozoic basement, Tuya Formation, and unconsolidated glacial, fluvioglacial, and alluvial deposits derived from the Jennings River 1:250 000 map sheet (Gabrielse, 1970). The lava plateau consists of areas of relief, shown in orange, as known outcrop and labeled Volcano vent, West vent, and Grizzly Butte. The inferred minimum extent of the vents is indicated by a dotted orange line, the GPS stations and sample locations are indicated by black dots.*



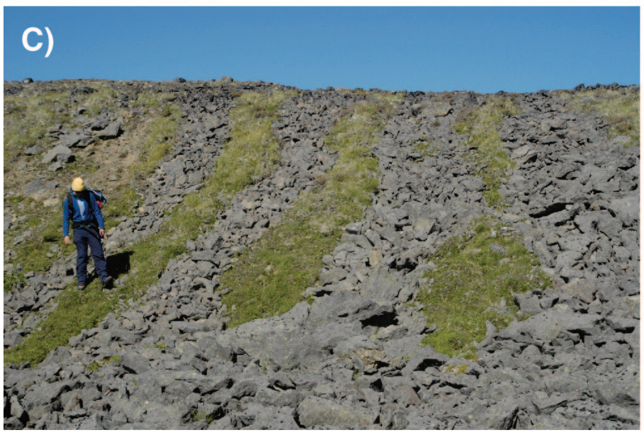


Figure 3.

A) *Boulder containing glacial striations in ravine south of Grizzly Butte.*

B) *Frost-heave polygons on top of Volcano vent. Rock hammer is 55cm long*

C) *Rock trains created by freeze-thaw processes creeping downslope of the southeastern side of Grizzly Butte.*

The 1:120 000-scale geological map of the West Tuya lava field was derived from regional mapping by Gabrielse (1969), as well as detailed field and aerial reconnaissance during this study. The central part of the map is dominated by the lava field, which is interpreted to have been an extensive lava plateau that has subsequently been disrupted by erosion. The inferred maximum extent of 12.5 km by 10 km is derived from Gabrielse's Jennings River map sheet (1969) and from aerial reconnaissance (Fig. 2).

The volcanic plateau is characterized by a number of glacial and periglacial features including glacially striated erratics (Fig. 3A), frost-wedge polygons (Fig. 3B), and rock trains (Fig. 3C).

The surrounding regional geology mapped by Gabrielse (1969) consists of Paleozoic basement to the south, Mesozoic basement to the north-northwest, Tuya Formation to the east, and unconsolidated glacial, fluvioglacial, and alluvial deposits throughout (Fig. 2). The Tuya Formation was mapped by Gabrielse (1969) as one formation that extends throughout the Dease Lake and Jennings River map areas. Although the primary focus in the field was specific to the areas of reported trachytic lava flows, adjacent areas of the Tuya formation were examined and a previously undescribed, separate tuya referred to as 'Blackfly' tuya (Fig. 2) was identified.

Volcano vent

Volcano vent (UTM centre: 389935 E, 6555499 N, Fig. 2) is located approximately 3400 m north of base camp, at an elevation of 1550 m (Fig. 4A). The area southwest of the vent comprises a series of disconnected plateaus (Fig. 5A) which may have come from the same vent. Outcrops vary from rubbly subcrop and rubbly outcrop to bouldery outcrop.

Much of the rock observed and sampled at Volcano vent is massive coherent basalt. Distinctive red volcaniclastic basalt breccia deposits are also present on the northern side of the vent. The nonvesicular to poorly vesicular porphyritic coherent basalt weathers dark grey and is covered by black lichen. Fresh rock ranges from red-brown to light grey. The coherent basaltic facies contain felsic, mafic, and troctolitic xenoliths, as well as xenocrysts of feldspar, olivine, and amphibole. Xenoliths range in size up to 3.5 cm (Fig. 5C). The coherent basalt facies is interpreted as subaerial basaltic lava flows.

The red volcaniclastic breccia deposits comprise ash to bomb-sized clasts, with the larger fragments commonly having a black, vitreous appearance in hand sample. Vesicularity ranges from highly vesicular scoria to poorly and nonvesicular glassy clasts. Vesicles range from less than 1 mm to less than 1 cm in size and are spherical, irregular, or elongate. The clasts are interpreted to have formed by explosive fragmentation from a subaerial vent.

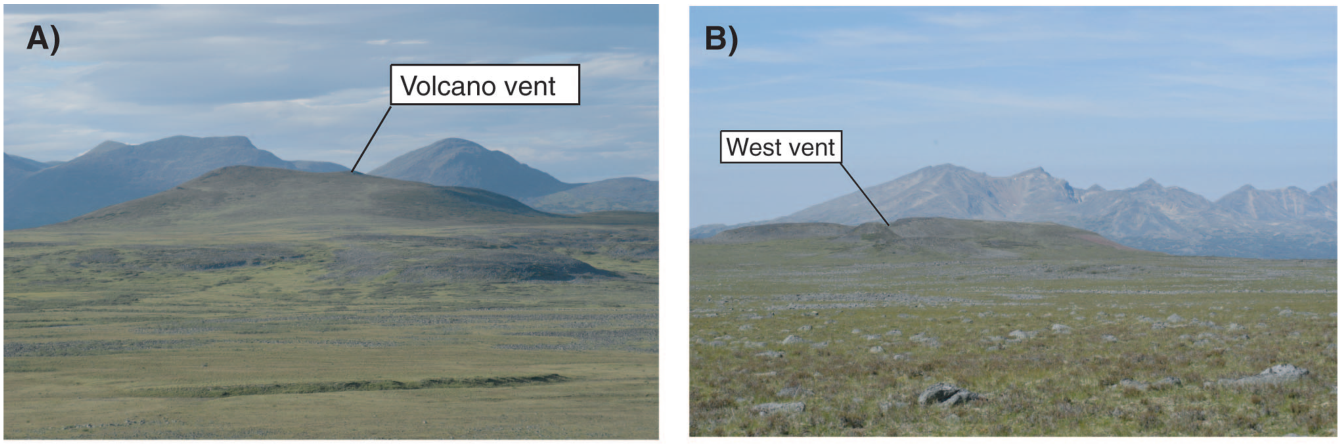


Figure 4. Field photographs showing general geological features from the West Tuya lava field.

A) *South side of Volcano vent taken facing north from the top of Grizzly Butte.*

B) *East view of West vent taken approaching the area from the east.*

C) *Boulder field of fine-grained lava.*

West vent

West vent (UTM centre: 384960 E, 6555850 N, Fig. 2) is approximately 7000 m northwest of base camp, at an elevation of 1480 m and consists of a group of knobs surrounding a main ridge (Fig. 4B, 6A, B). The outcrop varies from subcrop and frost-wedged outcrop to isolated rubbly knobs. What appear to be crude columnar joints having a diameter of 1 m were found on one of the northern knobs. The outcrop weathers into slabs along unusually platy horizontal joints at the southernmost knob (Fig. 6C).

Coherent fine-grained, porphyritic basalt is the dominant rock type at West vent. Weathered porphyritic basalt is red and grey, whereas fresh rock is red to dark grey. The coherent facies is nonvesicular to poorly vesicular and contains feldspar and olivine phenocrysts. Feldspar xenocrysts up to 4 cm long and olivine xenocrysts are present. Crustal xenoliths ranging from 3 to 4 cm were also found. The coherent basalt facies is interpreted as the remnants of subaerial lava flows.

At the northern part of the vent area, the base of the coherent facies is underlain by volcanic breccia consisting predominantly of less than 1 cm to less than 2 cm scoriaceous, subangular clasts. The clasts are highly vesicular, red, and have smooth ropey outer surfaces indicative of cooling surfaces. The clasts are interpreted to be the products of subaerial explosive eruptions.

Grizzly Butte vent

Grizzly Butte (UTM centre: 389814 E, 6550982 N, Fig. 2) is a flat-topped circular hill approximately 2000 m due south of base camp, at an elevation of 1500 m (Fig. 7A). The top of the butte is covered with frost-wedge polygons. The outcrop varies from competent cliff and talus slopes to steep cliff with overlying outcrop and large float blocks. The lava plateau terminates in a series of gullies south of Grizzly Butte.

Grizzly Butte consists of fine-grained porphyritic coherent basalt and subordinate volcaniclastic breccia. Coherent basalt facies are nonvesicular and massive, rare blocks are flow banded on a millimetre to centimetre scale. The weathered, porphyritic basalt is grey, whereas fresh rock is generally light grey. Abundant angular to rounded mantle xenoliths ranging from less than 1 to 4 cm (Fig. 7D) and less abundant crustal xenoliths as large as 10 cm were observed within the coherent basalt facies. Subhedral, rounded feldspar xenocrysts (Fig. 7D), as well as euhedral amphibole xenocrysts, were also observed. The coherent basalt facies is interpreted as the remnants of subaerial lava flows.

Volcaniclastic facies consist of loose, moderately to highly vesicular scoriaceous basalt clasts. The deposits are monomictic and contain angular to subrounded scoria clasts. Most of the clasts are a distinctive red colour, and less commonly, dark grey. Two clasts preserved an outer surface with

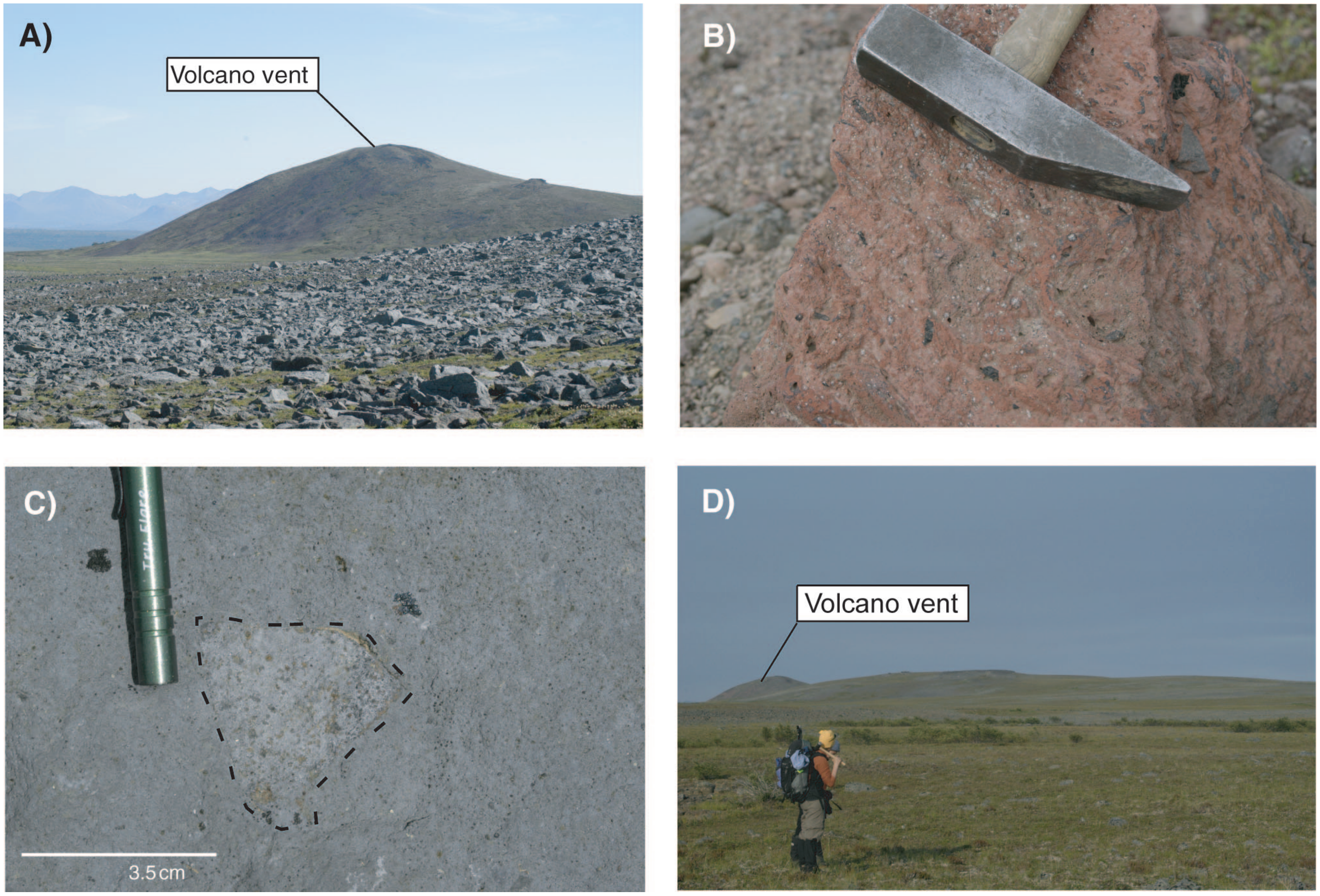


__Figure 5.__ __A)__ View looking east at the west side of Volcano vent. __B)__ Basaltic coriaceous breccia. Clasts appear to have sintered together on deposition. Red colouration likely due to oxidation. Sample collected from northeast side of Volcano vent. __C)__ Crustal xenolith in fine-grained mafic volcanic rock sampled on east side of Volcano vent. __D)__ View of lava buttes taken from the west, facing east. Volcano vent located in the background to the left.

a distinctive fracture network and were interpreted as bread-crust textured bomb fragments (Fig. 7B). The volcaniclastic facies are interpreted as the products of subaerial explosive eruptions.

Small mounds of orange to brown, coriaceous, nonresistant volcaniclastic deposits are found in the gullies south of Grizzly Butte (Fig. 7C). The lapilli-sized clasts are relatively well sorted and the deposits are clast supported. The deposits are overlain by coherent fine-grained, olivine-phyric vesicular mafic to intermediate volcanic rock similar to that seen at Grizzly Butte.

ArcGIS

Digital TRIM maps 1040.006, 1040.015, and 1040.016 were obtained from the Province of British Columbia. ArcGIS 8.3 software was used to analyze digital elevation models for the Tuya volcanic field, as well as to create a preliminary geological map of the West Tuya lava field. Three-dimensional models of the vents were generated using the 3D Analyst extension of ArcGIS, so that surface areas and volumes for the vents and the maximum inferred extent of the West Tuya lava field could be estimated. Three-dimensional models are created using a Triangulated Irregular Network (TIN) that represents a continuous surface through a series of irregularly spaced points. A network of linked triangles then forms the surface from these points (Minami, 2000). Methodology used to generate the TIN models is similar to that used by Edwards and Bye (2003).

Preliminary results (Table 1) indicate that the maximum extent of the West Tuya lava field has an inferred surface area of 126.3 km^2. The lava field has a minimum inferred volume of no less than 10.36 km^3, while the inferred maximum volume is no greater than 23.43 km^3. The discrepancy between the two volume estimates arises from the need to choose a single elevation as the base level for the calculation. It is likely that post-eruption erosion has removed a considerable volume of material from the lava field as well.

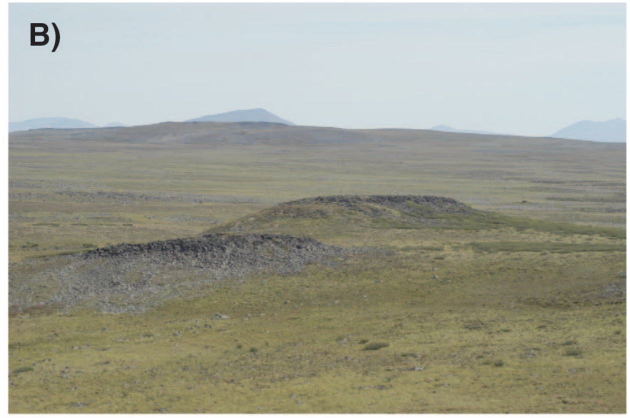


Figure 6.

A) *West view of isolated rubbly knob with person for scale near the top.*

B) *North view of southernmost lava mounds at West vent.*

C) *Unusual horizontal jointing which is fracturing southernmost mound into platy slabs. Rock hammer is 55 cm long.*

PETROGRAPHY

Hand samples were described in the field and representative samples were processed for microscopic analysis. As part of a preliminary study, two samples (03KW245, 03KW247) were analyzed using a JEOL 5900 Scanning Electron Microscope (SEM) with an Oxford Energy Dispersive Spectrometer (EDS) to estimate mineral compositions.

Sample 03KW245 is a coherent, fine-grained mafic to intermediate rock from Grizzly Butte, and was interpreted to be basalt in the field. SEM-EDS analysis shows that it comprises olivine (Fo_{64-89}), clinopyroxene (Di_{75-80}), alkali feldspar (~An_{0-6}, Ab_{47-60}, Or_{39-53}), nepheline and Ti-magnetite. The sample contains three inclusions; one a multigrained inclusion comprising mainly olivine (Fo_{85-86}) and the other an olivine crystal with a composition of Fo_{70-89}. The third inclusion is relatively fine grained and comprises ilmenite and clinopyroxene in a finer grained groundmass of nepheline.

Sample 03KW247 is also a coherent mafic volcanic rock from one of the small lava plateaus immediately southwest of Volcano vent. It is porphyritic and contains approximately 10% feldspar phenocrysts as well as less than 5% phenocrysts of olivine. Sample 03KW247 comprises olivine (Fo_{45-74}), clinopyroxene (Di_{74-80}), plagioclase feldspar (An_{20-68}), and magnetite.

Sixteen other samples are currently being examined with a petrographic microscope and appear to only have olivine microphenocrysts in a fine-grained groundmass of feldspar and opaque grains.

DISCUSSION

Assessment of 'trachyte' lava flows

One of the main goals of this study was to confirm the existence of trachytic lava flows as reported by Watson and Mathews (1944). While the ultimate answer to this question awaits completion of major-element analyses, the preliminary SEM-EDS work can be used to assess this claim. Watson and Mathew's (1944) report identified trachyte lava flows based on petrographic observations, in particular, alkali feldspar in the groundmass. SEM-EDS analysis confirms that a sample from Grizzly Butte does have alkali feldspar in its groundmass. However, the groundmass also contains abundant nepheline, and the clinopyroxene and olivine compositions of what appear to be phenocrysts are too magnesium-rich to have crystallized from typical trachytic magma. The preliminary interpretation is that this sample is a nephelinite/ mafic phonolite, which may be similar in composition to nephelinites found farther to the north in the Atlin volcanic

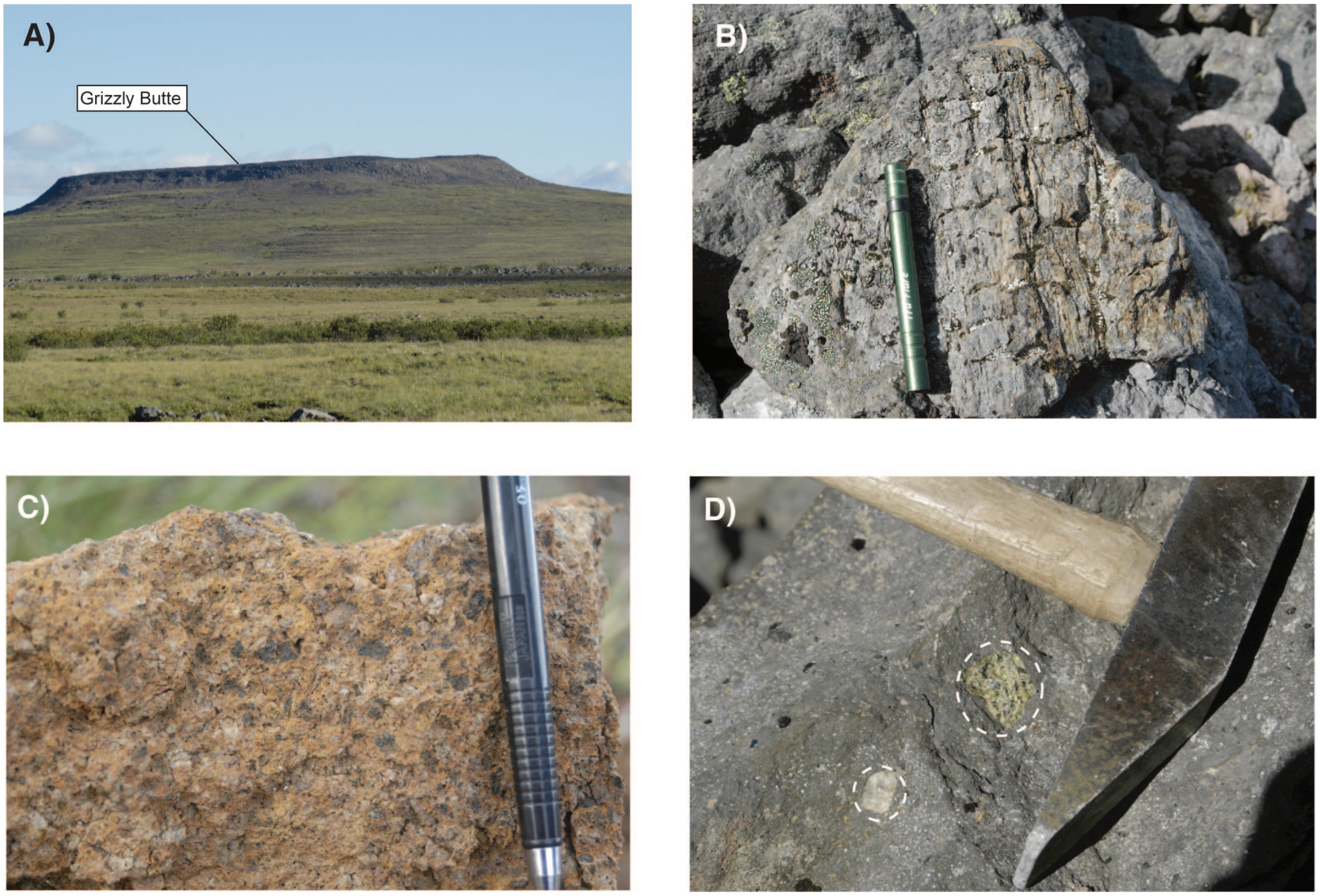


Figure 7. ***A)*** *Northern side of Grizzly Butte, approximately 2000 m south of base camp.* ***B)*** *Bread-crust bomb textured fragment found on the northern side of the butte.* ***C)*** *Volcaniclastic breccia in ravine cut southeast of Grizzly Butte.* ***D)*** *Feldspar xenocryst and ultramafic xenolith in basaltic lava flow from Grizzly Butte.*

Table 1. Surface area and volume calculations for West Tuya lava field, Tuya volcanic field, British Columbia.

Volcanic Feature	Location UTM	Elevation (Z min) m	Surface area (mapped) km^2	Surface area (inferred) km^2	Volume (mapped) km^3	Min volume (inferred) km^3	Max volume (inferred) km^3
Blackfly Tuya	393268 E 6553562 N	1373	1.315	5.725	0.0606	0.2304	N/A
Volcano vent	389935 E 6555499 N	1324	2.412	6.832	0.1091	0.4012	N/A
Grizzly Butte	389814 E 6550982 N	1411	6.797	4.995	0.0303	0.2217	N/A
West vent	384960 E 6555850 N	1452	2.968	2.989	0.004	0.004	N/A
Max Extent 05	381840 E 6551511 N	1240	N/A	21.41	N/A	6.226	6.226
Max Extent 06	389638 E 6550322 N	1363	N/A	34.00	N/A	3.035	4.916
Max Extent 15	383178 E 6555044 N	1324	N/A	23.58	N/A	2.325	8.676
Max Extent 16	389342 E 6555148 N	1319	N/A	47.34	N/A	5.002	3.606
			Max extent West Tuya	126.3	**Max extent West Tuya**	10.36	23.42

field (Francis and Ludden, 1995; Edwards et al., 2003; Harder et al., 2003) and in the Fort Selkirk volcanic field (Trupia and Nicholls, 1996; Francis and Ludden, 1990).

Development of the volcanic field

Field evidence for style of eruption in this part of the West Tuya volcanic field is consistent with the formation of a series of subaerial shield volcanoes produced by Hawaiian-style eruptions. These subaerial eruptions were dominated by effusive eruption of lava with only minor pyroclastic deposits adjacent to the three identified vents. It appears that in some cases the pyroclasts retained sufficient heat upon deposition to permit sintering together (Fig. 5B). Primary cooling surfaces on some clasts are still preserved and show smooth, ropey textures, suggesting air-cooling. Black, denser domains may represent the chilled, nonvesicular margins of clasts.

Volcanism probably occurred during the last interglacial period as the remnants of lava flows appear to have been glaciated. The relative ages of the vents cannot be determined due to lack of observable contact relationships. However, no one vent appears to be more glaciated than the others; therefore it is inferred that they erupted nearly synchronously. Although not all of the Tuya Formation vents in the Jennings River map area have been investigated in detail, preliminary work and aerial reconnaissance indicate that these vents, along with Gabrielse's cone to the northwest of Ash Mountain (Fig. 1), are three of the few subaerial eruption features in the map area.

Xenoliths and terrane boundaries

The western part of the Tuya volcanic field overlaps the boundary between the Cache Creek and Quesnellia terranes (Fig. 1). The preliminary assessment of the compositions of xenoliths from Grizzly Butte and Volcano vent suggest the xenoliths represent a range of different bedrock types and may be derived from different tectonostratigraphic terranes (i.e. Cache Creek for Grizzly Butte vent and Quesnellia for Volcano vent). This is inferred because the Grizzly Butte peridotite xenolith has higher Fo and Di ranges than xenocrysts from Volcano vent, Volcano vent has higher Mt ranges than Grizzly Butte, and Grizzly Butte includes nepheline and ilmenite while Volcano vent does not. It is likely that the xenolith (Fo_{86}) in sample 03KW245 is from the mantle as opposed to a cumulate that could have formed from the crystallization of basalt. Furthermore, the olivine xenocryst from the same sample was probably introduced into the magma sometime during transport.

ONGOING WORK

The continuation of this project is part of an undergraduate senior thesis at Dickinson College by KW. Petrographic and SEM-EDS work to characterize the mineral compositions of samples of lava and of xenoliths collected from the vents comprising the West Tuya lava field is continuing. Major-element analyses and trace-element analyses will be completed using XRF techniques to further characterize the samples of lava and determine if they are genetically related and if they derive from the same source lithologies. Compositions from the mantle xenoliths from this area will be compared to those from other parts of the northern Cordilleran volcanic province to assess possible differences in lithospheric mantle compositions beneath different tectonostratigraphic terranes.

CONCLUSIONS

Three volcanic occurrences in the West Tuya lava field were mapped, sampled, and found to be basaltic in composition rather than trachytic, as reported by Watson and Mathews (1944). Subaerial basaltic lava flows dominate with minor basaltic pyroclastic deposits. Three vents have been identified and are interpreted to represent three overlapping subaerial shield volcanoes. The rocks commonly contain feldspar and olivine xenocrysts as well as peridotite mantle xenoliths. The inferred total combined volume of the three vents ranges between 10.36 km^3 to 23.42 km^3 and comprises a plateau that contains three distinct areas of relief as well as a significant volume of rubble crop. The lavas are considered to predate the Holocene. The West Tuya lava field is one of the few exclusively subaerial features in the region.

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