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Preliminary field, petrographic, and geochemical analysis of possible subglacial, dacitic volcanism at the Watts Point volcanic centre, southwestern British Columbia

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Abstract: The Watts Point volcanic centre, located 40 km north of Vancouver, British Columbia, along the north shore of Howe Sound, is the southernmost volcanic centre in the Garibaldi segment of the Cascades volcanic arc. The Watts Point volcanic centre comprises approximately 0.02 km^3 of sparsely porphyritic, highly jointed hornblende and pyroxene dacite lava and lava breccia. Lavas from the centre overlie the mid-Cretaceous Coast plutonic complex and are overlain locally by sediments and glacial till. The rocks are characterized by columnar joints, ranging in diameter from 5 cm to 40 cm and exhibiting locally radiating patterns. The distinctive, radial columnar joint patterns, the glassy to fine-grained groundmass, the stratigraphic relationships to overlying glacial till, as well as previously published geochronometric constraints support the formation of the Watts Point volcanic centre in a subglacial to englacial environment.

Résumé : Le centre volcanique de Watts Point, situé à 40 km au nord de Vancouver (Colombie-Britannique) sur la rive nord de la baie Howe, est le centre volcanique le plus méridional du segment de Garibaldi de l'arc volcanique des Cascades. Le centre volcanique de Watts Point se compose d'environ 0,02 km^3 de coulées et de brèches de coulée dacitiques à pyroxène et à hornblende, par endroits légèrement porphyriques, qui montrent une forte densité de diaclases. Les coulées du centre volcanique reposent sur le Complexe plutonique côtier du Crétacé moyen et sont par endroits surmontées de sédiments et de till glaciaire. Les roches sont caractérisées par un débit prismatique. Les prismes montrent un diamètre de 5 à 40 cm et les diaclases qui les délimitent présentent par endroits une configuration radiale. La configuration radiale caractéristique des diaclases, la matrice vitreuse ou à grain fin des laves, les relations stratigraphiques avec le till sus-jacent et les limites géochronologiques définies par les résultats de datations précédemment publiés, appuient l'hypothèse de la formation du centre volcanique de Watts Point en milieu sous-glaciaire ou intraglaciaire.

INTRODUCTION

The Cascades volcanic arc (Fig. 1, inset) extends from northern California to southwestern British Columbia. It is a continental volcanic arc associated with subduction of the Juan De Fuca Plate underneath North America. Volcanism in the arc ranges in composition from basaltic to rhyolitic, but andesitic to dacitic eruptions are most common (Wood and Baldridge, 1990).

The Garibaldi belt is the northernmost chain of volcanoes in the Cascades volcanic arc (Fig. 1) (Souther, 1991; Hickson, 1994). The volcanoes in the Garibaldi belt are andesitic to dacitic in composition (Mathews, 1957; Green, 1977) and include dissected stratovolcanoes (Mount Garibaldi and Mount Meager), monogenetic cinder cones, and isolated lava flows (e.g. Ring Creek). Many of the volcanic features are characteristic of subglacial eruptions because volcanic activity in Garibaldi belt was locally concurrent with the Salmon Springs (>50 000 years ago) and Fraser (26000–10 000 years ago) glaciations (Mathews, 1952; Green et al., 1988).

Products of ice-lava interaction include the presence of pillows and lobes of lava, hyaloclastite (volcanic glass breccia), and radiating columnar joints of glassy lava (Furnes et al., 1980; Lescinsky and Sisson, 1998). Mathews (1958) first described radiating arrays of columnar joints at Mount Garibaldi. He interpreted these to be the product of rapidly cooled lava within a subglacial tunnel (Mathews, 1958). Columnar joints associated with rapid quenching typically have small (10–20 cm) diameters with orientations perpendicular to the cooling surface.

Another possible example of volcano-glacier interaction is the Watts Point volcanic centre, the southernmost in the Garibaldi belt. It is located along the northeast shore of Howe Sound, about 40 km north of Vancouver, British Columbia (Fig. 1). Previous K-Ar dating of two samples of dacite from Watts Point (Green et al., 1988) produced whole-rock K-Ar ages of 0.09 ± 0.03 and 0.13 ± 0.03 Ma. These ages overlap those of the Fraser glaciation (Green et al., 1988). The centre has an area of approximately 0.2 km^2 and an estimated volume of 0.02 km^3 of sparsely porphyritic, highly jointed

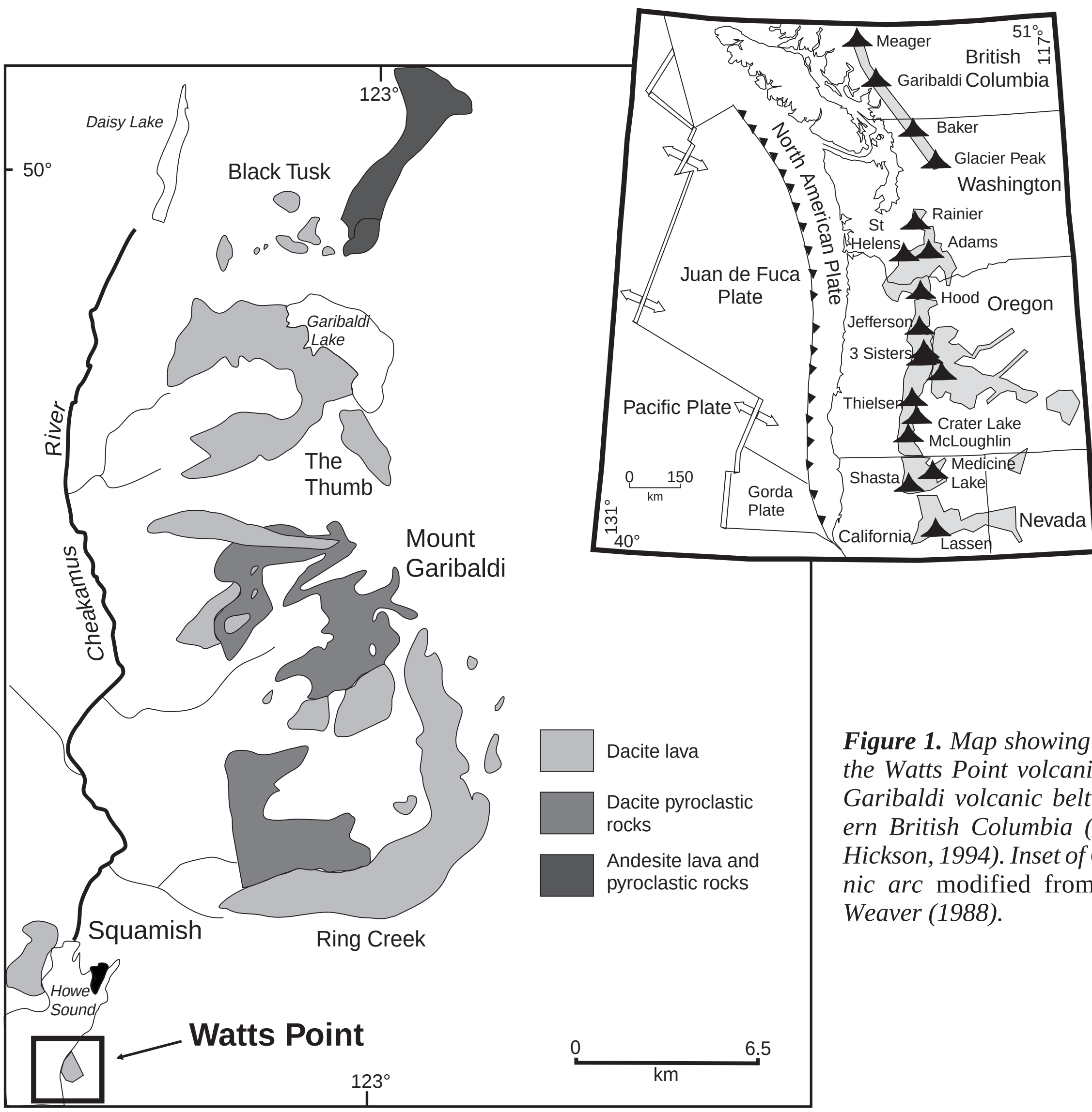


Figure 1. *Map showing the location of the Watts Point volcanic centre in the Garibaldi volcanic belt, in southwestern British Columbia (*modified from *Hickson, 1994). Inset of Cascade volcanic arc* modified from *Guffanti and Weaver (1988).*

dacitic lava (Fig. 2). The Watts Point area is heavily forested; the best outcrops occur in railroad ballast quarries and along a railroad thoroughfare.

Our study examines the possible subglacial origin of the Watts Point volcanic centre through mapping and petrographic and geochemical analyses and determines its relationship to other volcanoes in the Garibaldi belt. This report summarizes our preliminary results, which suggest that the Watts Point centre erupted in a subglacial to englacial environment and is petrographically and geochemically similar to other dacite lavas in the Garibaldi belt described by Mathews (1957).

FIELD AND LABORATORY METHODS

A 1:9500 geological map of the Watts Point volcanic centre (Fig. 2) was completed during fieldwork conducted between mid-July and early August 1999. The base map for this project was a 1:20 000 TRIM (Terrain Resource Information Management) map sheet (92 G.064). Three distinctive geographic features are found in the map area. A comma-shaped inactive quarry is located at about 210 m elevation, in the southeast portion of the map. An irregularly shaped, active quarry is located in the northeast portion of the map. The railroad follows the coastline of Watts Point, at about 40 m in elevation.

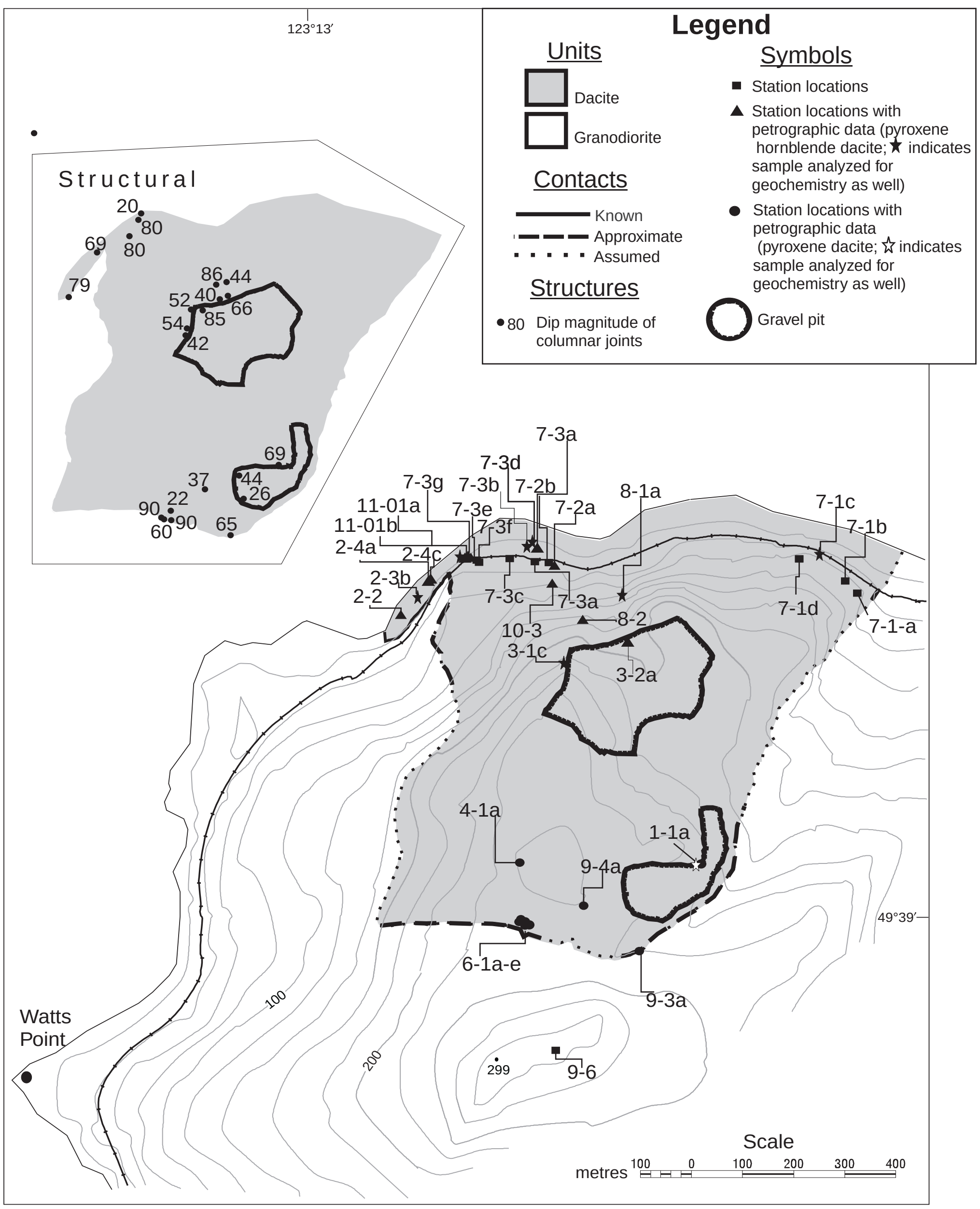


__Figure 2.__ Geological map of the Watts Point volcanic centre showing station locations and geological contacts. Inset shows dip angles of columnar joints.

While mapping, angles of dip for columnar joints were measured to document local variations (Fig. 2, inset) and samples were collected for petrographic and geochemical analysis. Eighteen samples were collected for petrographic analysis using standard light-transmitted petrographic techniques. Grain sizes were estimated using a built-in micrometer and calculated using predetermined calibrations. Images of thin sections were obtained using a Nikon LS-2000 slide scanner. Seven samples (Fig. 2) were sent to McGill University for geochemical analysis by X-ray fluorescence.

CHARACTER AND GEOLOGICAL RELATIONSHIPS OF WATTS POINT VOLCANIC CENTRE

Lava from the Watts Point volcanic centre overlies and is assumed to have intruded through the granodiorite of the mid-Cretaceous Coast plutonic complex, although the contact between the Watts Point dacite and the Coast plutonic complex was not directly observed. Contacts between the lava and the surrounding granodiorite were only well exposed at the northwestern end of the map area near the railroad. However, at three separate locations outcrops of dacite and granodiorite were found in close proximity to one another (stations 2-2, 6-1, 7-3g). Rocks of the Watts Point volcanic centre are overlain locally by glacial and fine-grained, postglacial sediments (stations 1-1a, 8-2; Fig. 2, 3). Glacial till is up to 2 m thick and poorly to moderately well indurated. At one location (station 1-1a, Fig. 3), a 20 cm thick layer of grey clay directly overlies dacite lava and is overlain by glacial till. Localized fluvial deposits of sand, gravel, and clay are unconsolidated. Colluvium covers much of the outcroppings, particularly on steep slopes. No mappable internal contacts within the centre were identified.

Jointed lava

Columnar joints are pervasive and common, making up the only significant structural feature to be found at the centre. Column diameters range from 5–70 cm (Fig. 4a), over the breadth of an outcrop. Columns narrow upward; however, at one location (station 6-1; Fig. 2), 25–40 cm diameter columns grade upward to massive dacite. Glassy columnar joints range in size from 5 cm to 25 cm; larger diameter joints tend to have a higher crystallinity. This point is illustrated dramatically at location 6-1 (cf. Fig. 2), where textures progress from glassy to devitrified to cryptocrystalline on outcrop scale. At this location the content of volcanic glass observed in hand samples increases with distance from the massive core of the outcrop (e.g. sample number 6-1a, in the core of the outcrop, is 50% devitrified, and sample number 6-1c, from the edge of the outcrop, is wholly glassy). Conversely, devitrification increases with proximity to the massive core (sample number 6-1e, from near the core, is 80% devitrified, and sample number 6-1d, located almost within the core, is completely cryptocrystalline). Column size also decreases away from the massive part of the outcrop.

Column orientation also varies on the outcrop scale, ranging from vertical to 30° dips (Fig. 2, inset), and commonly defines a radiating pattern (e.g. at station 3-2; Fig. 2). Along an approximately 1 km stretch of railroad cut, columnar joints in discontinuous outcrop decrease upward from 70 cm to 20–15 cm in diameter over an 8 m height. Columnar joints also exhibit radial (Fig. 4b) and inclined (Fig. 4c) patterns and abruptly change orientation over distances as small as 4 m.

Locally, abrupt changes in columnar jointing to flaggy jointing (Fig. 4d) are also accompanied by a change in the texture of the lava. Commonly the crystallinity, abundance, and size of phenocrysts increases with column diameter. Flaggy jointing and larger column diameters mark a transition from glassy to cryptocrystalline lava containing a greater abundance of larger phenocrysts.

Breccia

At one location (station 08-02; Fig. 2) a dacite breccia more than 4 m thick is overlain by 2 m of till (Fig. 5a, b) and occurs in poorly defined beds 20–30 cm thick (Fig. 5a). Clast sizes range from 50 cm at the base of the beds to less than 1 mm at the top of the beds (Fig. 5b). Exotic clasts of metamorphic and plutonic rocks increase in abundance towards the breccia-till contact. Some of the exotic clasts show striations and are anvil shaped.

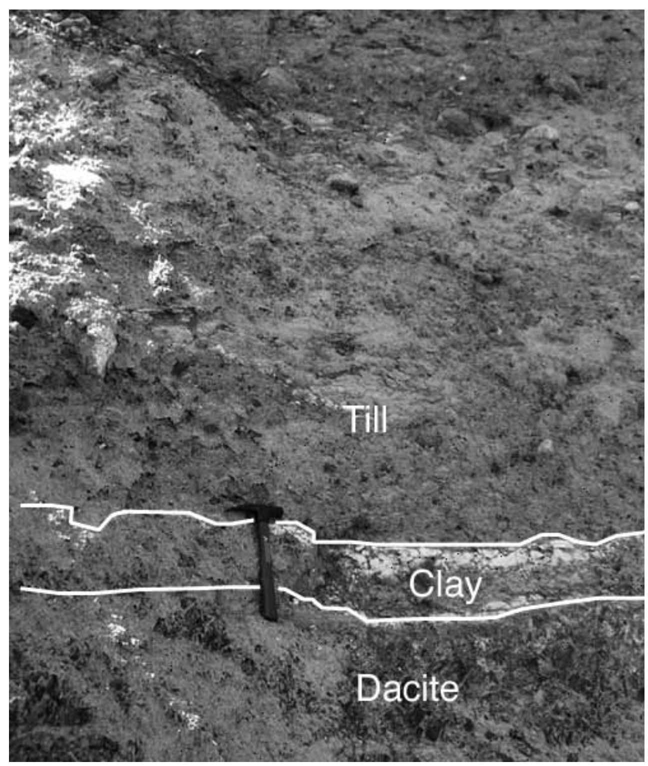


Figure 3. *Stratigraphic relationships among massive lava which is overlain by about 20 cm thick clay layer which is overlain in turn by about 2 m of unconsolidated till.*

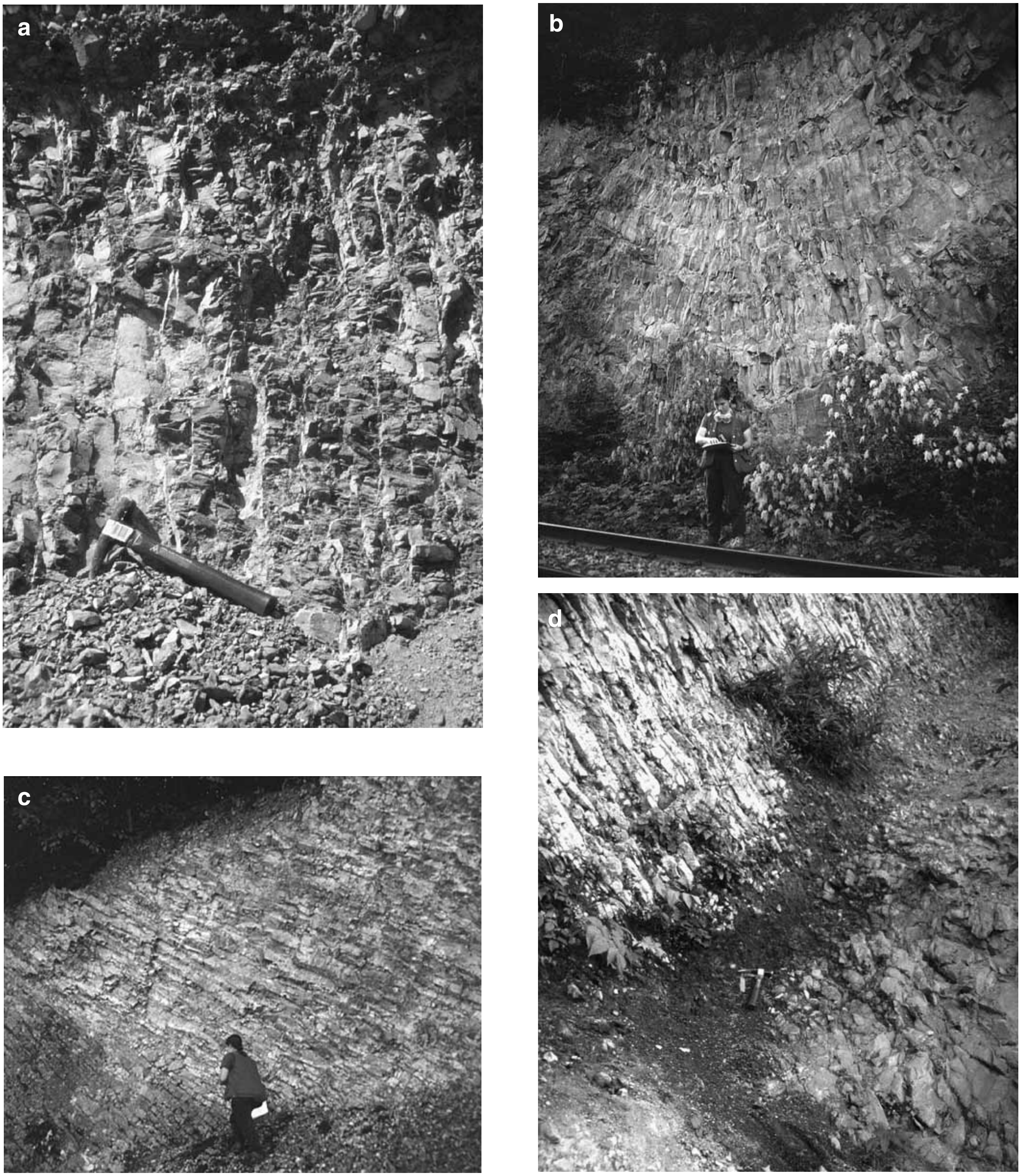
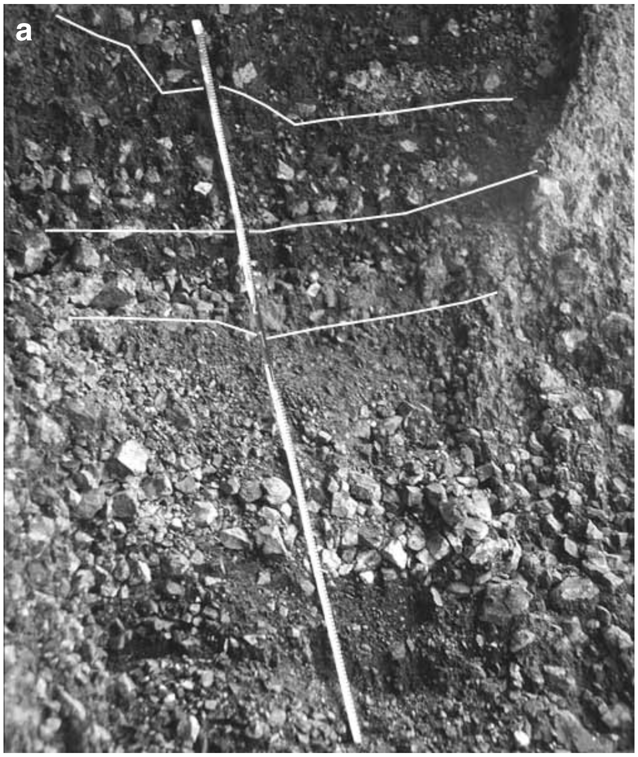


***Figure 4.** Variations in columnar jointing in the lava at Watts Point. **a)** Minimum joint size, 5–7 cm in diameter (map/station location 3-2). **b)** Radial joint patterns (map/station location 7-1) (cf. Fig. 2, station 8-4). **c)** Inclined jointing (map/station location 7-2). **d)** Transition zone from small columnar joints to larger joints and/or flaggy joints.*



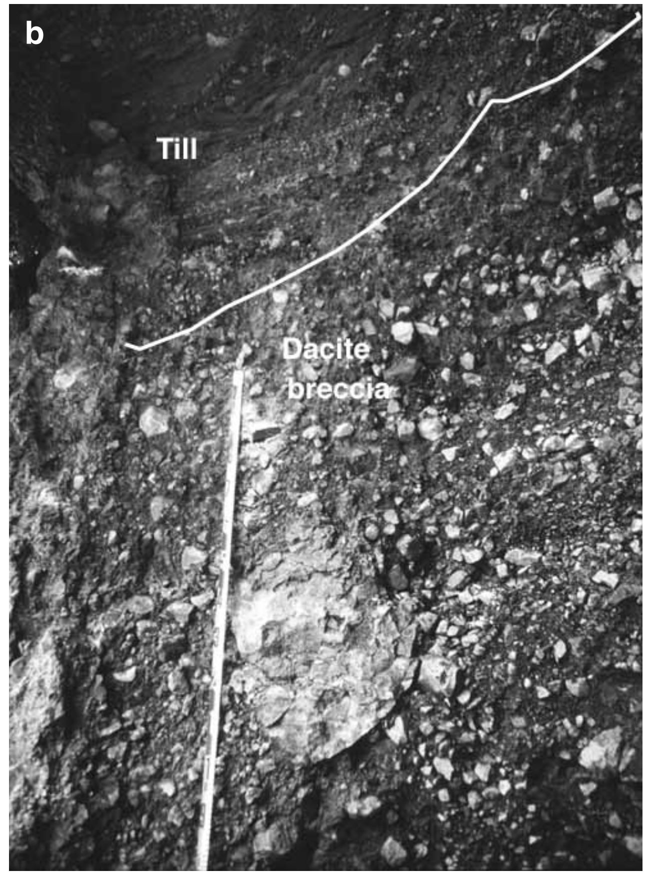


Figure 5. *Volcanic breccia, station 8-2. Tape measure is 200 cm in length.* ***a)*** *Coarse bedding defined by centimetre-size clasts in dacite breccia.* ***b)*** *Gradational contact between dacite breccia (bottom of photograph) and till (top of photograph).*

PETROGRAPHY

Three textures are observed in thin sections of the samples, 1) glassy, sparsely porphyritic pyroxene hornblende dacite; 2) glassy, sparsely porphyritic pyroxene dacite; and 3) devitrified, porphyritic pyroxene dacite. The pyroxene hornblende dacite units were found mainly along Howe Sound, on the northwestern edge of the centre, while dacite from the southeastern part of the centre contained no hornblende (Fig. 2).

Phenocrysts comprise about 5% of the lava (Table 1) by volume, and commonly occur as glomerocrysts. Plagioclase phenocrysts are the most common and are about twice as abundant as all the other phenocrysts within the lava. Clinopyroxene and orthopyroxene are less common in hornblende dacite samples. Hornblende occurred in nine samples out of 18 samples. Feldspar microphenocrysts, composing approximately 20–40% of the groundmass, show slight to strong trachytic texture. The groundmass is composed dominantly of volcanic glass.

Table 1. Phenocryst characteristics of Watts Point dacite.

Unit	Plagioclase (length in mm)	Orthopyroxene (length in mm)	Clinopyroxene (length in mm)	Hornblende (length in mm)
pyroxene-hornblende dacite	(0.05–0.84) subhedral-euhedral	(0.05–1.0) subhedral	(0.05–1.1) anhedral-subhedral	(0.05–1.60) subhedral-euhedral
pyroxene dacite	(0.05–1.1) subhedral-euhedral	(0.05–1.0) subhedral	(0.10–0.50) anhedral-subhedral	
devitrified pyroxene dacite	(0.12–0.84) subhedral-euhedral	(0.12–1.3) subhedral	(0.05–0.91) anhedral-subhedral	

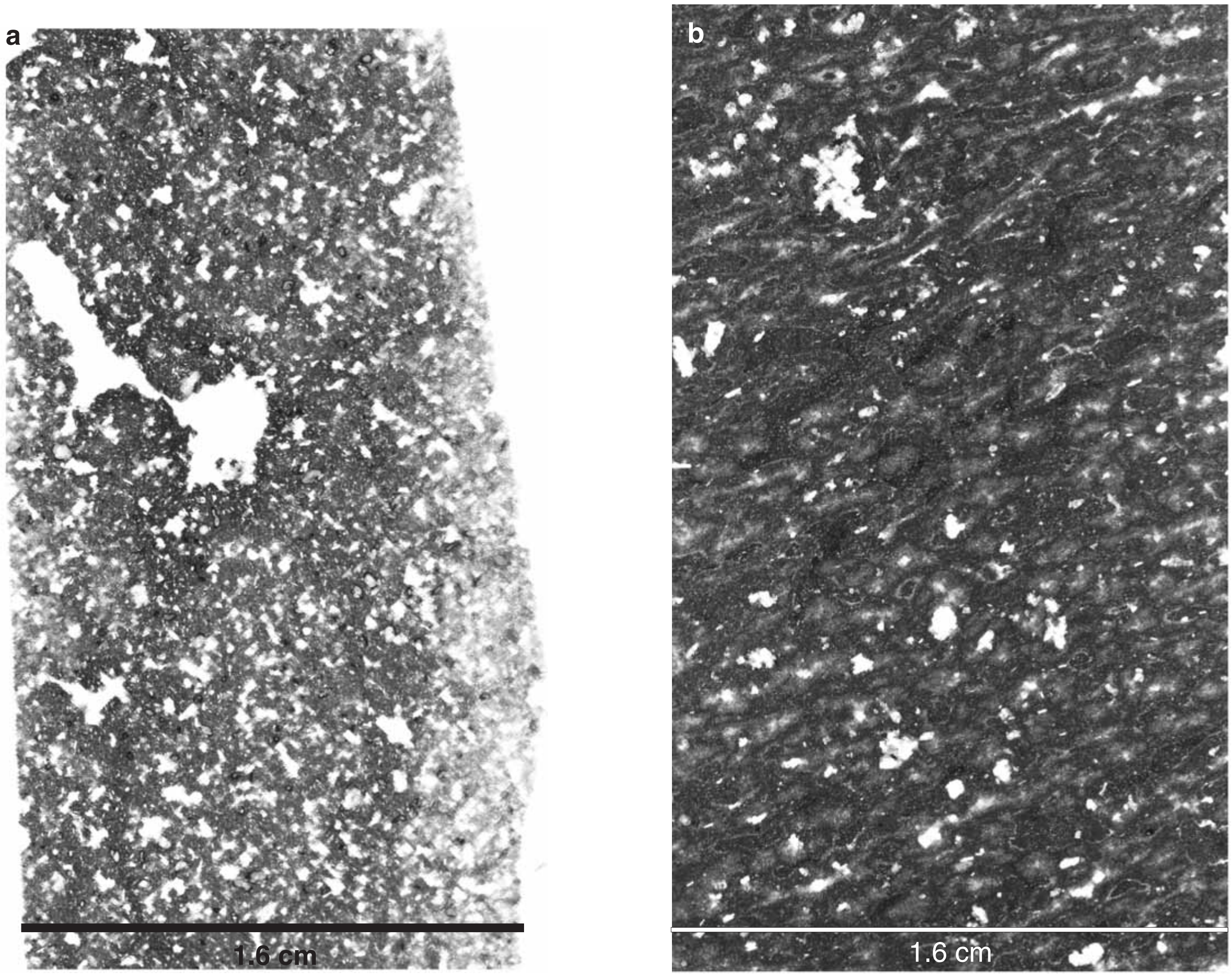


Figure 6. Petrographic textures of lava samples. ***a)*** *Porphyritic texture of dacite lava and weak trachytic alignment of microlites in groundmass from sample 7-3 (station 7-3, Fig. 2).* ***b)*** *Devitrification texture in sample 6-1e (6-1e, Fig. 2).*

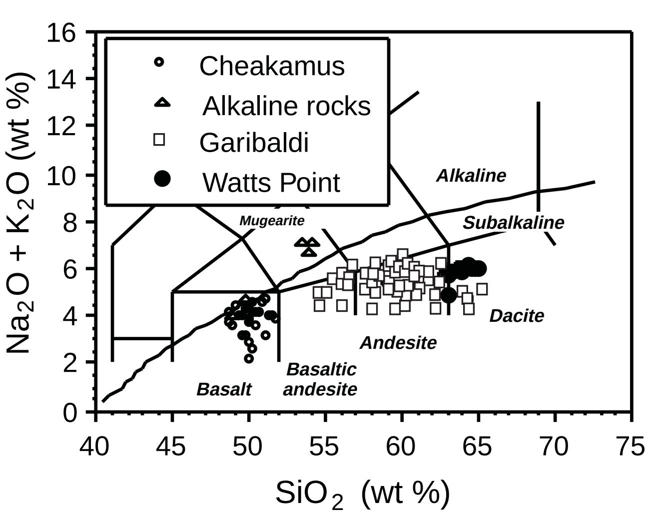


Figure 7.

Total alkali-silica classification diagram (fields after *LeBas et al. (1986)) showing data from this study for seven samples of lava from the Watts Point volcanic centre. Data from Green (1977) and Mathews (1957) for the Garibaldi Lake volcanic field are shown for comparison.*

Table 2. Comparison of major element geochemistry for the Watts Point dacite (this study) and dacite from the Mount Garibaldi area (Mathews, 1957).

Oxides (weight %)	Range for Watts Point (n = 7)	Range for Garibaldi (n = 4)
SiO_2	62.99–64.89	63.08–65.24
TiO_2	0.47–0.50	0.40–0.58
Al_2O_3	16.32–16.85	16.48–18.06
FeO*	4.67–5.00	3.99–5.05
MnO	0.07–0.08	b.d.–0.23
MgO	2.38–2.53	1.94–2.59
CaO	4.64–4.93	4.92–5.63
Na_2O	3.94–4.55	3.26–3.72
K_2O	1.58–1.88	1.22–1.65
P_2O_5	0.17–0.20	0.07–0.16
b.d. = below detection limit		

Three of nine samples of pyroxene dacite exhibit a unique, patchy groundmass texture which occurs at stations 4-1 and 6-1 (Fig. 6b). The patchy texture is likely due to devitrification.

GEOCHEMISTRY

Seven samples were chemically analyzed for major and selected trace elements by XRF at the McGill University analytical laboratory (*see* Fig. 2 for sample locations). Our preliminary analysis of the results show that all samples are subalkaline dacite based on the LeBas et al. (1986) classification (Fig. 7), with high Na/K ratios (>3) and a metaluminous character. The major element geochemistry of the Watts Point dacite is very similar to data reported for dacite from the Mount Garibaldi area by Mathews (1957) (Table 2).

DISCUSSION

The wide range in columnar joint size and crystallinity over a small scale supports a subglacial origin for Watts Point volcanic centre. Our interpretation of a subglacial eruption environment explains why the outer margins of the lava cooled more rapidly than the inner sections of the flow, leading to a decrease of column diameter with structural height. Columnar joint size is closely linked to the percentage of volcanic glass contained in the rock, as shown by station 6-1. However, the overall fine-grained to glassy texture in the groundmass of the lava indicates rapid cooling of lava throughout the centre. Radiating orientations of the columnar joints indicate that the lava had a highly irregular cooling surface, consistent with eruption beneath a glacier.

Green et al. (1988) proposed that the lava at Watts Point was emplaced abutting glacial sediments. Our field observations suggest that the eruption of the lava at Watts Point immediately predated the deposition of the overlying glacial sediments, and, because of the stratigraphic location beneath glacial till and sediments, most likely was erupted underneath glacial ice.

CONCLUSIONS

Our petrographic analysis identified two distinct groups of lava, pyroxene-hornblende dacite and pyroxene dacite. Textures vary from glassy to devitrified. Seven whole-rock, major-element geochemical analyses show that lava at Watts Point volcanic centre is subalkaline, metaluminous dacite, similar to dacite from Mount Garibaldi.

The information gathered during field research, such as pervasive, small diameter columnar jointing with locally radiating patterns, glassy to cryptocrystalline texture, and stratigraphic location beneath glacial till, points to a subglacial eruptive environment for this volcanic centre.

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