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H_2O-driven generation of picritic melts in the Middle to Late Triassic Stuhini arc of the Stikine terrane, British Columbia, Canada

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ABSTRACT

Basaltic to andesitic compositions predominate island arc magmatism; ultramafic magmas are rare. Ultramafic (MgO = 21–33 wt.%) tuff breccia, lapilli tuff, and ash tuff of the Middle to Upper Triassic Stuhini Group were erupted in the Stikine arc of the North American Cordillera shortly preceding an episode of prolific porphyry Cu–Mo(–Au) mineralization. The ultramafic tuff shows accumulation (20–65%) of olivine (Fo_{91}) and minor chromite into a subalkaline picritic parental magma with MgO ~16 wt.%. Despite the inferred high MgO content of the parental liquid, chromite phenocrysts record relatively low liquidus temperatures (<1200 °C) suggesting crystallization from relatively low temperature, hydrous melts, at oxygen fugacities one to three log units above the fayalite–magnetite–quartz (FMQ) buffer. The primary picritic magmas likely contained 5–7 wt.% H_2O, inferred on the basis of olivine-liquid thermometry and thermal models for subduction zones, thus alleviating the need for catastrophic thermal perturbations in the mantle wedge. Instead, efficient release of water through slab dehydration at 2.5–3.0 GPa allows generation of picritic melts at ordinary mantle wedge temperatures through moderate degrees ($F = 0.10$–0.15) of hydrous flux melting. The volatile-rich nature of the melt and the predominant extensional regime in the overlying lithosphere of Stikinia facilitated the near-adiabatic ascent of the Stuhini Group picrites. The high H_2O content of the rapidly ascending picrite melt may have played a key role in transport of metals into the crust of the Stikinia and subsequent porphyry mineralization.

1. Introduction

Primitive, mantle-derived magmas with picritic (MgO >12 wt.%) compositions are uncommon in recent arc settings, but have been identified in the central Aleutian (Nye and Reid, 1986), Japan (Yamamoto, 1988); Vanuatu (Eggins, 1993), Solomon Islands (Rohrbach et al., 2005), and Lesser Antilles arcs (Woodland et al., 2002), and inferred from the Mariana arc (Kelley et al., 2010; Tamura et al., 2011) Paleozoic and Mesozoic arc-related picrites are equally rare, but have been described in eastern Kamchatka (Kamenetsky et al., 1995), the northern Appalachian Orogen (Wilson, 2003), and the Quesnel (Russell and Snyder, 1997) and Stikine (Logan et al., 2000; Logan and Mihalynuk, 2014) arc terranes of the North American Cordillera. The genesis of these highly primitive magmas in arc environments remains poorly understood, in part due to their scarcity. Existing models for petrogenesis of arc picrites commonly invoke unusual or catastrophic geodynamic scenarios, such as ridge subduction, slab tear, assimilation of peridotite, or rapid mantle-wedge counter flow (Nye and Reid, 1986; Rohrbach et al., 2005; Logan and Mihalynuk, 2014).

Picritic rocks in the Stikine terrane comprise a variably serpentinized, olivine-rich pyroclastic unit composed of lapilli breccia, lapilli tuff, and ash tuff (Logan et al., 2000; Milidragovic et al., 2016). The ultramafic pyroclastic rocks form a volumetrically minor component of the Stuhini Group, a predominantly subaqueous volcano-sedimentary arc assemblage of Middle to Late Triassic age. Stuhini arc volcanism was accompanied by a pulse of prolific Late Triassic porphyry Cu–Mo(–Au) mineralization (Logan and Mihalynuk, 2014). Widespread recognition that large porphyry deposits form in response to tectonic and thermal perturbations in the underlying mantle wedge (e.g. Cooke et al., 2005; Logan and Mihalynuk, 2014), requires a closer examination of the spatially and temporarily associated ultramafic rocks. In this paper, we demonstrate that the picritic rocks of the Stikine terrane are hydrous,

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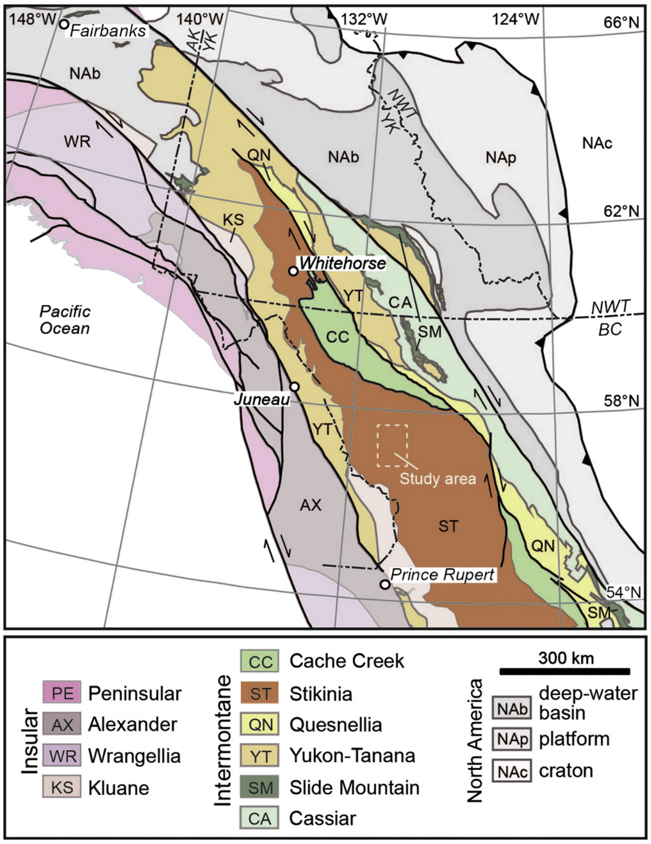

Fig. 1. Terranes of the Canadian Cordillera and the location of Middle to Upper Triassic ultramafic pyroclastic rocks (modified from Nelson et al., 2013).

moderate-degree melts ($F = 0.10$–0.15) of the underlying, depleted arc mantle wedge. We argue that the ultramafic character of the Stuhini Group picrites does not require catastrophic changes to the mantle wedge configuration. Instead we argue that efficient dehydration of the subducting Panthalassan plate is the key in the generation and near-adiabatic ascent of the picritic magmas of the Stuhini Group.

2. The Stikine arc

The Stikine terrane (Fig. 1) of the North American Cordillera preserves a history of island arc magmatism, sedimentation, and deformation spanning from Middle Devonian to Middle Jurassic (Logan et al., 2000; Nelson et al., 2013). One current model (Nelson et al., 2013 and references therein) posits that the Stikine and related terranes formed on variably attenuated Laurentian continental crust, upon which successive magmatic arcs were built. The earliest of these, initiated during the Late Devonian to Early Permian (Stikine Assemblage; Logan et al., 2000), was followed by magmatic hiatus, tectonic quiescence and development of carbonate slope to shale basin by the Middle Triassic.

A resurgence of late Triassic arc activity in the Stikine terrane resulted in deposition of voluminous basalt and andesite of the Stuhini Group (Mihalynuk et al., 1999; Logan et al., 2000). This phase of arc activity was followed by a brief magmatic hiatus, deposition of carbonates, and deformation. The final phase of arc magmatism occurred during the Latest Triassic to Middle Jurassic (Hazelton Group; Barresi et al., 2015), and was followed by accretion of the Stikine terrane to the Laurentian margin.

2.1. The Stuhini Group

The Stuhini Group of northwestern British Columbia, and the correlative Lewes River (southern Yukon) and Takla (central British Columbia) groups, comprise volcano-sedimentary rocks deposited over a wide area of the Stikine terrane in response to Middle to Late Triassic arc volcanism (Hart, 1997; Mihalynuk et al., 1999; Logan et al., 2000). The duration of Middle to Late Triassic arc magmatism is constrained by Ladinian–Carnian fossils at the base of the Stuhini Group (Logan et al., 2000) and by Late Norian to Rhaetian conodonts within limestone that caps the Stuhini and Lewes River groups (Hart, 1997; Mihalynuk et al., 1999). Intrusive activity, evidenced by the ca. 228–215 Ma Stikine plutonic suite (Logan et al., 2000; Logan and Mihalynuk, 2014; Milidragovic et al., 2016), accompanied volcanism and deposition of the Stuhini Group. The Stuhini Group is $\leq$2 km thick (Logan et al., 2000) and composed predominantly of subaqueous mafic to intermediate augite- and/or plagioclase-phyric volcanic flows of tholeiitic to calc-alkaline affinity, pyroclastics, and related volcaniclastic and epiclastic rocks, including pyroxene and feldspar-rich sedimentary rocks, carbonaceous shale, siltstone, and limestone (Logan et al., 2000; Mihalynuk et al., 1999). Ultramafic pyroclastic rocks constitute a volumetrically minor component of the Stuhini Group and are limited to the basal part of its proximal volcanic facies (Mess Lake facies; Logan et al., 2000).

3. Ultramafic pyroclastic unit of the Stuhini Group

Ultramafic pyroclastics form a grey to green-weathering, $\leq$100 m thick, volumetrically minor unit within the Stuhini Group (Logan et al., 2000; Milidragovic et al., 2016). Although the unit can be traced along strike for up to 5 km, it weathers recessively and appears to have served as a locus for late brittle faulting and veining. Despite pervasive serpentinization, the unit preserves primary igneous and depositional textures both on outcrop and thin-section scales. A $\sim$35 m thick, undeformed section of the pyroclastic unit exposes four fining-upward sequences composed of normally-graded tuff breccia and olivine lapilli tuff, capped by beds of rhythmically layered ash tuff (Fig. 2). Layering in ash tuff varies from coarse to fine ($\leq$3 mm to $\geq$5 cm), and is parallel and continuous on outcrop scale. The base of each fining upward sequence is sharp and locally marked by low-amplitude scouring of underlying ash tuff beds (Milidragovic et al., 2016).

The primary mineralogy of the ultramafic rocks has been largely replaced by serpentine, magnetite, talc, tremolite, and chlorite. Primary minerals comprise sparse relict olivine, and chromite mantled by late/metamorphic magnetite. The euhedral to subhedral shape of pseudomorphed olivine and chromite grains suggests they are cognate crystals from a primitive parental magma, rather than xenocrysts acquired during magma ascent and explosive eruption. The frequent inclusion of euhedral chromite crystals in pseudomorphed olivine (Fig. B1–1F) indicates that the two minerals co-crystallized as high-temperature liquidus phases. Rare clinopyroxene also occurs as euhedral to subhedral grains that typically form clusters and may be xenocrysts entrained during magma ascent. Plagioclase is entirely absent. Similarly, non-cognate lithic clasts are sparse. Bomb and lapilli-sized fragments are vesicular and contain abundant dark, euhedral to subhedral serpentine pseudomorphs (lizardite partially overprinted by antigorite and talc), magnetite, trace calcite, and rare chromite phenocrysts. Late calcite rarely replaces serpentine and is often spatially associated with mm-scale veinlets. Pseudomorphed olivine and chromite phenocrysts are hosted in a fine-grained, commonly frothy, devitrified groundmass composed of very fine-grained chlorite and clay. Scoriaceous lapilli, entirely composed of vesicular, devitrified glass are less common, although intense serpentine and chlorite alteration and overprinting of primary pyroclastic textures may, in part, account for this apparent scarcity. Very fine-grained, pale green tremolite crystals often occur as randomly oriented mats overprinting earlier alteration. The lapilli and bomb-sized fragments