Stratigraphy and regional implications of unstrained Devono-Mississippian volcanic rocks in the Money Creek thrust sheet, Yukon-Tanana Terrane, southeastern Yukon[1]

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ABSTRACT

Relatively unstrained Devonian-Mississippian volcanic and volcano-sedimentary rocks have been documented in the Money Creek thrust sheet in Finlayson Lake map area. The succession comprises a five-unit volcanic stratigraphy containing subaerial and subaqueous mafic and felsic volcanic and volcaniclastic rocks and associated sedimentary rocks that are underlain, and locally crosscut by, sub-volcanic mafic intrusions and quartz porphyritic granite. Magma-mingling relationships between mafic dykes and quartz-porphyritic granite suggest that mafic and felsic volcanism was broadly coeval. A published 360.5 ± 1 Ma U-Pb date on a quartz porphyritic granitic intrusion establishes the age of volcanism.

Biotite-hornblende granitic rocks of the Simpson Range Plutonic Suite (SRPS) intrude and metamorphose the volcanic sequence and related sub-volcanic intrusive rocks, and coupled with previously published U-Pb dates (345-350 Ma), this relationship implies that the SRPS is a distinctly younger pulse of magmatism.

Mafic and ultramafic rocks of the Money Creek thrust sheet have previously been correlated with the Pennsylvanian-Permian Campbell Range belt and together both have been considered part of the Anvil Allochthon or Slide Mountain Terrane. Field characteristics, age, and geochemistry show that neither correlation is valid.

RÉSUMÉ

Des roches volcaniques et volcanosédimentaires relativement peu déformées, datant du Dévonien-Mississipien, ont été documentées dans la nappe de charriage de Money Creek, dans la région de Finlayson Lake. La succession inclue un ensemble stratigraphique volcanique de cinq unités comprenant des roches volcaniques et volcanoclastiques mafiques et felsiques subaériennes et subaquatiques, ainsi que des roches sédimentaires associées. Ces roches recouvrent des intrusions subvolcaniques mafiques et du granite à phénocristaux de quartz qui par endroits peuvent recouper les roches volcaniques. Les relations de mélange magmatique entre les dykes mafiques et le granite à phénocristaux de quartz suggèrent que le volcanisme mafique et le volcanisme felsique étaient généralement contemporains. Une datation à l'U-Pb, précédemment publiée, de 360,5 ± 1 Ma pour une des intrusions de granite à phénocristaux de quartz fixe l'âge du volcanisme.

Les roches granitiques à biotite-hornblende de la Série plutonique de Simpson Range (SPSR) recoupent et métamorphisent la séquence volcanique et les roches intrusives subvolcaniques associées. Cette observation combinée avec des datations à l'U-Pb déjà publiées (345 à 350 Ma) implique que la SPSR représente un épisode magmatique sensiblement plus jeune.

Les roches mafiques et ultramafiques de la nappe de charriage de Money Creek ont auparavant été corrélées avec la ceinture de Campbell Range du Pennsylvanien-Permien et ont été interprétées comme appartenant soit à l'allochtone d'Anvil ou au terrane de Slide Mountain. Les caractéristiques de terrain, l'âge et la géochimie démontrent que ces corrélations ne sont pas valables.

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INTRODUCTION

The Yukon-Tanana Terrane (YTT) over much of the Yukon is characterized by the presence of abundant greenstone, chloritic schist, gabbro, diabase and ultramafic rocks (e.g., Tempelman-Kluit, 1979; Mortensen, 1992a, b; and others). The origin and significance of the greenstones are ambiguous and the source of controversy (e.g., Tempelman-Kluit, 1979; Mortensen and Jilson, 1985). In most previous work, all mafic rocks have been placed under the same header, be that Anvil Allochthon (Tempelman-Kluit, 1979; Erdmer, 1981, 1985), Slide Mountain Terrane (Mortensen and Jilson, 1985; Mortensen, 1992a, b), or Anvil Assemblage (Wheeler and McFeely, 1991). However, recent mapping in different parts of the YTT has shown that there are different greenstone units within the YTT (e.g., Stevens et al., 1995; Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999; Piercey et al., 1999a, b). Others have questioned the validity of correlating the Slide Mountain Terrane with the Anvil Assemblage based on geochemical and isotopic grounds (Creaser et al., 1997; Grant, 1997; Grant et al., 1996).

Recent geochemical and isotopic data suggest that there are differences in the chemical and isotopic compositions of the greenstones (e.g., Piercey et al., 1999a, b; Creaser et al., 1997; Grant et al., 1996; Grant, 1997); however, only a few workers have outlined field criteria to distinguish between the different greenstone units (e.g., Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999a, b, c). Most of the ambiguities in the distinction between the greenstone units arise because of the highly variable degree of strain recorded within them. In the Finlayson Lake region, Murphy and Timmerman (1997), Murphy (1998), and Murphy and Piercey (1999a, b, c) show that the YTT contains at least three distinct mafic horizons at different stratigraphic levels. Similarly, other workers have shown the different mafic units have distinctive geochemical characteristics. For instance, the lowermost mafic unit (unit 2) exhibits primitive arc (Piercey et al., 1999a, b; Sebert and Hunt, 1999) through calc-alkalic geochemistry (Grant et al., 1996; Grant, 1997; Piercey et al., 1999a, b); the middle mafic unit (unit 4) has rift-like geochemistry (Piercey, unpublished data); and the upper mafic units of the Campbell Range belt exhibit rift alkaline through E-MORB to N-MORB signatures (Plint and Gordon, 1997; Piercey et al., 1999a, b; Piercey, unpublished data).

In this paper we present results from mapping of a previously undocumented section of Devono-Mississippian basalt and rhyolite and spatially associated intrusive rocks in the hanging wall of the Money Creek thrust (Murphy and Piercey, 2000; Figs. 1 and 2). These rocks are now considered unique in that they are essentially unstrained and relatively undeformed,

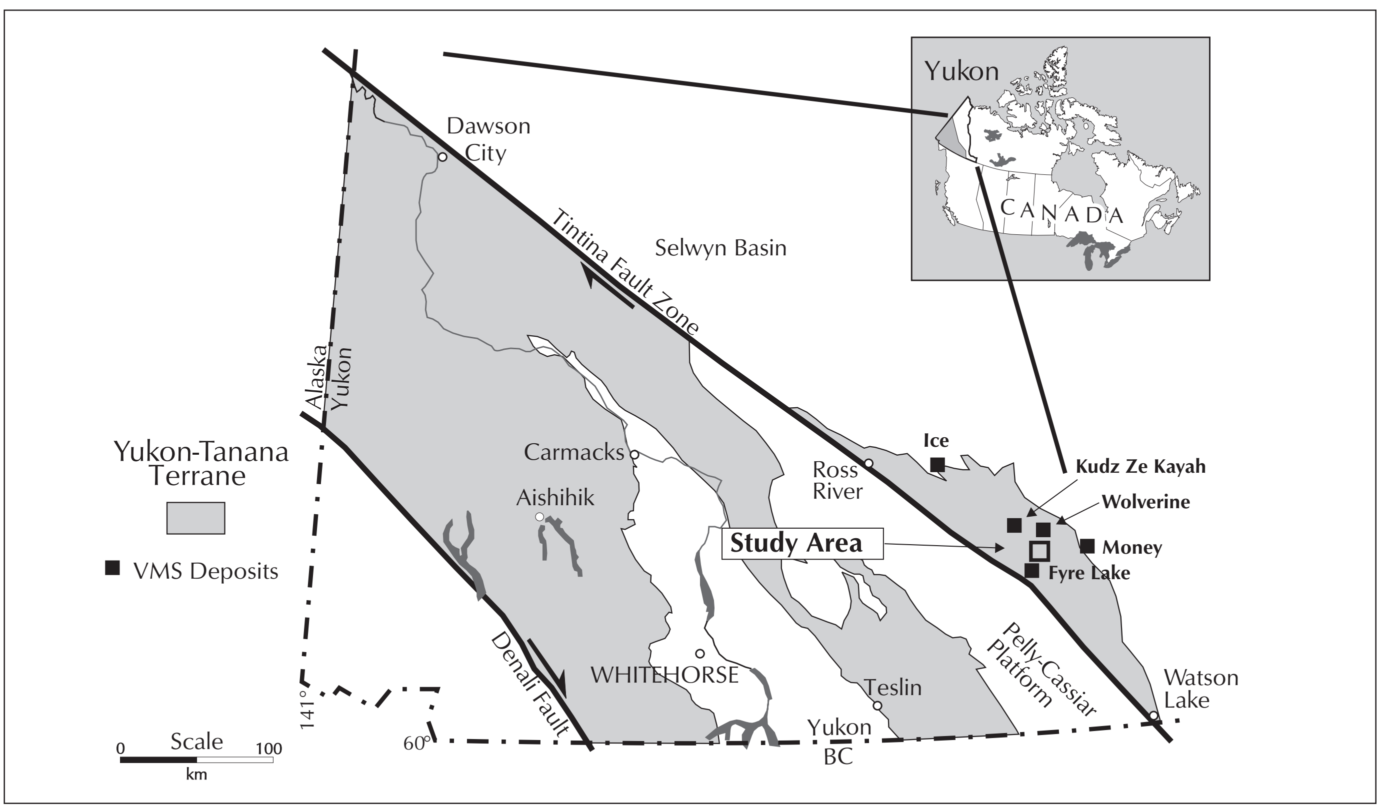

Figure 1. Geological setting and distribution of the Yukon-Tanana Terrane in the Yukon and the location of the study area with respect to the Finlayson Lake region. Map modified from Hunt (1998) and Wheeler and McFeely (1991).

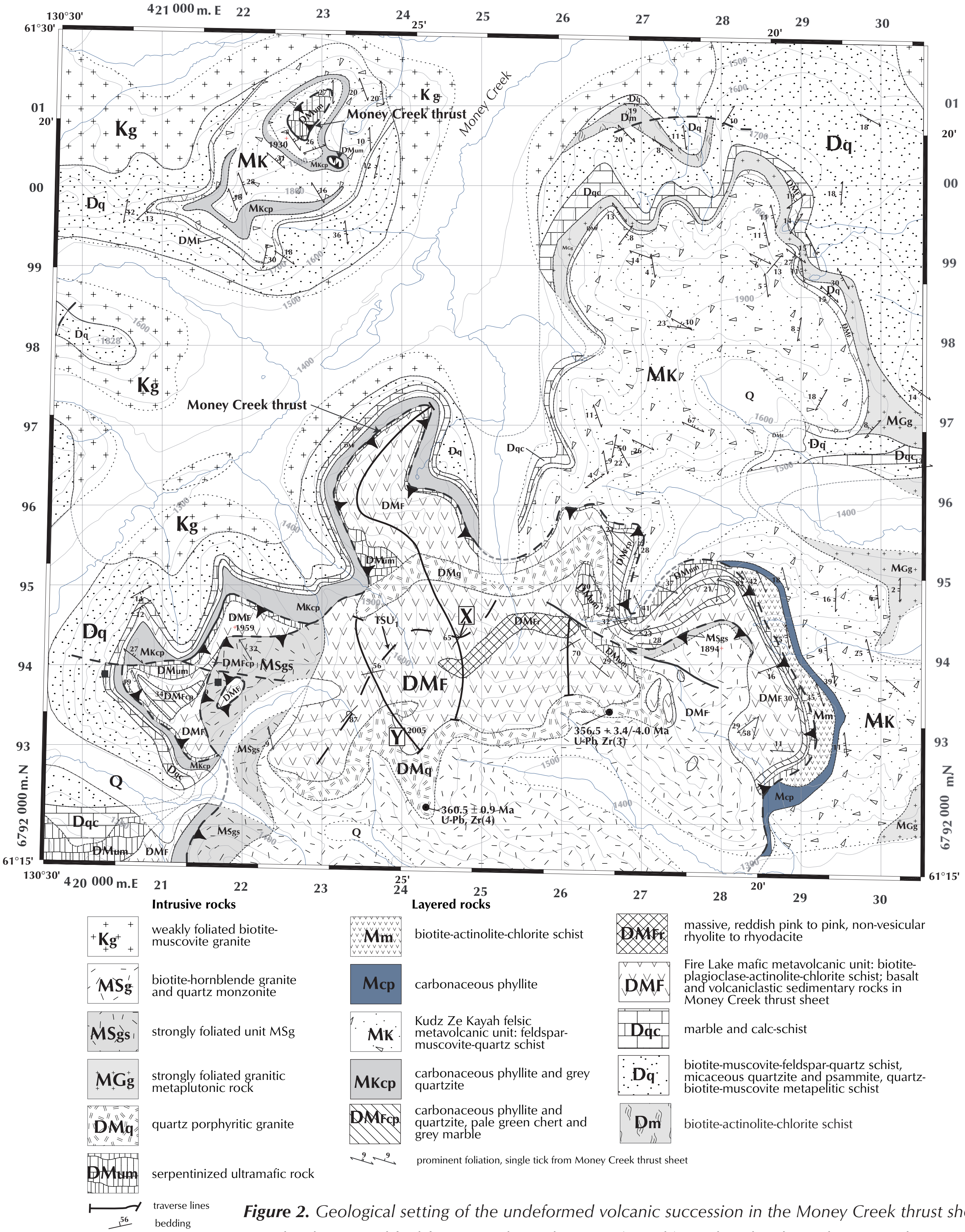

Figure 2. *Geological setting of the undeformed volcanic succession in the Money Creek thrust sheet. Map has been modified from Murphy and Piercey (1999b). Further details on the regional setting can be obtained from Murphy and Piercey (1999a, b, c). X and Y are locations discussed in the text.*

providing a window into the early Mississippian tectonic setting that has not been complicated by strain and metamorphism. Our goals for this paper are as follows:

1) to describe the stratigraphy of the undeformed volcanic sequence;
2) to describe the spatially associated intrusive rocks and clarify the definition of the Simpson Range Plutonic Suite (SRPS);
3) to provide insights into the nature and setting of volcanism recorded in the undeformed volcanic sequence; and
4) to compare and contrast the style of volcanism with that of the younger, and also relatively well-preserved rocks of the Campbell Range belt with which they have been correlated and lumped together into Slide Mountain Terrane.

PREVIOUS WORK

Tempelman-Kluit (1977, 1979) briefly described the volcanic rocks as an undeformed Cretaceous volcanic ‘plug’ comprising subequal amounts of porphyritic, pyritic quartz-rhyolite and hornblende andesite that were inferred to ‘invade’ the Money Klippe. Erdmer (1981) also interpreted the volcanic assemblage to be a Cretaceous ‘plug’ that ‘invaded’ the Money Klippe. He stated that the margins of the plug overlie the cataclastic rocks, but the contact was not readily visible and did not exhibit significant thermal alteration. He also said that the present outcropping of the plug likely represented the erosion level of a subaerial volcanic edifice. Mortensen (1983) questioned the Cretaceous age for the volcanic ‘plug’ based on a ca. 345-380 Ma U-Pb age from near-concordant zircon fractions from a quartz-porphyry body that intruded the mafic rocks of the plug. Although imprecise, these ages disproved a Cretaceous age and Mortensen (*op cit*) included the plug in the Anvil Assemblage. Similarly, the latter age designations led Erdmer (1985) to include the volcanic plug in the Anvil Allochthon. Mortensen and Jilson (1985) and Mortensen (1992b) suggested that the plug intruded the Anvil Assemblage and was transported with it during subsequent, post-Mississippian thrusting. Mortensen (1992b) refined the age of the quartz-porphyry body within the plug, producing a discordant crystallization age of 360.5 ± 1.9 Ma.

Grant (1997) undertook a geochemical, isotopic and U-Pb geochronological study of SRPS and YTT metasedimentary rocks, and his study partly encompassed the undeformed volcanic sequence. He mapped a small portion of the sequence and documented the occurrence of rhyolites, flow-banded rhyolites, quartz-potassium feldspar rhyolitic porphyry, and black to green plagioclase- and augite-bearing mafic rocks. He suggested that the composite plug was part of the SRPS and was the structural top of the Money Klippe. U-Pb dating of the quartz-feldspar porphyry (356.5 +3.4/-4.0 Ma) affirmed Mortensen’s (1992b) age; geochemical and isotopic data suggested that both the felsic and mafic members of the plugs reflected magmatism within a continental arc with variable crustal thickness.

Hunt and Murphy (1998) mapped a portion of the composite plug as part of a study of the geology near the Fyre Lake Cu-Co-Au volcanogenic massive sulphide (VMS) deposit (Yukon Minfile, 1997, 105G 034). Their work documented mafic volcanic breccias and augite-porphyritic volcanic rocks lying as roof pendants within quartz-porphyry. Furthermore, they suggested that the mafic rocks were not part of the SRPS, but were part of Yukon-Tanana Terrane, correlating with the mafic metavolcanic unit that hosts the Fyre Lake deposit. Additional regional mapping in the vicinity of the porphyry and outside this region is also presented in Murphy and Piercey (this volume).

STRATIGRAPHY OF THE VOLCANIC SUCCESSION

The unstrained volcanic succession consists of subaqueous and subaerial mafic and felsic volcanic rocks and associated marine sedimentary rocks. Most rocks are pristinely preserved within the sequence. However, near the margins of the sequence along the Money Creek thrust (cf. Murphy and Piercey, this volume), or near younger SRPS intrusive rocks, the volcanic rocks have been altered and deformed (see Intrusive Rocks; Fig. 2).

UNIT MVU_1

In the lower unit (MVU_1), mafic volcanic rocks are subaqueous in nature and range from pillowed to massive flows with abundant volcaniclastic rocks. Pillowed flows typically contain green to black pillows that are well preserved with very little flattening, and range in size from 10-15 cm up to 1.5 m in diameter (Fig. 4a). Typically all pillows have ~1-2 cm glassy rinds that grade into inter-pillow hyaloclastite breccia that contains 1-2 cm angular fragments of commonly glassy pillowed material, and are associated with red (hematitic) to purple inter-pillow chert. Pillow lavas are variably vesicular and range from non-vesicular up to 10% vesiculation. Minor vesiculation is common in all pillow lavas. Vesicles are often infilled with quartz and/or carbonate material.

The relationship between massive and pillowed flows within MVU_1 is uncertain; however, it is assumed, based on the stratigraphic continuity of the unit, that the relationships are conformable. Massive flows (?) have similar colouration as the pillowed flows, but their extent is uncertain.

Mafic volcanic rocks of unit MVU_1 are somewhat distinctive from the other mafic units; they contain abundant spherulites up to 13 mm in diameter. The spherulites occur as rounded blebs with radial devitrification structures. One to 3 mm-sized euhedral augite (?) or hornblende phenocrysts are common within the volcanic rocks of unit MVU_1.

Volcaniclastic rocks of unit MVU_1 consist primarily of pillowed breccias and re-sedimented (?) pillowed fragments (Fig. 4b). Most volcaniclastic breccias contain 0.5- to 3.5-cm-sized angular fragments of variably vesicular (+amygdaloidal) pillow material that are locally bleached to a white colouration (Fig. 4b). The angular nature of the clasts suggests deposition proximal to the parent mafic flows, possibly due to auto-brecciation of the parent flows. Volcaniclastic fragments of similar size but with more rounded character may have been re-sedimented by bottom currents; however, this interpretation needs to be tested by more detailed mapping. No tuffaceous rocks or other rocks indicative of explosive volcanism were documented or observed by the authors.

UNIT $FMVU_1$

Both felsic and mafic rocks occur in unit $FMVU_1$ and are in part sub-aerial. The top of unit MVU_1 exhibits a ~25 m transition zone of interlayered (?) reddish, highly vesiculated mafic lavas ($FMVU_1$), and green, weakly to non-vesiculated mafic lava. Mafic volcanic rocks from unit $FMVU_1$ are typically reddish to maroon in colour and locally have a white bleached appearance. Typically, the mafic rocks in this unit exhibit a

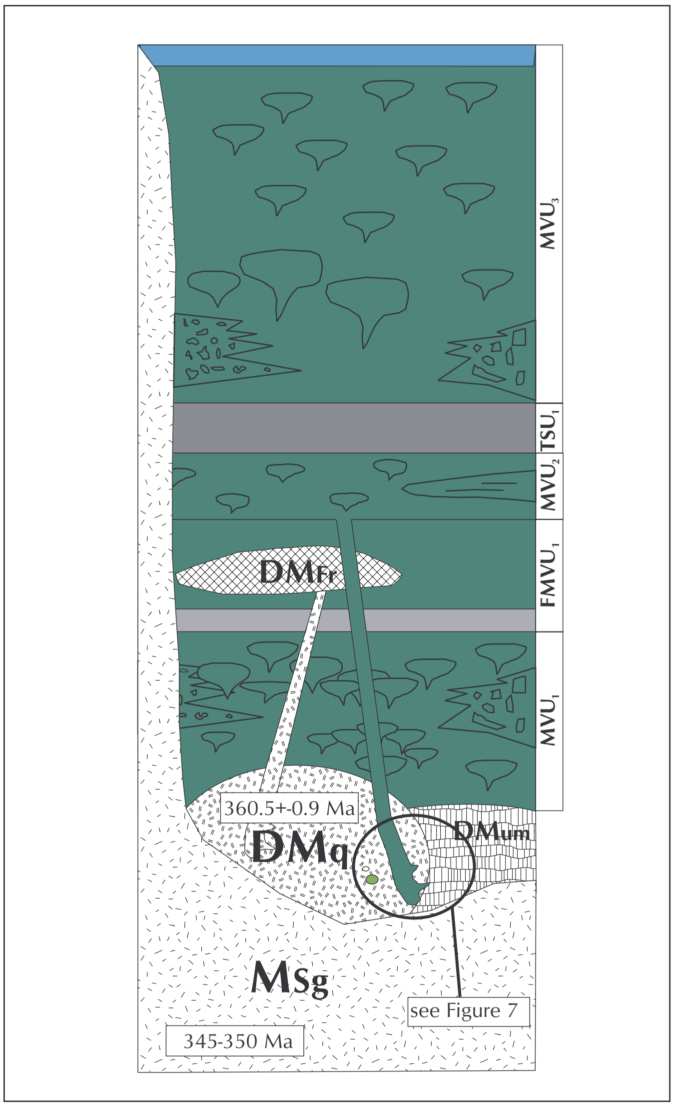

Figure 3. *Schematic composite stratigraphic section of the undeformed unit DMF in the hanging wall of the Money Creek thrust and its relationship to intrusive rocks in the region. Section was compiled from observations along traverses indicated in Figure 2. Ages are from Mortensen (1992a, b) and Grant (1997).*

Figure 4. *(a) Typical large-sized pillowed mafic lava flows from unit MVU_1. These pillowed flows are not dissimilar to those found in units MVU_2 and MVU_3. (b) Typical pillowed breccias and volcaniclastic rocks of MVU_1. Directly above the pen is a dark fragment of pillowed material that is similar to the dark finer grained mafic matrix; to the left of the pen are bleached augite-bearing pillowed fragments.*

greater degree of vesiculation than in unit MVU$_1$ ranging from 5-30%, with mostly ~10-15% (Fig. 5a). Vesicles are commonly relatively small, leading to the surfaces of the basalt flows having a very pumiceous nature. In other places the vesicles are up to 5 mm in diameter; most larger vesicles are 2-3 mm in size (Figs. 5a and b). In many outcrops, the vesicles exhibit a trachytic alignment that gives a crude indication of flow banding; however, this feature is not ubiquitous. Commonly, the larger vesicles are infilled by carbonate and/or quartz.

Fragmentation and brecciation of the mafic lavas is not as common as in unit MVU$_1$; however, this may be a function of the limited exposure of unit FMVU$_1$. Breccias that have been observed have fragments that are angular and typically range in size from 1-5 cm. Locally, these breccias have a matrix of rusty carbonate that may represent a post-depositional (post-volcanic) infilling and breakup by later carbonate-rich fluids, possibly from the SRPS.

Felsic volcanic rocks (DMFF on Figure 2) are interlayered with the mafic volcanic flows, but are less abundant than the mafic volcanic rocks (Fig. 5c). The felsic volcanic rocks are typically massive, reddish pink to pink, non-vesicular rhyolite to rhyodacite (Fig. 5c). They are of limited areal extent (Fig. 3) and are commonly associated with rhyolitic hyaloclastite breccias with large 20-30 cm blocky fragments (Fig. 5d).

UNIT MVU$_2$

The contact between unit FMVU$_1$ and the mafic volcanic rocks of unit MVU$_2$ is gradational and characterized by an increase in green mafic volcanic rocks, somewhat similar to those of unit MVU$_1$. Mafic volcanic rocks from unit MVU$_2$ are typically pillowed to massive, dark black to greenish with 0-5% vesiculation. Inter-pillow hyaloclastite breccias are common, as are minor cherts; however, on the whole, volcaniclastic rocks are minor in comparison to unit MVU$_1$.

UNIT TSU$_1$

Although relatively thin (~5-50 m, Fig. 2), turbiditic clastic rocks of unit TSU$_1$ form a distinctive marker horizon within the undeformed volcanic sequence. The thickest section of unit TSU$_1$ consists of minor interlayered coarse, green greywacke, coarse white greywacke, and finely laminated finer grained

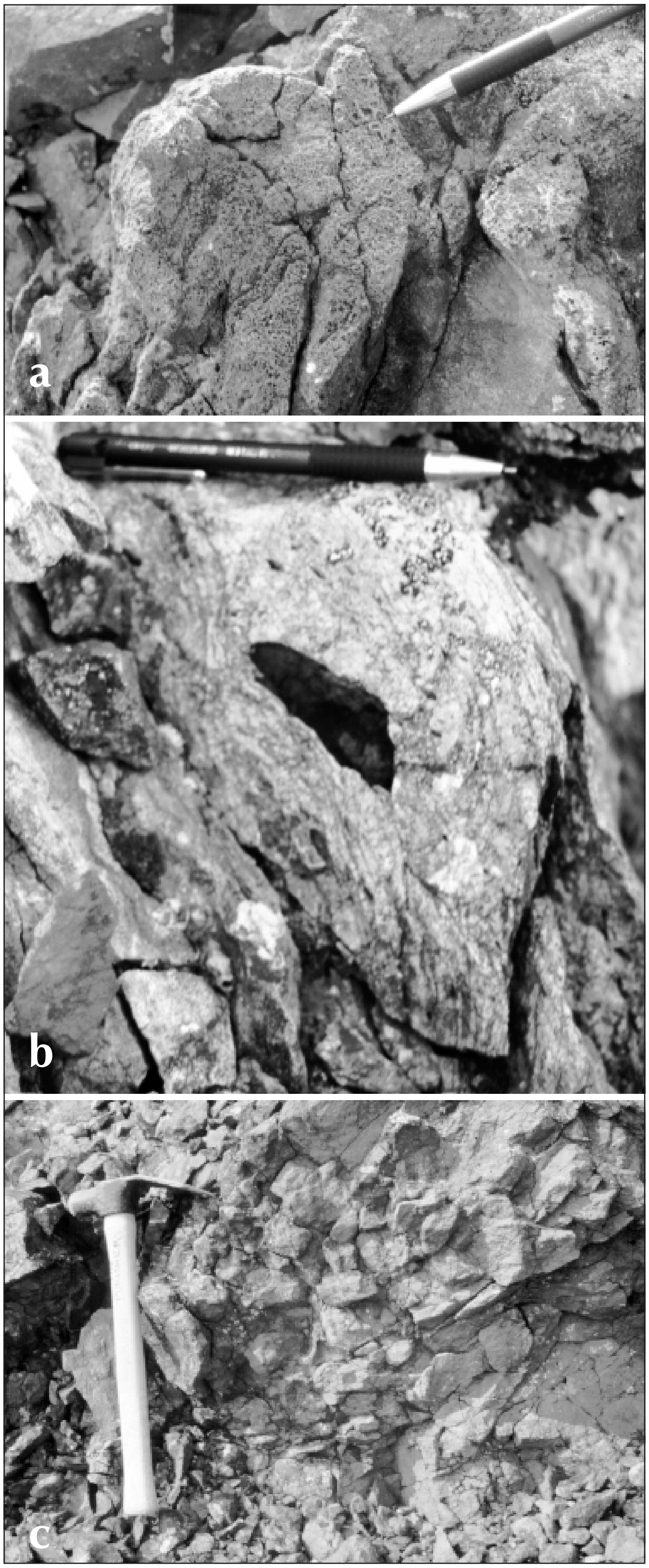

Figure 5. *In (a) are highly vesiculated (pumiceous) subaerial basaltic lavas from unit FMVU$_1$. Some of the vesicles in the basaltic rocks become quite large; in (b) this single vesicle is nearly 2 cm in diameter. Subaerial to subaqueous felsic flows in unit FMVU$_1$ commonly exhibit a rubbly in situ brecciation along their margins as show in (c).*

clastic rocks. Laterally away from this location where the unit is thinner, finely laminated clastic rocks predominate (Figs. 3 and 6). Green greywacke is volumetrically minor and consists of green medium-grained sand with fragments of ~0.5 to 1-cm-sized volcanogenic (?) material and mafic minerals. Green greywacke was observed in only one location forming 2- to 5-m-thick beds, capped by very fine- to fine-grained, dark green to grey, finely laminated cherty siltstone (Fig. 6a). These generally occur in 0.5- to 1-m-thick beds with abundant mm-scale internal laminae interlayered with beds of white greywacke (Figs. 6a and b). Laterally away from the interlayered coarse clastic rocks, finely laminated turbiditic rocks predominate, and in one location they are very fine-grained to glassy. These glassy units may be turbiditically re-sedimented volcanogenic ash.

In the thickest portion of this section, the white greywacke unit is composed of coarse white sand with reddish pink and green fragments (Fig. 6b). The sands typically form 0.5- to 2-m-thick beds which are commonly interlayered with ~30-cm-thick fine cherty layers as described above. The reddish pink clasts are typically rounded and 2-3 mm in diameter with some resemblance to the underlying rhyolitic rocks of unit $FMVU_1$. Similarly, smaller green fragments have features akin to the underlying mafic volcanic rocks; however, some larger fragments appear to be akin to the finely laminated chert layers. The white sand layers of this unit provide the best evidence for the upright-facing direction of the sequence. The lower parts of white sandy beds consist of abundant clasts of the underlying rocks, as described above. Well defined 2- to 3-cm-lode and flute casts ornament the bases of beds (Fig. 6b), providing unambiguous stratigraphic-top indicators. The sandy material within the TSU_1 unit decreases laterally from point X to nil to the northeast and southwest (Fig. 2) and is replaced by very siliceous, in places glassy, fine-grained laminated turbiditic sedimentary rocks.

UNIT MVU_3

The contact between unit TSU_1 and MVU_3 is abrupt, and marked by an abundance of mafic and lesser felsic volcanic rocks. Immediately above the TSU_1 – MVU_3 contact is a variably vesiculated and plagioclase-phyric, green, pillowed basalt sequence that is interlayered with ~5-m-thick flows (?) of plagioclase-phyric, red to white rhyolite and rhyodacite. Felsic volcanic rocks are only observed in this location. The remainder of the unit consists predominantly of pillowed and massive flows, akin to the underlying mafic units. Pillowed lavas are variably vesicular and have vesicles infilled with carbonate and/or quartz. Pillows range from 30-60 cm in diameter and commonly have reddish to purple inter-pillow chert. Pillows and massive flows range in colour from black to purple and in places greenish. The areal extent of the massive flows is uncertain. Plagioclase phenocrysts are present in some samples; rarely hornblende (pyroxene?) phenocrysts are present. Sedimentary and volcaniclastic rocks are rare in unit MVU_3. Locally, near the top of this unit, are discontinuous marble horizons of detrital origin.

INTRUSIVE ROCKS

Intrusive rocks are spatially associated with the undeformed volcanic sequence; however, not all of them are temporally or genetically related to the sequence. Intrusive rocks in this region include: 1) mafic/ultramafic intrusive phases; 2) quartz-porphyritic intrusions; and 3) intrusions of the Simpson Range Plutonic Suite (SRPS). Our data show that the first two types are coeval and comagmatic with the undeformed volcanic sequence and the SRPS post-dates the volcanic rocks.

Gabbroic and ultramafic rocks are common within the undeformed sequence, particularly along the Money Creek thrust (see Murphy and Piercey, 1999b, c). Near the thrust, the gabbroic rocks are variably strained; however, original gabbroic textures are recognizable. Spatially associated with the gabbroic rocks are serpentinized harzburgitic ultramafic rocks that appear

Figure 6. *Typical finely laminated, locally glassy, siliceous sedimentary rocks common in unit TSU_1 (a). These laminated sedimentary rocks are interlayered with white sandy layers at location X in Figure 2. Directly atop of the pencil in (b) is a typical flute cast within a white greywacke common along their basal surfaces in unit TSU_1.*

to underlie the gabbros and may represent either residues from gabbroic melt extraction or cumulations of ultramafic minerals below a gabbroic magma chamber. The authors infer that the mafic and ultramafic intrusions are comagmatic with the basalts based on their spatial association, similar U-Pb age constraints and similarity in the petrology of the volcanic and gabbroic rocks (Grant, 1996). The gabbroic and ultramafic rocks may thus be the intrusive roots of the basalts in the undeformed volcanic sequence.

Quartz-porphyritic intrusive rocks (Dmq) look superficially similar to the SRPS rocks, but typically lack hornblende and biotite and are older than the SRPS (~357-361 Ma; Mortensen,

Figure 7. *Mafic dykes intruding and mingling with a ~361 Ma (Mortensen, 1992b) quartz-porphyritic granite intrusion. In (a) the dyke margins are characterized by flame-like terminations into the granite host. Commonly, the dykes have ball structures of mafic material disassociated from the dyke margins within the granite host. Tentacle-like intrusive contacts and very diffuse margins of the mafic dykes with the granite host are also common (b). These features suggest that the granite host was still warm and not solidified during the intrusion of the dykes implying that they are nearly coeval.*

1992a, b; Grant, 1997; Grant et al., 1996). Unit DMq is generally medium-grained, less commonly fine-grained, and are typically pink to pink-white to white-grey. It typically contains 2-3 mm quartz phenocrysts dispersed in a pink to white, fine- to medium-grained groundmass.

At location Y in Figure 2, the quartz-porphyritic rocks are intruded by, yet mingle with, mafic dykes that are interpreted to represent feeders to the overlying basaltic units (Fig. 7). The mafic dykes that intrude the QP are medium- to fine-grained with abundant 2-3 mm euhedral augite and plagioclase phenocrysts, and are widely spaced with south-southeast trends. Dyke margins are variably straight, but do not exhibit well defined chill margins typical of warm dykes intruding cold wall rocks (Fig. 7). In places along the dykes they exhibit tentacle-like terminations into quartz-porphyritic granite (Fig. 7b), whereas in other places the dyke walls are bulbous and grade into a flame-like termination into the quartz porphyry (Fig. 7a). Common are ball structures of mafic material disassociated from the dyke margins and floating within the granite (Fig. 7a). These magma-mingling relationships with the quartz-porphyritic rocks suggest that they are coeval and that the quartz-porphyritic intrusions are the sub-volcanic feeders to rhyolite and rhyodacite interstratified with basalt in parts of the volcanic sequence. The ~357-361 Ma ages on the quartz porphyry would therefore constrain the age of part of the volcanic succession.

The SRPS consists of numerous granitoid types including hornblende-granodiorite, biotite-monzogranite, and K-feldspar granite (cf. Mortensen, 1983; Mortensen, 1992a, b; Grant, 1997). The relationships between the different granitoid phases were not discerned during our field study. The SRPS clearly intrudes the mafic rocks of the undeformed sequence, as evidenced by distinctive patchy purple-yellow epidote-rich alteration of the mafic rocks along the contact, dykes of hornblende-bearing granitoids cutting the sequence, and pendants and xenoliths of mafic volcanic rock within the granitoids. U-Pb geochronological constraints suggest that the Simpson Range Plutonic Suite intruded between 345 and 350 Ma (Mortensen, 1992b; personal communication, 1997; Grant, 1997), well after the extrusion of the volcanic sequence at ~357-361 Ma.

DISCUSSION

The new data and conclusions from our study of the undeformed volcanic rocks of the Money Creek thrust sheet have broader implications. This discussion will be divided into three parts, dealing with: 1) definition of the Simpson Range Plutonic Suite; 2) emergent volcanism in the undeformed sequence; and 3) criteria to distinguish the succession in the Money Creek thrust sheet from the Campbell Range belt with which it has been correlated.

DEFINITION OF THE SIMPSON RANGE PLUTONIC SUITE

As defined by Mortensen (1983), the SRPS consists of hornblende-biotite granodiorite and quartz diorite; that is, granitoids of metaluminous affinity that differ from suites of peraluminous affinity in YTT such as the Mink Creek or Houle River orthogneiss bodies. Erdmer (1985), Grant et al. (1996) and Grant (1997) subsequently included the mafic and felsic rocks of the volcanic 'plug' and related gabbroic intrusions in the SRPS. The geological relationships described in this report, as well as published and unpublished U-Pb geochronological data, show that the volcanic succession is older than and crosscut by intrusions of the SRPS; hence, they should not be included in the SRPS.

EMERGENT VOLCANISM IN THE UNDEFORMED SEQUENCE

Given the state of strain that most greenstones within the YTT exhibit, it is typically impossible to determine the ambient volcanic environment in most areas of the YTT. The lack of strain in volcanic rocks in this part of the Money Creek thrust sheet gives us the opportunity to determine the local environment of deposition. The change from predominantly subaqueous pillowed flows and related volcaniclastic rocks in unit MVU_1 to mixed subaerial and subaqueous volcanism in unit $FMVU_1$ is inferred to represent the emergent growth of a volcanic edifice from subaqueous to subaerial conditions. Unit MVU_1 basalts are unequivocally subaqueous, exhibiting features such as pillowed flows, pillowed breccias, and inter-pillow chert and hyaloclastite breccias. Near the top of MVU_1, however, the dominantly subaqueous basalts change to reddish lava flows alternating with black to green subaqueous flows, implying a transition to more oxidizing conditions indicative of a subaerial environment. Furthermore, in the overlying $FMVU_1$ the presence of trachytic textures, abundant vesiculation, scoriaceous textures, and predominant reddish colouration are features typical of volcanism in a subaerial environment. We suggest that, based on this transition from subaqueous to subaerial conditions, there was growth of a volcanic edifice from below to above the ambient sea level, akin to many volcanic archipelagos present in the modern oceans.

It appears from the volcanic stratigraphy that the phase of emergent volcanism in $FMVU_1$ was replaced by subaqueous turbiditic sedimentation, and mixed mafic and felsic magmatism (TSU_1, MVU_2, MVU_3). It is possible that this return to subaqueous activity may represent either an inundation of the volcanic edifice by rising sea levels, or more likely, rifting or intra-volcano subsidence (caldera?) with subsequent subaqueous activity. Given the presence of turbiditic sedimentation in association with subaqueous lavas, the latter situation is most probable.

COMPARISON WITH CAMPBELL RANGE BELT

The correlation between the mafic and ultramafic rocks of the Money Creek thrust sheet and similar rocks in the Campbell Range belt (CRB) is rendered obsolete by the geological relationships presented in this study, and published and unpublished U-Pb geochronological data. The volcanic and sub-volcanic rocks of the Money Creek thrust sheet are Devono-Mississippian and those of the CRB are Pennsylvanian to Permian (Harms, in Plint and Gordon, 1997). In this section (Table 1), we compare and contrast the volcanic rocks of the

Table 1. *Sumary of salient stratigraphic, geochemical and temporal differences and similarities of the volcanic rocks of the Money Creek thrust sheet and the Campbell Range belt.*

	Money Creek thrust sheet	Campbell Range belt
Mafic volcanism[1]	Pillowed to massive flows and volcaniclastic rocks; subaqueous and subaerial	Pillow to massive flows and volcaniclastic rocks; all subaqueous
Felsic volcanism[1]	Rhyolite-rhyodacite; subaqueous and subaerial	Felsic volcanism absent
Sedimentary rocks[1]	Turbiditic sedimentary rocks; minor detrital carbonate rocks; minor volcanic greywackes; rare chert	Dark argillite and sandstone; diamictite; volcanic greywacke; abundant chert and chert-pebble conglomerate; carbonate (possibly as olistostromes)
Age[2]	Devonian-Mississippian	Pennsylvanian-Permian
Geochemistry[3]	Arc - calc-alkaline	Non-Arc - N-MORB, E-MORB, OIB
Tectonic setting[4]	Continental arc	Marginal basin with terrigenous input

[1]CRB data from Murphy and Piercey (1999a, b, c) and Plint and Gordon (1997).

[2]Age data from Mortensen (1983, 1992b), Grant et al. (1996) and Grant (1997).

[3]Geochemical attributes for undeformed sequence from Grant (1997), CRB from Plint and Gordon (1997) and Piercey et al. (1999a,b); N-MORB = normal mid-ocean ridge basalt (MORB), E-MORB = enriched MORB, and OIB = ocean island basalt.

[4]Interpretations based on inferences from this paper and Grant (1997), Grant et al. (1996) and Plint and Gordon (1997).

Money Creek thrust sheet and the Campbell Range belt to provide criteria with which to distinguish them.

Mafic volcanic rocks are common to both sequences; the sequences differ primarily in the nature of the other rock types. For example, subaqueous pillow lavas and massive flows are common to both sequences, as are pillowed breccias and vent-proximal volcaniclastic material (e.g., Murphy and Piercey, 1999a; Plint and Gordon, 1997). However, rhyolitic and rhyodacitic rocks are a common feature of the rocks of the Money Creek thrust sheet and are notably absent in the CRB rocks. Turbiditic sedimentary rocks such as TSU_1 are present, although not necessarily abundant, in the Money Creek thrust sheet. In contrast, sedimentary rocks including chert, chert-pebble conglomerate, cherty argillite, siltstones, sandstones and olistostromal carbonate blocks are the common sedimentary rocks of the CRB (Plint and Gordon, 1997; Murphy and Piercey, 1999a, b, c; this volume). Although the sedimentary rocks of the CRB may have had similar origins as TSU_1 (i.e., mass flows), they do not exhibit the turbiditic layering and characteristics common of those in the Money Creek thrust sheet (*op cit*). There is also a significantly greater abundance of chert and chert-rich material in the CRB than in the Money Creek thrust sheet, suggestive of a quiescent environment with significant gaps in volcanism that allowed the accumulation of chemical sediments. The sequence in the Money Creek thrust sheet also contains abundant evidence for subaerial volcanism that has yet to be described or observed in the CRB (*op cit*).

In addition to the field-based differences, the sequences differ geochemically. Grant (1997) showed that the mafic and felsic rocks from the Money Creek thrust sheet have geochemical and isotopic signatures typical of calc-alkalic continental arc magmatism. In contrast, the CRB is characterized by non-arc signatures consisting of various basalt types ranging from rift through normal mid-ocean ridge basalt (N-MORB) composition (Plint and Gordon, 1997; Piercey et al., 1999a, b).

To summarize, the undeformed Money Creek package can be distinguished from the Campbell Range belt (and possibly similar rocks of the Slide Mountain Terrane?) lithologically, geochemically (arc versus non-arc) and geochronologically (mid- versus late Paleozoic). By using this combined approach greenstones from other portions of the YTT and Slide Mountain Terrane may be effectively discriminated and separated.

CONCLUSIONS

- Undeformed volcanic rocks of the Money Creek thrust sheet provide a window into the mid-Paleozoic volcanic history of this portion of the YTT. This undeformed sequence consists of a five-component volcano-sedimentary stratigraphy with associated sub-volcanic intrusions that record volcanism in a shallow water subaqueous to subaerial setting (archipelago-like environment);
- Magma-mingling relationships between augite-plagioclase-porphyritic mafic dykes, interpreted as feeders to the basalts in the volcanic sequence, and ~357-361 Ma quartz-porphyritic granitoids, inferred to feed the felsic volcanic rocks, imply coeval Devono-Mississippian mafic and felsic volcanism. This relationship provides a key temporal pin on primitive through mature arc activity (e.g., Grant, 1997; Piercey et al., 1999a, b) in Yukon-Tanana Terrane.
- Many workers have suggested that the mafic and felsic volcanic rocks, as well as quartz-porphyritic granitoids and gabbroic-ultramafic intrusions were part of the SRPS (e.g., Erdmer, 1981, 1985; Grant et al., 1996; Grant, 1997). We exclude these units from the SRPS based on our field observations and U-Pb geochronological data and restrict the SRPS to metaluminous granitoids of ~345-350 Ma age.
- Field, geochemical and geochronological criteria can be used to distinguish the Devono-Mississippian mafic volcanic rocks from Pennsylvanian-Permian rocks of the Campbell Range belt.

Greenstones within the Yukon-Tanana Terrane are diverse in geological character and paleotectonic environments of formation. It is only with keen field observations and geological mapping augmented with relevant laboratory data (i.e., geochemistry, geochronology) that we can obtain a clearer picture of the nature and origin of mafic to felsic volcanism within the YTT and other terranes of the northern Cordillera.

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