Volcano-sedimentary megaclast in Wernecke breccia, Yukon, and its bearing on the Proterozoic evolution of northwestern Laurentia

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ABSTRACT

A group of hydrothermal breccias, collectively known as Wernecke breccia, formed at approximately 1.60 Ga in Yukon. The breccias consist of a hydrothermally precipitated matrix that cements clasts derived mainly from the metasedimentary Wernecke Supergroup. Locally, clasts and megaclasts of the Bonnet Plume River intrusions, the Slab volcanics, and other volcanic rocks are also present within the breccias. This paper describes a volcano-sedimentary succession interpreted as a megaclast within Wernecke breccia. The succession consists of pyroclastic and epiclastic rocks that formed in a volcanic environment in a region of evolved crust. This finding adds detail to the character of a postulated Proterozoic terrane that may have collided with the northwestern margin of ancestral North America toward the end of the Paleoproterozoic.

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INTRODUCTION

The Wernecke breccias are a group of early Mesoproterozoic hydrothermal breccias located in Yukon (Thorkelson, 2000; Thorkelson *et al.,* 2001b). The breccias formed within meta-sedimentary rocks of the Wernecke Supergroup and are unconformably overlain by the Pinguicula and Fifteenmile groups (Thorkelson, 2000). In addition to the clasts of dolostone, siltstone, slate, phyllite, and schist derived from the Wernecke Supergroup, which is the predominant clast source, the breccias contain fragments of plutonic and volcanic rock including the Bonnet Plume River intrusions and the Slab volcanics (Thorkelson *et al.*, 2001a; Laughton *et al.*, 2005). The model for brecciation proposed by Thorkelson (2000) involves incorporation of the plutonic, volcanic and sedimentary clasts and megaclasts into the breccias zones during surges of hydrothermal fluids that occurred after deformation and metamorphism of the Wernecke Supergroup.

The area studied in the summer of 2010 (Fig. 1) is near the Yukon Olympic mineral occurrence (Yukon MINFILE 116G 082) along the Dempster Highway, approximately 150 km north of its junction with the Klondike Highway. The work was carried out over an interval of three days and yielded two sample sets west of the Blackstone River. The first set consists of 25 samples of Wernecke breccia collected from talus and rip-rap along the Dempster Highway. The second set was obtained on a traverse atop a ridge in the area, and consists of 16 samples from a succession of lapillistone, volcaniclastic wacke and volcano-sedimentary breccia. The succession is interpreted as a megaclast within Wernecke breccia, herein informally named the Blackstone River megaclast. This paper provides hand specimen and thin section descriptions of selected samples from both localities to provide an interpretation of the provenance of the sediment, environment of formation, and origin of the volcano-sedimentary megaclast.

REGIONAL GEOLOGICAL FRAMEWORK

WERNECKE SUPERGROUP

The Wernecke Supergroup (Delaney, 1981) is a metasedimentary succession that was deposited as two cycles of basinal siliciclastic to platformal carbonate rock during two corresponding intervals of extension and subsidence that formed the Wernecke basin (Thorkelson, 2000; Thorkelson *et al.*, 2005; Hunt *et al.*, 2006). Delaney (1981) and Thorkelson (2000) place the minimum thickness of the Wernecke Supergroup between 13 and 14 km. The Wernecke Supergroup consists of the Fairchild Lake Group, which represents the first cycle of basin infill and the conformably overlying Quartet and Gillespie Lake groups, which represent the second cycle (Delaney, 1981; Thorkelson, 2000; Thorkelson *et al.*, 2005). The Fairchild Lake Group is inferred to lie on >1.84 Ga basement rock of cratonic Laurentia (ancestral North America), although this relationship is nowhere exposed and drilling in mineral exploration projects has not been deep enough to test this theory. At present, the Proterozoic rocks of the Wernecke Supergroup are exposed as inliers in Yukon (Fig. 1b; Thorkelson *et al.,* 2005). The age of the Wernecke Supergroup was previously thought to be >1.71 Ga (Thorkelson *et al.,* 2001a), but recent detrital zircon studies by Furlanetto *et al.* (2009a,b) indicate that the Wernecke Supergroup is <1.64 Ga.

RACKLAN OROGENY

The Wernecke Supergroup was deformed to greenschist grade metamorphism by the compressional Racklan Orogeny before 1.60 Ga (Thorkelson, 2000; Brideau *et al.*, 2002; Laughton *et al.*, 2005; Thorkelson *et al.,* 2005). Deformation occurred first as easterly contraction, resulting in fold and foliation development in the Wernecke Supergroup, and was followed by additional folding and kink-banding (Thorkelson, 2000). The results of the Racklan Orogeny are especially evident in the Fairchild Lake Group near Slab Mountain, where schist, exhibiting crenulations and kink-banding, is present (Brideau *et al.,* 2002). Racklan deformation is not observed in Wernecke breccia except in individual breccia clasts with random foliation orientations, indicating that deformation occurred before breccia formation (Thorkelson, 2000; Brideau *et al.,* 2002; Laughton *et al.,* 2005).

WERNECKE BRECCIA

Wernecke breccia is a group of numerous breccia occurrences in the Wernecke and Ogilvie mountains, and one local occurrence in the Richardson Mountains, in Yukon (Thorkelson, 2000; Thorkelson *et al.*, 2001b). Several models for the formation of the breccias have been proposed, but the most plausible model according to the most recent evidence is that structurally influenced hydrothermal fluid ascent and volatile-induced expansion caused brecciation of host rocks (Hitzman *et al.*, 1992; Thorkelson, 2000; Thorkelson *et al.*, 2001b). This process occurred at depths of 7.5-9 km and involved

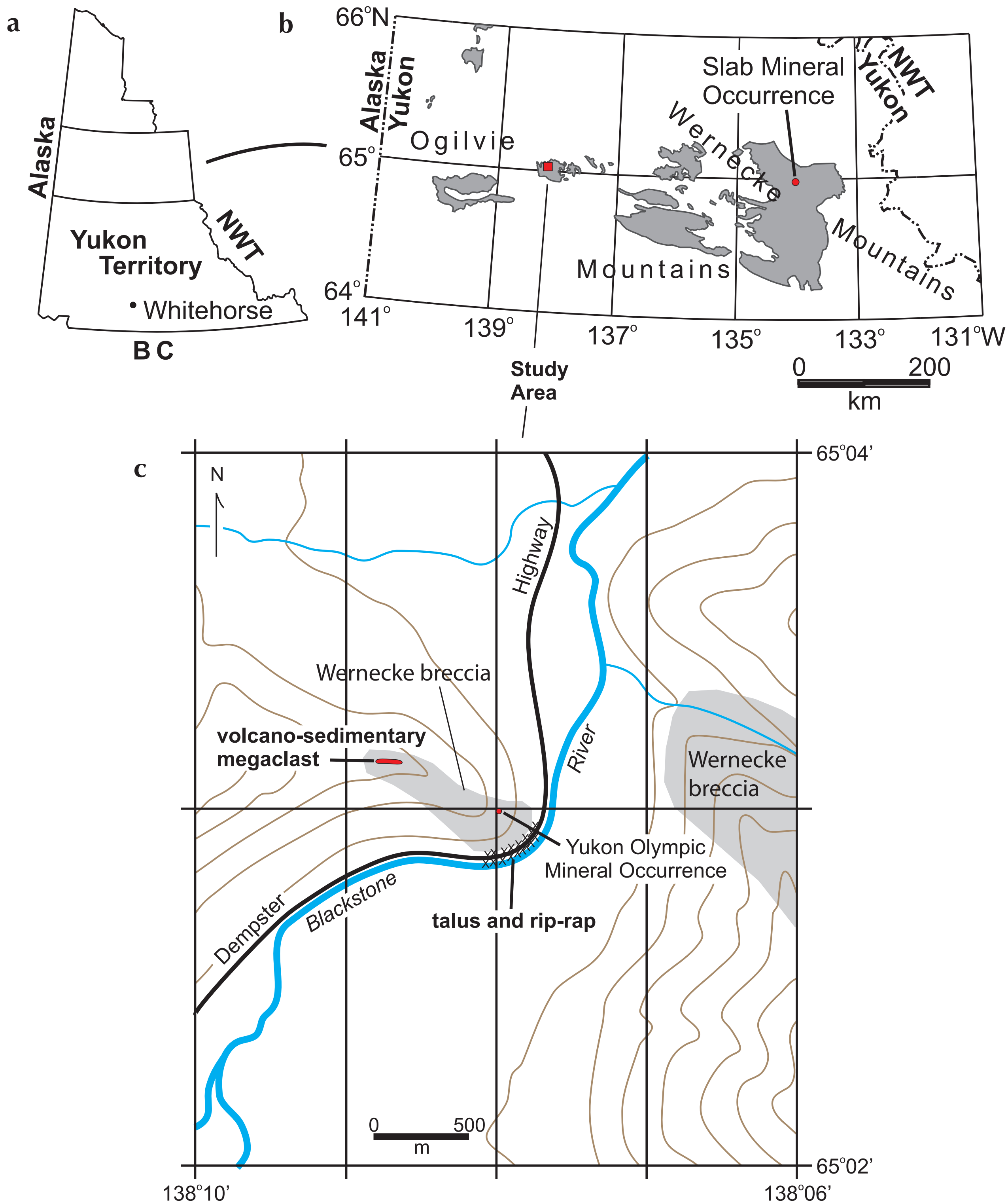

Figure 1. *Location of the study area. Longitude and latitude in (b) and (c), are expressed as NAD27 coordinates.* ***(a)*** *Map of Yukon illustrating the locations of inliers* ***(b)*** *of the Early Proterozoic Wernecke Supergroup (inliers are shaded in grey; modified from Thorkelson et al., 2001a).* ***(c)*** *Map of the study area depicting the minimum extent of Wernecke breccia and the location of the volcano-sedimentary megaclast.*

non-magmatic fluids that were generally present in only modest amounts (Hunt *et al.*, 2005; Hunt *et al.,* 2007). Most of the brecciation occurred at approximately 1.59 Ga during several hydrothermal 'pulses' that crosscut each other and their host rocks (Thorkelson *et al.,* 2001b; Hunt *et al.*, 2005; Hunt *et al.*, 2007). The hydrothermal processes that created the breccias produced abundant iron oxide copper-gold-type (IOCG) mineralization and hydrothermally precipitated material in veins, fractures and among matrix rock fragments, as well as metasomatic alteration, to a variable extent, within breccia clasts (Hitzman *et al.*, 1992; Thorkelson *et al.*, 2001b; Hunt *et al.*, 2005). Breccia clasts are commonly granule to cobble in size, but are locally as large as boulders; they are dominantly derived from the Wernecke Supergroup, but igneous clasts of Bonnet Plume River intrusions and Slab volcanics (described later) are common at many localities (Thorkelson, 2000; Thorkelson *et al.*, 2001b). Alteration is commonly either potassic (yielding mainly pink and red colours) or less commonly sodic (grey), and late carbonate veins are typically present (Thorkelson *et al.*, 2001b; Hunt *et al.*, 2005; Laughton *et al.*, 2005; Hunt *et al.*, 2007). Clasts that may be interpreted as basement rock are nowhere observed (Thorkelson *et al.*, 2001b).

BONNET PLUME RIVER INTRUSIONS

The Bonnet Plume River intrusions are dominantly dioritic to gabbroic igneous rocks that occur as clasts of variable size within zones of Wernecke breccia (Thorkelson, 2000; Laughton *et al.,* 2002). Clasts typically range in size from a few centimetres to tens of metres wide, but can be as large as 0.2 km by 1 km (Thorkelson *et al.,* 2005). Lithification of the rocks occurred before their incorporation into the breccias (Thorkelson, 2000). Many clasts are hydrothermally altered, veined, and mineralized (magnetite, hematite, chalcopyrite and gold), but most lack foliation (Thorkelson *et al.,* 2005). The intrusions were dated at ≥1.71Ga based on four U-Pb zircon dates (Thorkelson *et al.*, 2001a). These intrusive bodies were previously thought to be dykes and stocks that intruded the Wernecke Supergroup (Thorkelson, 2000; Thorkelson *et al.,* 2001a) and were later dismembered during Wernecke breccia formation. However, Furlanetto *et al.* (2009b) demonstrated that the Bonnet Plume River intrusions are ~70 m.y. older than the Wernecke Supergroup and that the intrusive rocks were probably derived from a terrane that was thrust over the Wernecke Supergroup and involved with subsequent Wernecke breccia development.

SLAB VOLCANICS

The informal term 'Slab volcanics' refers to several occurrences of volcanic clasts within Wernecke breccias that are proximal to each other, the largest being a 160x380 m megaclast at the Slab mineral occurrence (Fig. 1b; Thorkelson, 2000; Laughton *et al.*, 2002; Laughton *et al.*, 2005). Their presence in the Wernecke breccia indicates that they are older than 1.60 Ga (Thorkelson, 2000). The incorporation of the volcanic rocks into the Wernecke breccia may have been facilitated by hydrothermal venting at the surface that ejected host rock material and allowed clasts to move to stratigraphically lower positions by several hundred metres (Thorkelson *et al.*, 2001b; Laughton *et al.*, 2005). Thorkelson (2000) suggested a possible comagmatic relationship between the Slab volcanics and the Bonnet Plume River intrusions based on geochemical affinity.

RESULTS

WERNECKE BRECCIA

The samples of Wernecke breccia taken from talus and rip-rap in the study area display compositional and textural characteristics that are typical of the widespread Wernecke breccias in Yukon described by Thorkelson (2000), Thorkelson *et al.* (2001b) and Hunt *et al.* (2005; 2007). Although the samples were not derived from outcrop, they are similar to (and were probably derived from) a zone of Wernecke breccia that is exposed in nearby outcrops and road-cuts.

The breccia samples consist of clasts, matrix, and younger veins. They commonly contain disseminated specular hematite. Some samples contain macroscopic chlorite. The matrix of the samples consists mainly of dark purple mud, sand and silt-sized quartz grains and rock fragments, carbonate cement, and opaque minerals such as hematite. Locally, the matrix also contains sericite and possible titanite. In some samples, the matrix is dark greenish-grey, but is compositionally similar to the purple matrix, including quartz sand and silt fragments, polycrystalline quartz, carbonate and hematite.

Clast size is highly variable and ranges from sand to boulders. The clasts are mainly light brown-weathering, light pink to medium purple, very fine grained sandstone and siltstone and dark green volcanic rock. The sedimentary clasts are commonly laminated and some display trough cross-lamination. They are composed of dominantly angular and subangular quartz, but also contain biotite and muscovite (ranging in size from silt to very fine sand), hematite and possibly other metallic minerals, carbonate minerals, and possible titanite and zircon. The volcanic clasts consist predominantly of feldspar laths, secondary chlorite (probably after pyroxene), and accessory hematite and/or titanite. Some clasts also contain sericite or muscovite flakes, and some contain quartz and/or calcite amygdules.

VOLCANO-SEDIMENTARY MEGACLAST

The volcano-sedimentary megaclast is surrounded by a zone of Wernecke breccias (Fig. 1c). It is approximately 125 x 15 m in size and outcrops approximately 0.7 km west of the Dempster Highway. The succession consists of pyroclastic rock, including lapillistone and lapilli tuff, and epiclastic rock, including wacke and volcaniclastic breccia. Most of the clasts consist of fine-grained volcanic rock, but some are epiclastic, including quartz-rich siltstone and fine-grained sandstone. The clasts are typically ≤1 cm in diameter and rarely >2 cm in diameter. The stratigraphic order is not evident, although the succession appears to be structurally intact. Contacts with Wernecke breccia are not exposed, although Wernecke breccia appears to surround the outcrop, implying that the succession is megaclast engulfed by breccia. Such a relationship between igneous clasts and breccia is common in many other localities (Thorkelson *et al.*, 2001a,b; Nielsen *et al.*, this volume). Four samples from the outcrop were chosen to be examined critically based on the variability of lithologic textures.

SAMPLE 1

Sample 1 is a lapillistone. It consists of volcaniclastic fragments, lesser sedimentary rock fragments and minor monocrystalline and polycrystalline quartz, and a matrix of clay, quartz silt, and local very fine volcanic quartz. The rock is clast-supported and almost all of the clasts are lapilli (pebble-sized fragments). The volcanic clasts consist of an isotropic groundmass with variable amounts of feldspar and quartz microphenocrysts, and abundant chlorite patches (Fig. 2a). These patches are interpreted as variably collapsed vesicles that were subsequently converted to amygdules by chlorite precipitation. The direction of elongation of the amygdules is interpreted as the plane of flattening that developed perpendicular to the orientation of maximum compressive stress during vesicle collapse. The planes of flattening among the grains are remarkably similar, typically differing from one another by only a few degrees and seldom by more than 25˚ (Fig. 2b). Several of these volcanic grains also display extensive replacement by calcite. The sedimentary rock fragments are very fine grained sandstone and siltstone, composed of quartz and feldspar, and lesser mudstone or accretionary lapilli clasts. Some of the sedimentary clasts contain minor mica and at least one contains zircon (Fig. 2c). Many of the grains share concavo-convex or curviplanar contacts, and display greater amounts of vesicle flattening near such contacts (Fig. 2b).

SAMPLE 2

Sample 2 is a lapillistone. It consists mainly of granule-sized, variably shaped volcaniclastic fragments with secondary chlorite. It contains deformed and chloritized vesicles similar to those in Sample 1. There are also subangular to rounded grains of crystalline volcanic rock containing feldspar laths and chlorite (possibly as grain replacements), very fine sandstone and siltstone fragments, and monocrystalline and polycrystalline quartz. Also present are clasts of mud or volcanic ash that display ductile fabrics (Fig. 2d). The sample has a muddy matrix.

SAMPLE 3

Sample 3 is a succession of poorly sorted granule and pebble breccia that is interlaminated with wacke and mudstone. The matrix is composed of clay and silt to sand-sized quartz grains. Breccia layers consist of a variety rock fragment types, including clasts of laminated siltstone, mudstone and volcanic rock deposited as lava or coarse tephra. The siltstone clasts are composed of quartz and feldspar with lesser amounts of muscovite and biotite. Some of the volcanic fragments are dominated by feldspar laths and locally contain chlorite and quartz amygdules (Fig. 3a). Other fragments consist mainly of isotropic groundmass, which probably originated as volcanic glass; the groundmass is composed of microlites, devitrified glass and chlorite alteration. Clast sizes range from mud, to a maximum of approximately 1 cm diameter. The breccia layers are clast-supported, and are approximately 0.5 mm to nearly 1 cm thick. The rock is compositionally and texturally immature due to relatively high clay content, the abundance of volcanic rock fragments, the high range in grain size from clay matrix to pebble-sized conglomerate clasts, and the variability in grain rounding from angular to rounded. The rock shows evidence of dewatering of fine-grained layers and subsequent compaction around competent grains within coarse-grained layers (Fig. 3b). There are also dark brown cataclastic foliations at high angles to bedding (Fig. 3c), as well as local concavo-convex grain contacts.

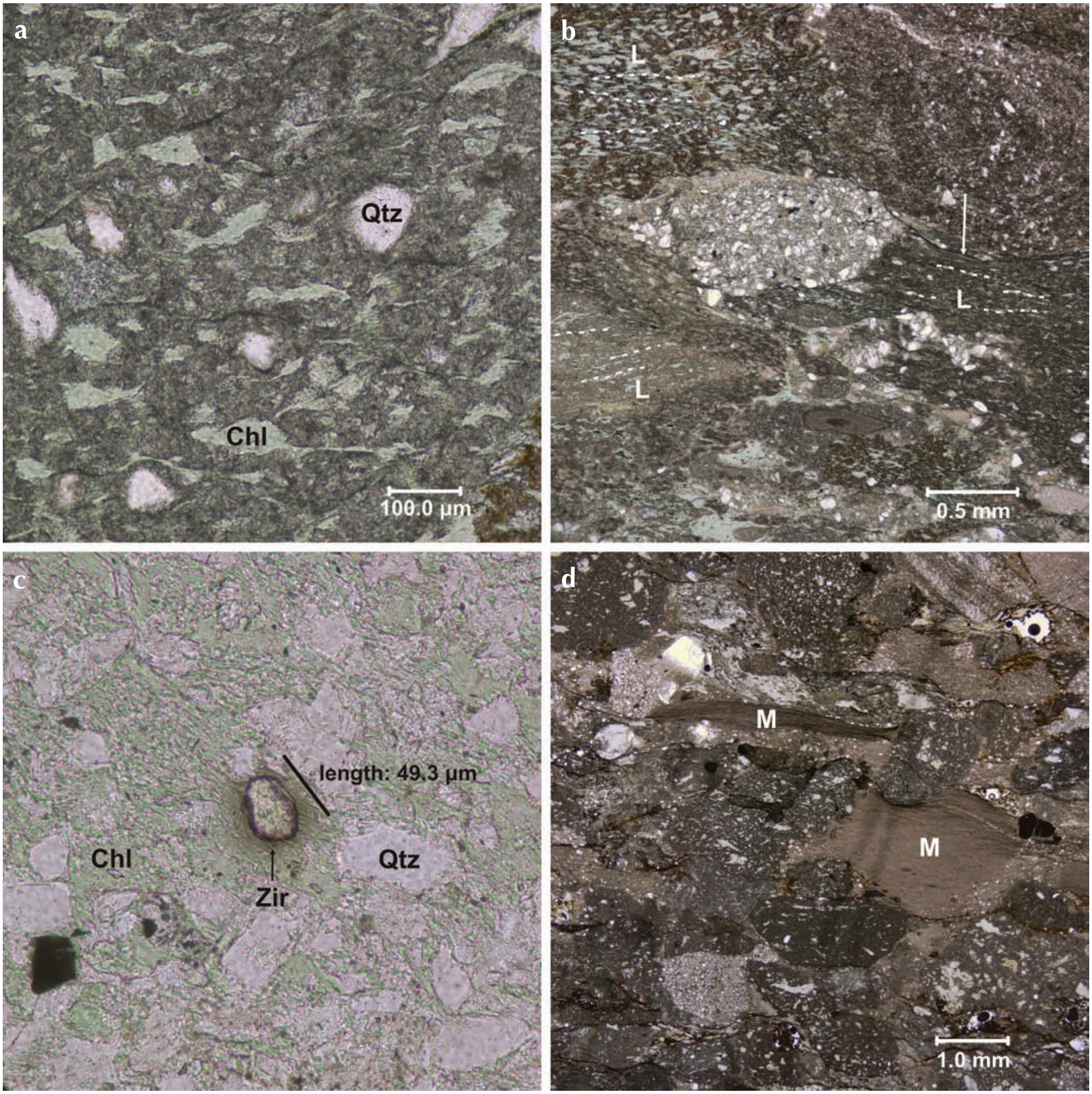

Figure 2. *Photomicrographs of pyroclastic rock samples: (a) to (c) from Sample 1, and (d) from Sample 2.* ***(a)*** *A lapillus consisting of isotropic groundmass, quartz microphenocrysts (Qtz) and chlorite amygdules (Chl); and* ***(b)*** *lapilli (L) with similarly oriented amygdule flattening fabrics (outlined with dashed white lines). The white arrow indicates the location of a concavo-convex grain contact.* ***(c)*** *An accidental siltstone clast that contains zircon (Zir); and* ***(d)*** *clasts of mudstone or volcanic ash (M) displaying ductile fabrics.*

SAMPLE 4

Sample 4 is a lithic wacke. Clasts are dominantly angular, subangular and occasionally subrounded, monocrystalline, very fine sand and silt-sized quartz, but the rock contains subangular to rounded, granule to pebble-sized volcaniclastic fragments (none larger than about 1 cm in diameter) that display calcite replacement (Fig. 3d). The rock also contains small (<0.6 mm diameter) mudstone fragments. Secondary calcite is abundant in the sandstone as cement and as grain replacements. Although the rock contains volcanic rock fragments, there is also a high proportion of quartz sand suggesting that the rock is compositionally submature to mature. Texturally, the sample is immature due to the bimodal grain size distribution and angularity of many of the quartz grains. Subparallel alignment of linear, dark brown concretions and locally linear bands of secondary chlorite (possibly as mica replacement), suggest that a deformational event produced minor foliation.

DISCUSSION

The volcano-sedimentary succession occurs within a zone of typical, hematitic Wernecke breccia and is interpreted as a large breccia clast, herein informally named the Blackstone River megaclast. Numerous clasts of volcanic rock (mostly or entirely derived from lava) occur in this breccia zone and are abundant in the talus and rip-rap located along the Dempster highway (Fig. 1), and east of the Blackstone River (A. Nielsen, pers. comm, 2009). Megaclasts of lava and subordinate sedimentary rock also occur in a zone of Wernecke breccia located at Slab Mountain in the Wernecke Mountains (Fig. 1b; Slab mineral occurrence; Yukon MINFILE 106D 070; Laughton *et al.*, 2005).

The Blackstone River megaclast can be distinguished from the other volcanic megaclasts in Wernecke breccia on the basis of its felsic composition, and association with quartz-rich sediment. A felsic magma composition is implied by the abundance of micro-phenocrysts of quartz and/or potassium feldspar in some of the lapilli. Other volcanic clasts in the enclosing breccia, and at Slab Mountain (Laughton *et al.*, 2005), are mafic in composition. The Blackstone River megaclast is the only known clast in Wernecke breccia to contain quartz-rich sediment. The quartzose material occurs in two forms: as crude laminations in the volcaniclastic wacke; and as accidental clasts in the lapillistone (Fig. 2c).

The Blackstone River megaclast is also characterized by a subaerial origin, as implied by the elongated amygdules in the lapilli, and the consistent orientation of the inferred flattening fabric among lapilli in the same sample (Fig. 2b). The consistent direction of flattening in the lapilli may be explained by flattening upon impact. Alternatively, the flattening could have been caused by the weight of an overlying and rapidly accumulating layer of tephra, soon after the grains were deposited; the grains would have remained hot enough to deform ductilely in a manner similar to welding of fiamme in pyroclastic flow deposits (Fisher and Schmincke, 1984). The slight inter-grain variation in the orientation of planes of flattening may be the result of grain rotation during, or after, deformation. Regardless of whether impact and/or penecontemporaneous welding were the cause(s), the ductile deformation of the lapilli is indicative of subaerial deposition.

The relative coarseness of the volcanic clasts (up to 2 cm in diameter) suggests a transport distance of no more than a few kilometres from the volcanic vent. The inferred hot, ductile character of the volcanic clasts upon deposition also suggests a short aerial transport time after their expulsion from the volcano. The volcano may have been a cinder cone or a large, explosive composite volcano, but in either case the minimal amount of lapilli transport implies a volcanic environment of deposition. The presence of mud as matrix and as laminae within the epiclastic, quartz-rich sediment suggests an environment capable of low-energy transport and deposition, perhaps on the gently sloping base of the volcano.

This interpretation is important for the refinement of a new model that explains the origin of the igneous clasts in Wernecke breccia (Furlanetto, 2009a). The new model involves obduction of a terrane onto the western margin of Laurentia, followed by Wernecke breccia formation that involved downward movement of igneous rocks of the terrane. The terrane was considered to consist of mafic volcanic rocks and associated mafic intrusions, as indicated by the composition of the igneous clasts in Wernecke breccia. With the recognition of felsic volcanism and quartz-rich sediment in the Blackstone River megaclast, the obducted terrane of Furlanetto *et al.* (2009a) should be adjusted to include not only felsic, explosive volcanoes, but also a source of quartz-rich sediment hosting rounded and possibly long-travelled detrital zircon grains. The age and origin of the zircon grains has not yet been determined, and it is possible that they were derived from local rhyolitic igneous rocks, or

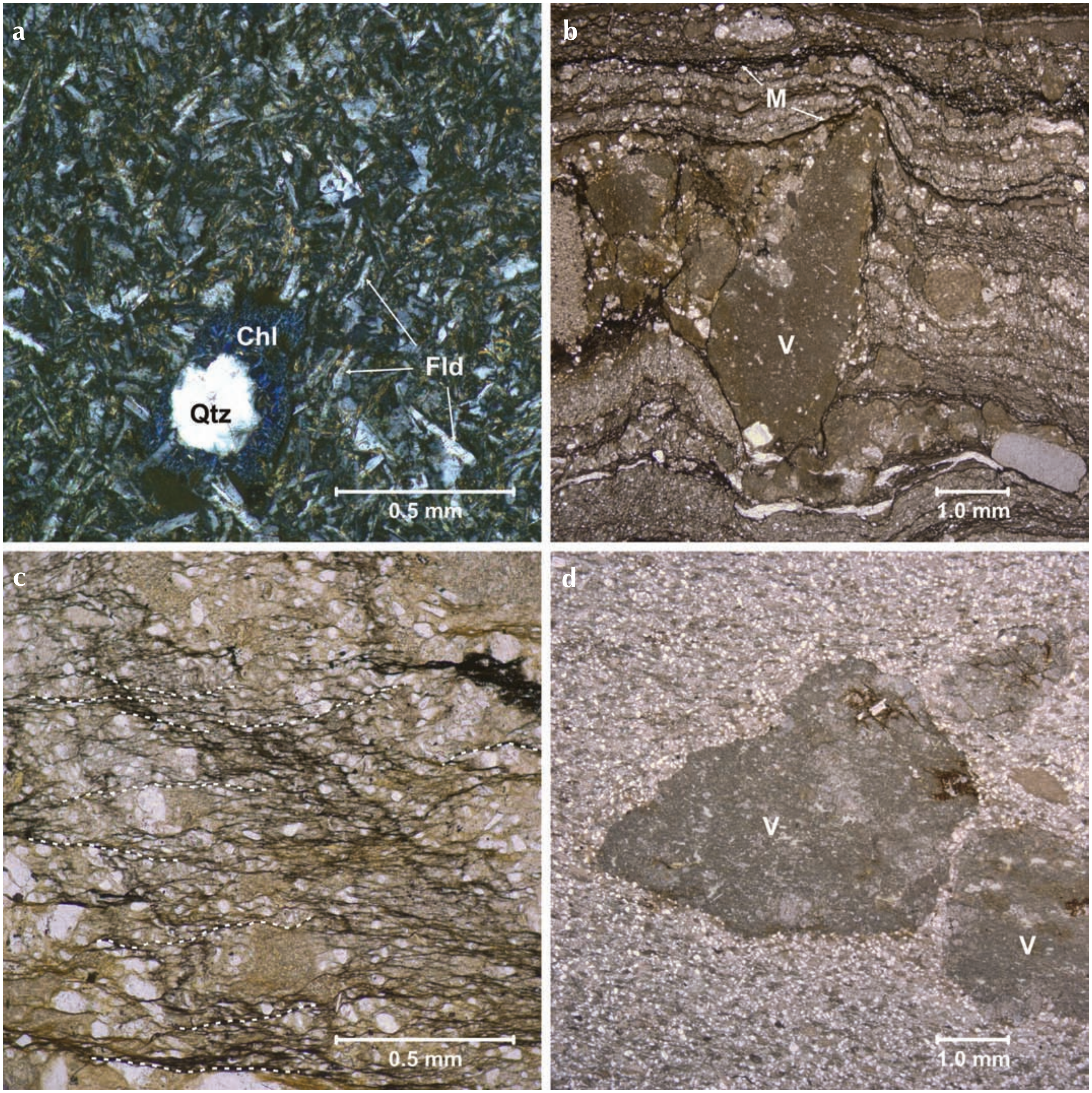

Figure 3. *Photomicrographs of epiclastic rock samples: (a) to (c) from Sample 3, and (d) from Sample 4.* ***(a)*** *A volcanic rock fragment consisting of feldspar laths (Fld) and quartz (Qtz) and chlorite (Chl) amygdules.* ***(b)*** *A volcanic rock fragment (V) with dewatered mud layers (M) that have been compacted around it.* ***(c)*** *Cataclastic foliations at high angles to bedding (outlined with dashed white lines).* ***(d)*** *Volcanic rock fragments (V) surrounded by very fine sand and silt-sized quartz grains.*

from older basement exposures. The now-vanished terrane may have been part of another landmass such as Australia. Additional work on this megaclast may provide solutions to this question, and further refine the understanding of the obducted terrane.

CONCLUSIONS

The Blackstone River megaclast is a clast within the Wernecke breccia in Yukon. It consists of felsic, subaerially deposited pyroclastic rocks and lesser quartz-rich epiclastic rocks. Flattening textures in the pyroclasts and overall felsic composition of the megaclast imply that the succession was deposited in a volcanic environment in an area of evolved crust. These observations augment the terrane model of Furlanetto *et al.* (2009a), which involves obduction of a terrane onto Laurentia in late Paleoproterozoic time.

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