

# Geology of the Carpenter Creek and McKay Hill areas (NTS 106D/6, 11), central Yukon

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## Abstract

The Carpenter Creek area straddles the Paleozoic basin-platform transition which is coincident with the Dawson thrust in north-central Yukon. North of the thrust, the strata can be broadly divided into two groups: (1) Proterozoic sedimentary and intrusive rocks, and (2) Paleozoic platformal strata with volcanic rock horizons. The two groups of rocks are separated by an angular unconformity. Below the unconformity, Hart River gabbro sills and dikes (ca. 1.38 Ga) intrude the Gillespie Lake Group. Younger Proterozoic rocks that are not intruded by the gabbro occur on the other side of a fault that traces through the Carpenter Creek valley. These rocks are interpreted to be younger than Gillespie Lake Group and are tentatively assigned to Pinguicula Group. Above the unconformity, Paleozoic volcanic and volcanoclastic rocks are interstratified with carbonate rocks. The volcanic rocks occur near the base and top of the Bouvette Formation.

South of the Dawson thrust, in its direct hangingwall, volcanic and volcanoclastic rocks are interlayered with shale, chert and sandstone and intruded by discontinuous gabbro bodies of unknown age. Rare limestone lenses within the volcanic rocks contain coral fossils that constrain the age of these rocks to Middle Ordovician or younger. Hyland Group rocks are thrust over the volcanic unit and comprise shale, quartz grit and limestone. Shale exhibits a well-developed foliation, oriented parallel to the northwest-trending structural grain. Tight folds with NW-SE-striking axial planes repeats stratigraphy south of the Dawson thrust.

Within the mapped area, Ag-Pb-Zn ± Au mineralization near Grey Copper Hill occurs right along the unconformity between Upper (?) Proterozoic rocks and the Bouvette Formation (Figs. 1 and 2). Au-Ag-Cu-Pb-mineralization is spatially associated with a strike-slip fault that offsets shale, volcanic rocks and small gabbro bodies near McKay Hill (Figs. 1 and 2).

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## Introduction

Detailed mapping (1:25 000-scale) centred on Carpenter Creek was carried out over the summers of 2019 to 2021 to provide geologic context to the igneous rocks exposed in the area and to several mineral showings in the region. The Carpenter Creek area includes parts of NTS map sheets 106D/6, 11, and part of the area is described in detail in an earlier report (Cobbett, 2020). The area is located approximately 60 km north of Keno Hill, Yukon (Fig. 1a), where previous work includes reconnaissance-scale mapping by Green (1972) and detailed, property-scale mapping by local exploration companies since the 1920s (Fig. 1; e.g., Blackburn 2010). Of note is McKay Hill (Fig. 1b), a mineral occurrence that is located south of the Dawson fault, where exploration efforts have discovered Au-Ag-Cu mineralization (e.g., Blackburn, 2010; Blackburn and Haid, 2018). Several other mineral occurrences occur north of the Dawson thrust including Grey Copper Hill, a polymetallic Ag-Pb-Zn vein prospect (Fig. 1b), where mineral exploration was conducted between 1920 and 1974, and more recently explored by Metallic Minerals in 2019 (e.g., Haid and Blackburn, 2019).

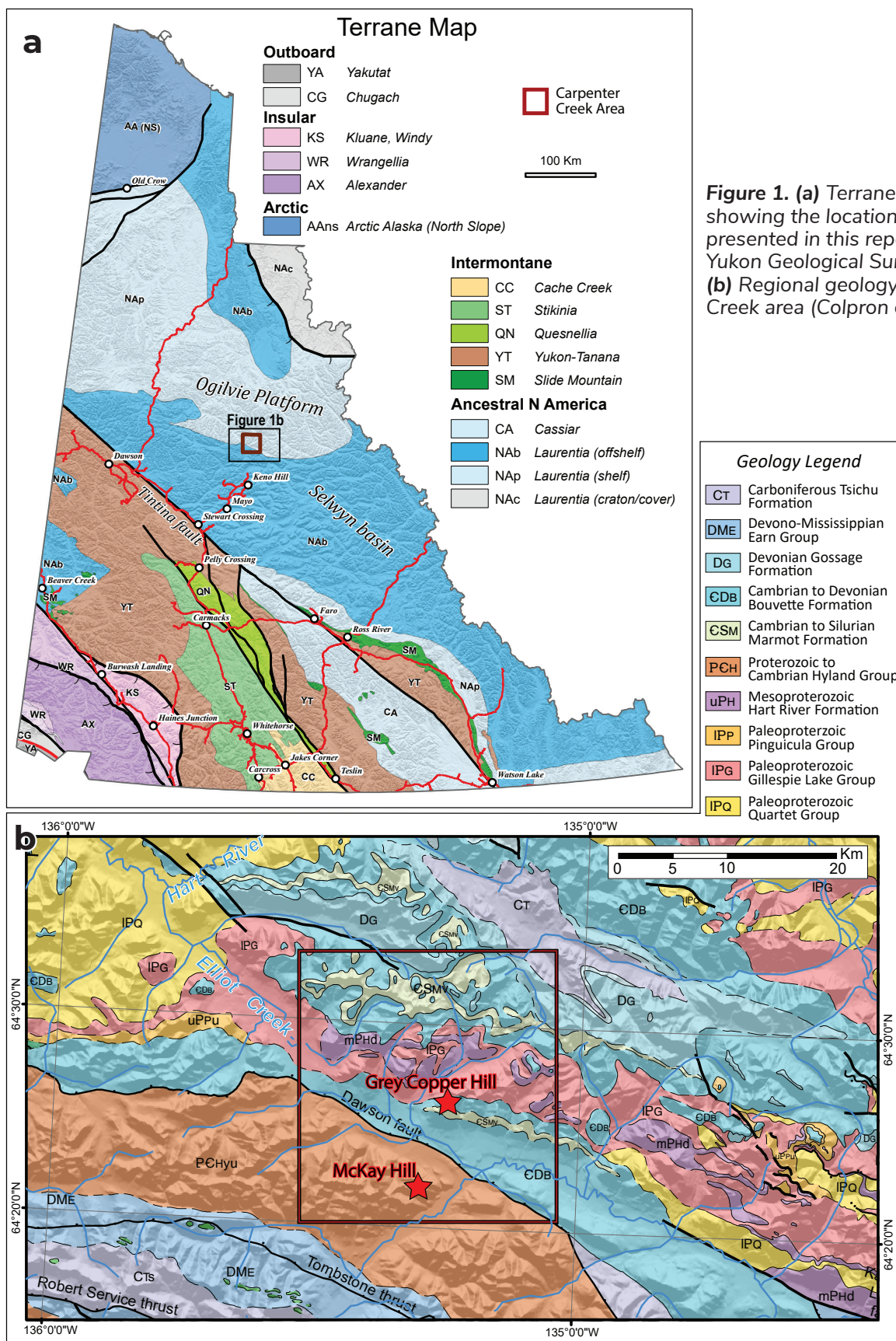
Paleozoic volcanic rocks are documented along the length of the Canadian Cordilleran in autochthonous western Laurentian stratigraphy (e.g., Abbott, 1997; Colpron et al., 2002; Pigage, 2004; Pigage et al., 2015; Eyster et al., 2018). The volcanic rocks are linked to rifting along the western Laurentian margin during the early Paleozoic, but there is a paucity of information about their age and significance (e.g., Campbell et al., 2019). This report describes the results of detailed geologic mapping undertaken to provide context to, and better characterize, volcanic rocks that occur in the Carpenter Creek area. The area includes igneous rocks that range in age from Mesoproterozoic to Late Ordovician and possibly younger. The map, cross sections, and detailed stratigraphic sections presented and described in this report provide geologic framework for future studies that will examine the geochemistry and geochronology of the volcanic rocks (Fig. 2).

## Geologic Framework

The mapped area straddles the Paleozoic basin-platform transition, which coincides in this region with the Dawson thrust (Figs. 1b and 2). South of the fault, basal facies of the Selwyn basin crop out, including Hyland Group shale, sandstone and limestone, and Ordovician shale and volcanic rocks (Skipton, 2022; Fig. 2). North of the fault, carbonate rocks of the McKenzie Platform, including the Bouvette Formation, are exposed along two east-west trending belts in the north and central parts of the map (e.g., Cecile et al., 1997). Proterozoic sedimentary rocks are exposed in an east-west trending belt that occupies the centre of the mapped area between two belts of Bouvette Formation strata.

Stratigraphy in the Carpenter Creek area includes rocks as old as lower Proterozoic (Gillespie Lake Group) and as young as Devonian (upper parts of the Bouvette Formation). The older rocks are part of the Mesoproterozoic Wernecke Supergroup, which comprise clastic and carbonate rocks that were deposited in response to subsidence and subsequent basin infilling (Thorkelson, 2000). These rocks were intruded by the Hart River gabbro sills and dikes, which have been dated at ca. 1.38 Ga (Abbott 1997; Verbaas 2017). Upper (?) Proterozoic sedimentary rocks that are not intruded by gabbro sills and dikes are interpreted to be younger than 1.38 Ga, forming part of the Pinguicula Group that unconformably overlies the Gillespie Lake Group (Abbott 1997; Thorkelson, 2000; Medig et al., 2009). Deposition of the Bouvette Formation occurs above an angular unconformity on top of these older units.

South of the Dawson thrust, the Hyland Group is thrust over Ordovician volcanic and sedimentary rocks that have been tentatively assigned to the Road River Group.



**Figure 1. (a)** Terrane map of Yukon showing the location of map area presented in this report. Modified from Yukon Geological Survey, 2021. **(b)** Regional geology of the Carpenter Creek area (Colpron et al., 2016).

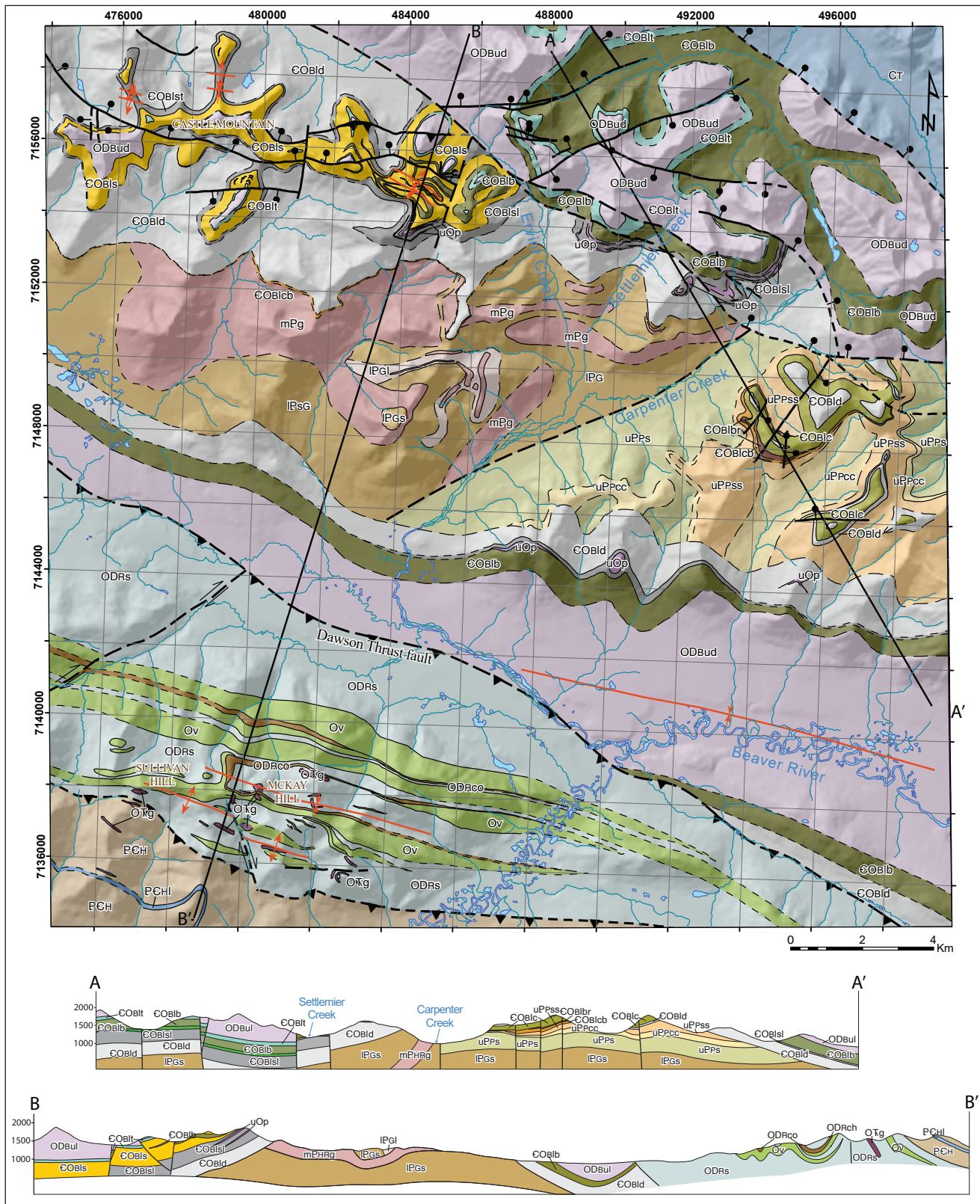


Figure 2. Geologic map, cross sections and legend (see next page) of Carpenter Creek-McKay Hill area.

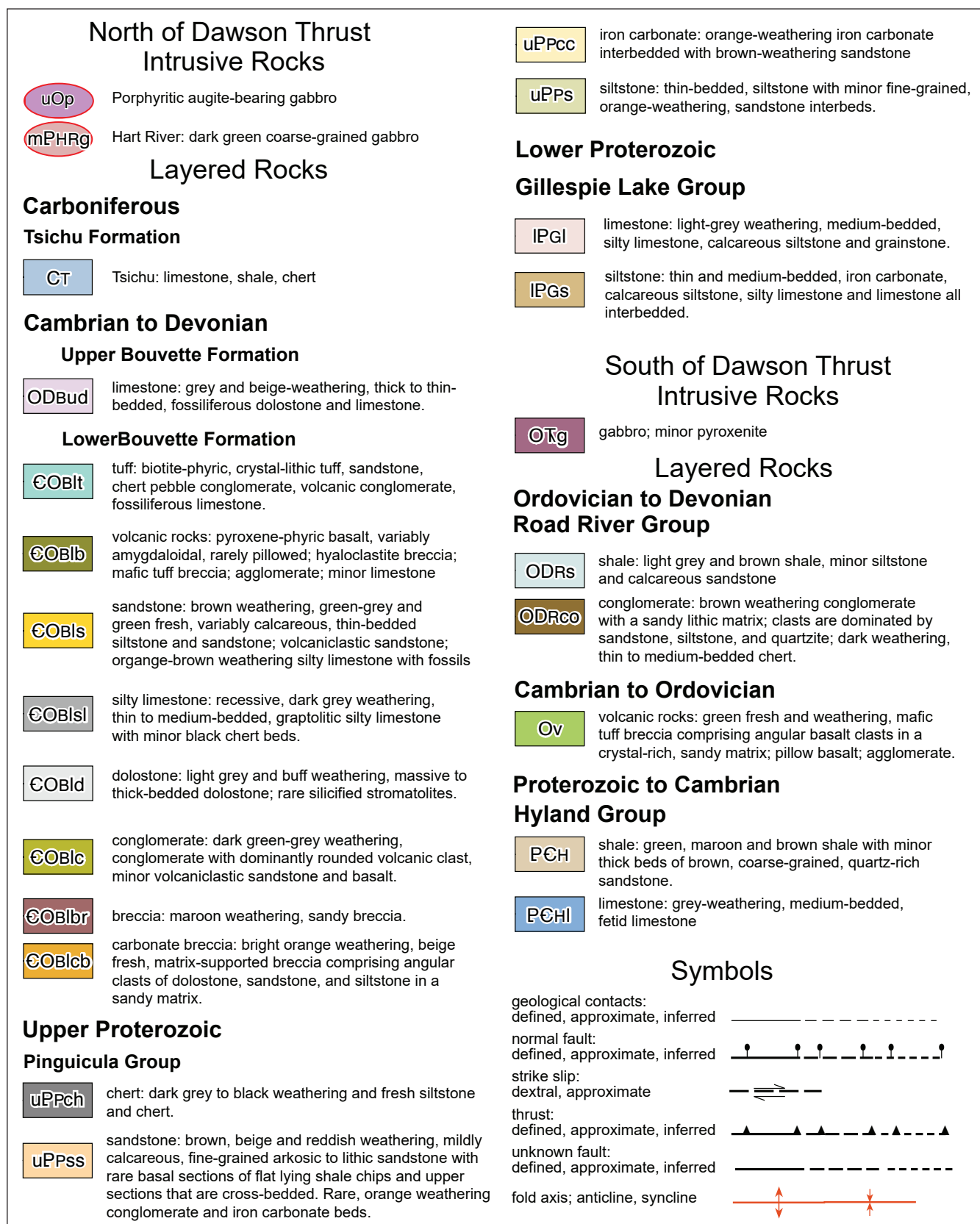


Figure 2 continued.

## Stratigraphy north of the Dawson thrust

The stratigraphy north of the Dawson thrust can be divided into three groups based on two unconformities. The first unconformity, that separates Proterozoic sedimentary rocks and Hart River gabbro from the Paleozoic Bouvette Formation, is angular (Fig. 3). The second is a disconformity that occurs at the break between volcanic and coarse-grained clastic rocks of the lower Bouvette Formation and reefal limestone and dolostone of the upper Bouvette Formation (Fig. 3). Below are detailed descriptions of each unit and their relationships with adjacent strata.

### Lower Proterozoic Gillespie Lake Group (IPGs, IPGI)

The oldest rocks in the mapped area are broadly divided into limestone and bedded carbonates, which form steep ridges that trend north-northeast between Carpenter Creek and Castle Mountain (Fig. 2). The relationship between the two units is obscured by abundant Hart River gabbro sills and dikes that intrude into the bedded rocks. The limestone unit (IPGI) comprises medium-bedded, light grey weathering limestone to silty limestone interbedded with orange

and brown weathering iron carbonate and calcareous siltstone beds (Fig. 4a). The silty limestone beds rarely show cross-stratification and are hornfelsed near gabbro. The remaining volume of sedimentary rocks that make up this succession comprise thin-bedded, orange weathering, dark grey fresh, dolo-siltstone interbedded with bright orange dolo-sandstone and iron carbonate (Fig. 4b). Minor, green and dark grey, laminated to thin-bedded siltstone crop out locally but are not sufficiently extensive to map as a separate unit at 1:25 000-scale.

As the gabbro intrusions complicate structural mapping and impede lithological correlations between outcrops, it is difficult to estimate the thickness of the Gillespie Lake Group in this area. Consistently steeply-dipping bedded rocks occur continuously along one ridge (Fig. 4c). Unless the rocks are isoclinally folded across this section (no field relationships were observed to suggest this), the minimum thickness of the Gillespie Lake Group is inferred to be 1 km. The base of the Gillespie Lake Group was not observed in the mapped area. The upper contact with the Bouvette Formation is marked by an angular unconformity characterized by steeply dipping Gillespie Lake siltstone overlain by subhorizontal beds of dolostone of the Bouvette Formation (Fig. 5).

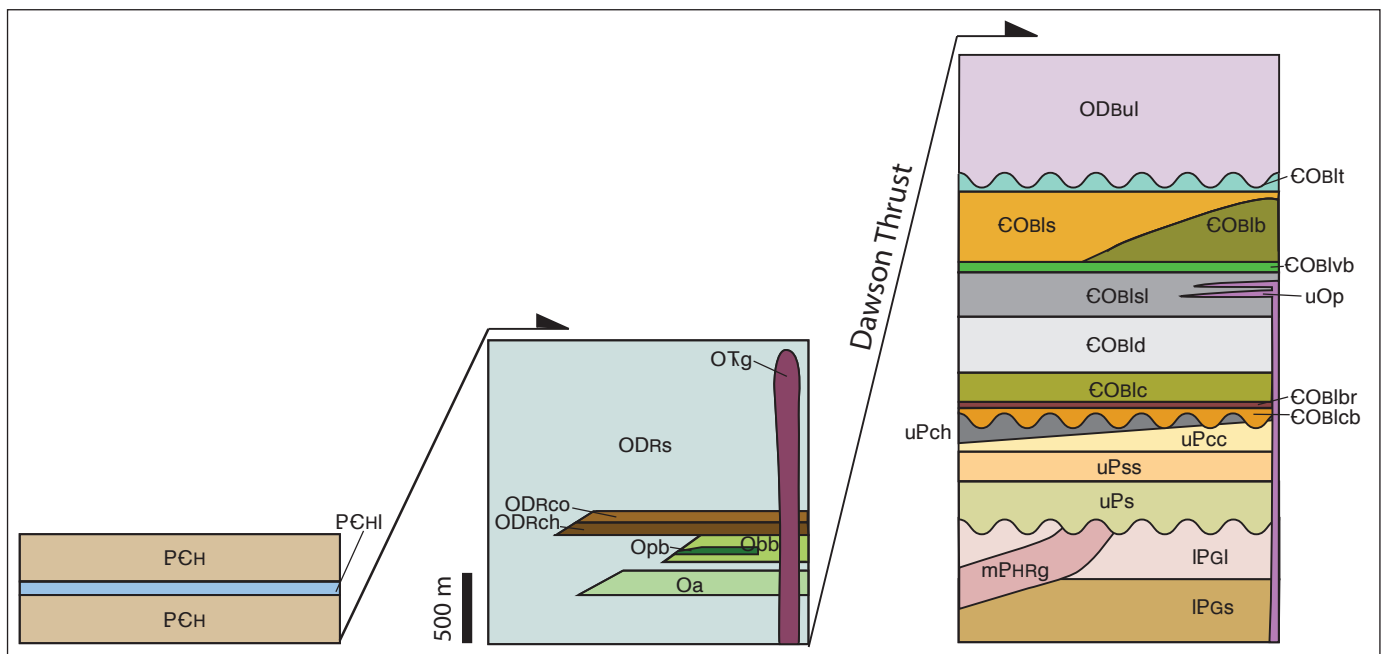
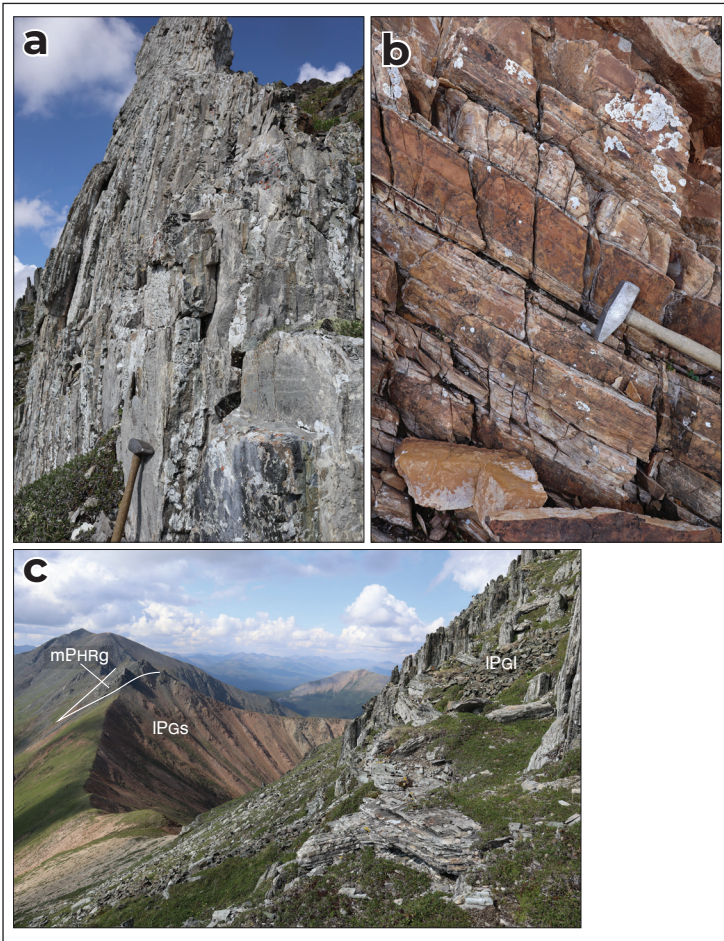


Figure 3. Schematic stratigraphy of the Carpenter Creek area.



**Figure 4.** Gillespie Lake Group rocks and Hart River gabbro. **(a)** Thin bedded, variably hornfelsed limestone of the Gillespie Lake Group. Beds dip near vertical in this photo (485197E, 7150267N). **(b)** Medium-bedded, dolostone, siltstone and dolo-sandstone of Gillespie Lake Group (485197E, 7150267N). **(c)** Photograph looking south at Gillespie Lake limestone in the foreground and the orange weathering dolomitic rocks in the middle ground. The dark coloring rocks at the far end of the ridge is gabbro (485197E, 7150267N). All coordinates are UTM Zone 8 NAD83.



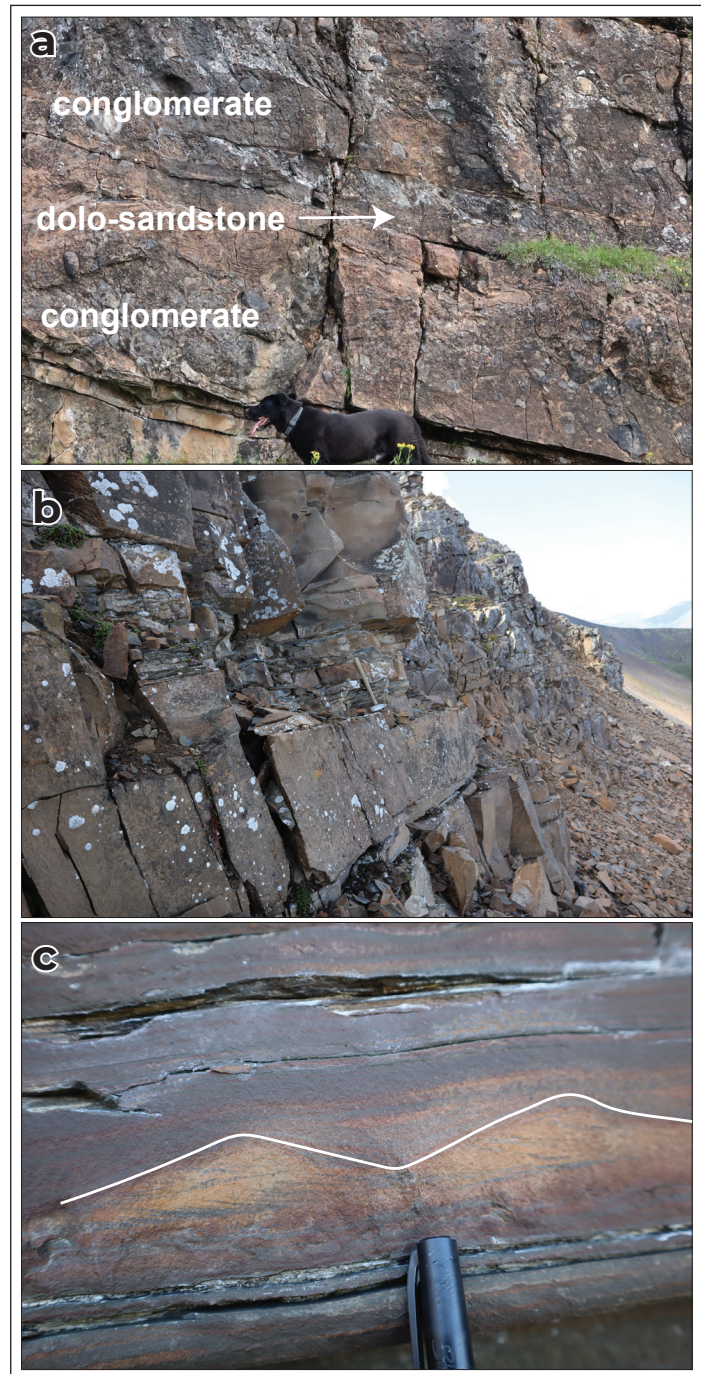
**Figure 5.** The lower Bouvette Formation overlies the Gillespie Lake Group and Hart River gabbro along an angular unconformity (horizontal white dashed line).

### Upper (?) Proterozoic Pinguicula Group (uPPs, uPPcc, uPPss, uPPch)

Southeast of Carpenter Creek a succession of siliciclastic and lesser carbonate rocks are exposed in the east-central part of the map area. The succession can be subdivided into three units which are described below from stratigraphically deepest to shallowest.

The deepest part of the stratigraphy was only observed along the eastern boundary of the mapped area, where several creek exposures comprise dark brown weathering, grey fresh, thin-bedded siltstone with minor orange-brown weathering, fine-grained sandstone (uPPs). Stratigraphically above the siltstone unit, orange-brown weathering, thin-bedded, sandstone is interlayered with bright reddish-orange iron carbonate beds and rare medium-sized beds of floatstone (uPPcc). Near the eastern boundary of the map area, this unit comprises thick-bedded, orange weathering dolostone, matrix-supported conglomerate and pebbly dolo-sandstone (Fig. 6a). The conglomerate has pebble to boulder sized clasts of carbonate, sandstone and quartz-rich sandstone supported by a sandy, carbonate-dominated matrix. Stratigraphically above the orange weathering dolostone unit, exposed along the north-south striking ridge in the east-central part of the map area, lies thick-bedded sandstone that weathers in shades of orange, brown and red (uPPss; Fig. 6b). The sandstone ranges from arkosic to lithic in composition and grades upwards from pebbly sandstone to siltstone. The base of the beds commonly contains shale chips that are oriented parallel to bedding. Farther east, the sandstone unit (uPPSS) includes brown weathering and fresh, thin to medium-bedded fine-grained sandstone with rare cross-beds (Fig. 6c). Locally, dark grey to black, thin to medium bedded chert lies on top of the iron carbonate rocks at the same stratigraphic level as the sandstone (uPPch; Fig. 3).

Assuming an overall flat-lying configuration for this succession, the minimum thickness for the upper Proterozoic strata is 800 m. The stratigraphic relationship between these rocks and the Gillespie Lake Group was not observed because the contact is faulted (Fig. 2). The base of the succession was not observed



**Figure 6.** Upper Proterozoic rocks exposed southeast of Carpenter Creek. **(a)** Orange weathering thick-bedded, matrix supported conglomerate is interbedded with medium beds of pebbly, dolo-sandstone (496074E, 7147037N). Dog for scale is 1 m long. **(b)** Brown weathering, medium to thick-bedded lithic sandstone that grades up into siltstone and has pebble trains near the bases of the beds (493598N, 7147627E). **(c)** Dark brown weathering, well-bedded sandstone with asymmetric ripples with internal cross-stratification (497486E, 7148274N). All coordinates are UTM Zone 8 NAD83.

but is assumed to unconformably overlie the Gillespie Lake Group. (e.g., Medig et al., 2009). The upper contact with the Bouvette Formation is an angular unconformity best observed where chert beds are cut off by overlying dolostone of the Bouvette Formation (Fig. 2).

### **Cambrian (?) to Ordovician Lower Bouvette Formation (€OBlt, €OLV, €OLBs, €OBls, €OBld)**

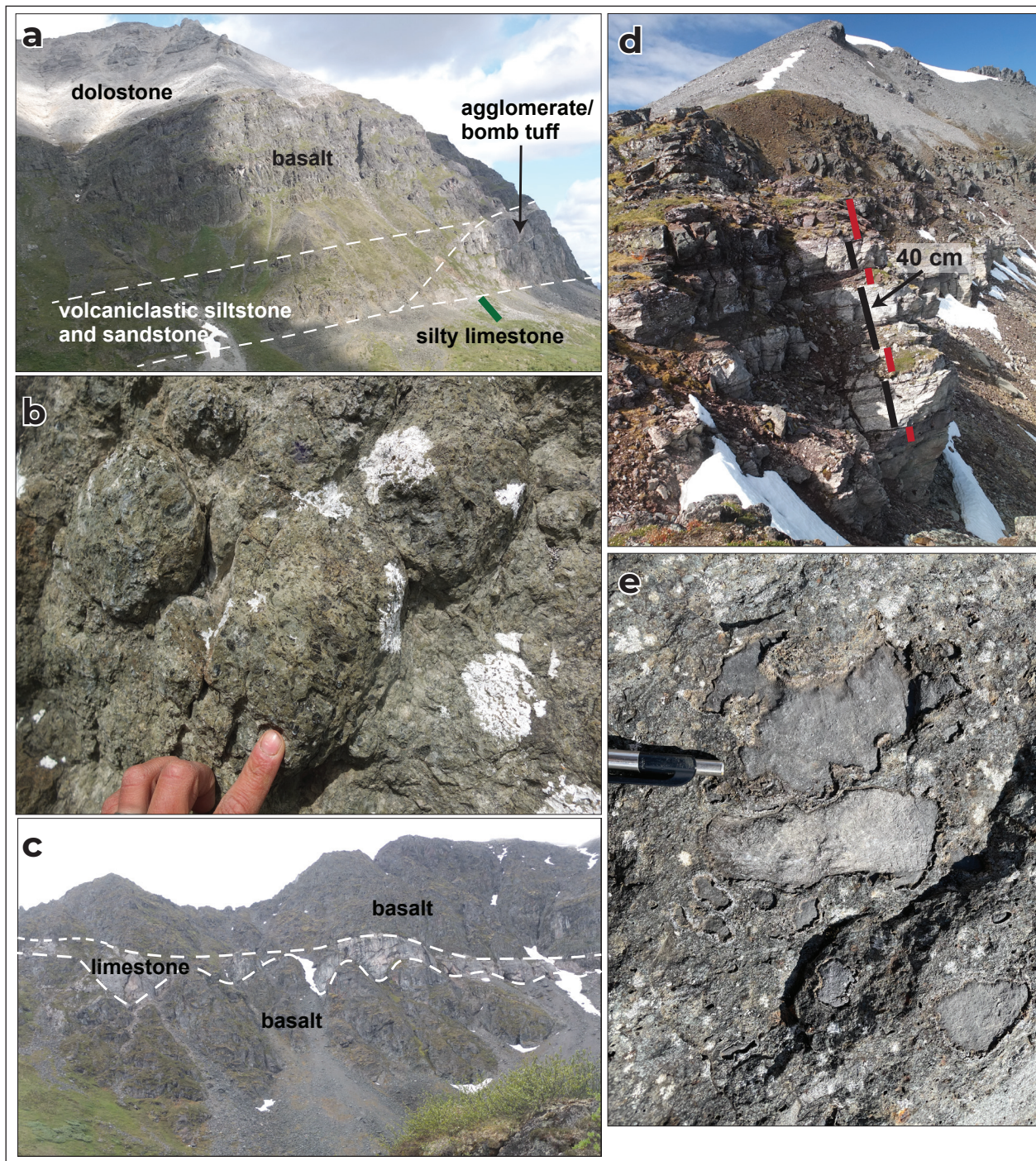
Rocks of the lower Bouvette Formation are exposed throughout the northern two-thirds of the mapped area. The stratigraphy across the northern part of the area and the band across in the middle is comparable, and therefore, described together. Lower Bouvette rocks that are exposed southeast of Carpenter Creek are described separately because, (1) they are in fault contact with other Bouvette Formation outcrops, (2) the stratigraphy is different than the Bouvette Formation elsewhere in the mapped area, and (3) the correlation with the lower Bouvette Formation is inferred as there were no geochronological data to confidently ascertain the age of this strata (Fig. 2).

Castle Mountain stratigraphy is described in detail in Cobbett (2020). A summary is provided below, followed by more detailed descriptions for the rocks exposed in the northeastern corner of the map. Along the east-west trending ridge system where Castle Mountain is centred, the stratigraphically lowest exposed rocks consist of distinctly orange weathering, beige fresh, sandy breccia comprising clasts of dolostone, sandstone and siltstone in a calcareous, sandy matrix. This unit ranges in thickness from 0 to 10 m. Conformably above the breccia, light grey and beige weathering, massive dolostone (€OBld) with rare horizons of silicified stromatolites comprise a large part of the lower slopes of Castle Mountain. Up section, recessive, dark grey weathering, thin and medium-bedded, graptolitic, silty limestone with black chert horizons (€OBls) form a band around Castle Mountain. In the eastern part of the map area, this unit is intruded by two, porphyritic, gabbro sills (uOp). Conformably overlying the silty limestone, a succession of calcareous, variably volcanoclastic siltstone and sandstone is well-bedded and commonly fossiliferous (€OLBs).

Fossils in this part of the stratigraphy include trilobites, ammonites, brachiopods, cephalopods, sponges and corals. Farther east from the summit of Castle Mountain this unit includes basalt and tuff (€OBlv), and on the easternmost end of the Castle Mountain ridge system, light grey limestone is interbedded with basalt. A lithologically diverse succession of distinctly dark and sometimes red weathering, volcanic, carbonate and clastic rocks comprise the overlying unit (€OBlt) and the highest part of the stratigraphy that is included in the lower Bouvette subdivision. For example, this unit includes crystal-lithic tuff, conglomerate, sandstone, siltstone and fossiliferous limestone in varying abundances and thicknesses across the northern part of the area. Common fossils in this unit include bivalves, gastropods and corals.

Between Carpenter Creek and Ervin Creek, the lower Bouvette Formation includes primarily volcanic rocks and overlying sedimentary rocks. Above the silty limestone unit in this area, up to 300 m of combined volcanoclastic rocks and basalt are locally interbedded with lenses of limestone. Some areas include a basal basalt breccia, volcanoclastic siltstone and sandstone, or volcanic-derived conglomerate comprising rounded clasts of basalt in a volcanic-derived, sandy matrix (Fig. 7a,b). Light grey weathering limestone forms discontinuous bands surrounded by basalt. Some bands have strongly undulating basal contacts and flat upper contacts (Fig. 7c). The basalt includes pyroxene-phyric and aphanitic flows and locally has amygdaloidal tops. Stratigraphically above the basalt, red weathering siltstone and arkosic sandstone (red beds) becomes interbedded with micrite up-section (Fig. 7d). Gastropods and bivalves commonly occur in this part of the stratigraphy. Above the red beds, brown and grey weathering, pebbly, lithic sandstone grades upwards into a calcareous, locally fossiliferous, muddy, siltstone.

North of the Beaver River, the mafic volcanic rocks include fine-grained basalt with amoeboid-shaped, variably fossiliferous limestone clasts (Fig. 7e), crudely bedded volcanic-derived, variably cross-bedded sandstone, and basalt with brecciated tops.

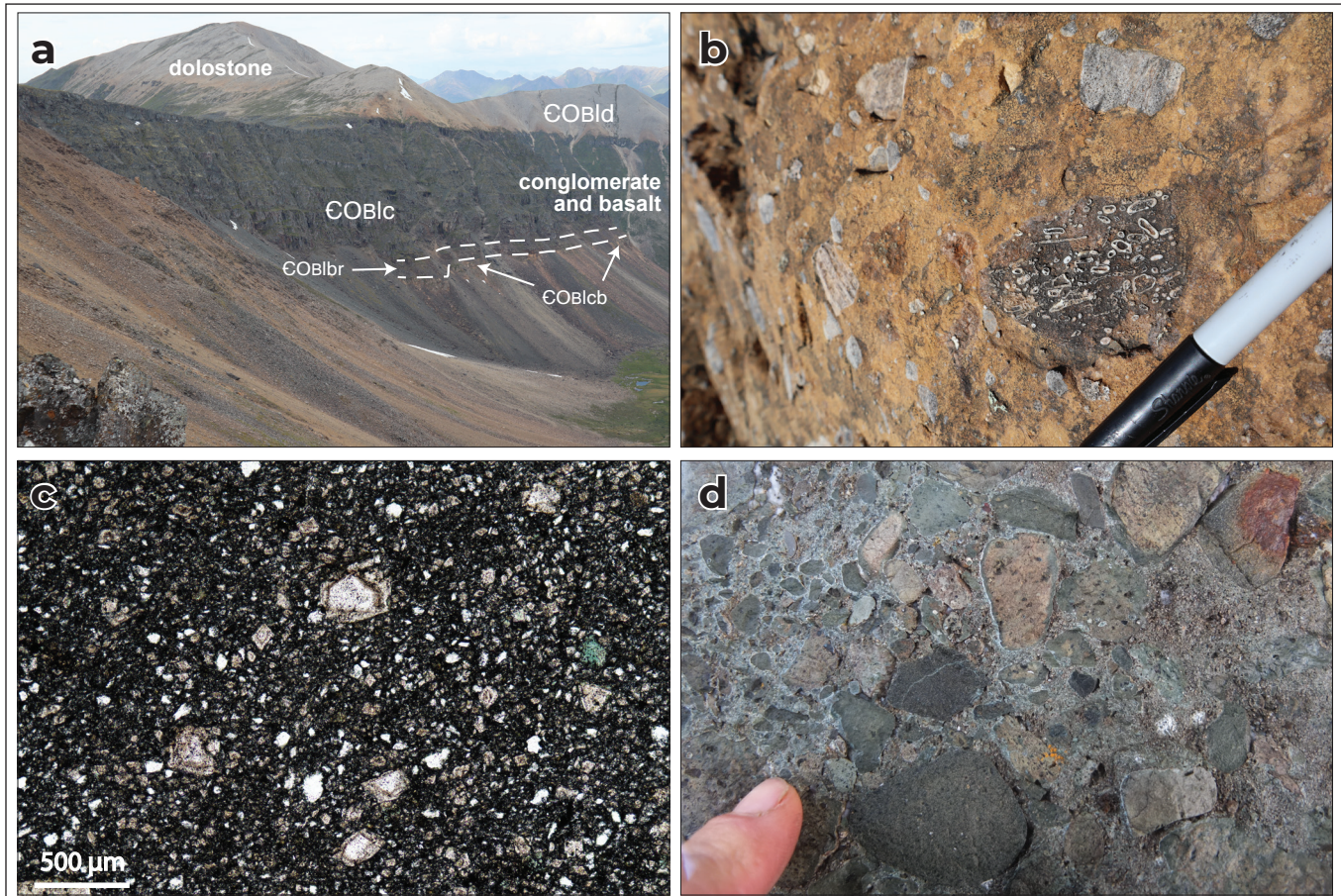


**Figure 7.** Lower Bouvette Formation rocks exposed between Ervin and Carpenter Creeks, and north of Beaver River. **(a)** Volcanic rocks typical of the stratigraphy east of Ervin Creek. The base of the volcanic section includes a lens-shaped pile of agglomerate or block and bomb tuff comprising rounded cobbles of pyroxene-phyric basalt with interstitial volcanic-derived sandstone. A mafic dike (green line) cuts through the silty limestone below the volcanic rocks. For scale, the basalt and volcaniclastic rocks together are approximately 300 m thick (493855E, 7153011N). **(b)** Rounded clasts of pyroxene-phyric basalt with interstitial basaltic material. Similar rocks comprise the lens of volcanic material highlighted in (a; 485894E, 7154567N). **(c)** A limestone bed that conforms to the irregular flow top shape of the underlying basalt flow and has a generally flat top, which dictates the basal form of the overlying flow (489802E, 7157926N). **(d)** Interbedded red weathering sandstone (red lines) and light weathering micrite (black lines; 487365E, 7156937N). For scale, the micrite bed that the black arrow points to is approximately 40 cm thick. **(e)** Amoeboid-shaped limestone clasts in basalt (492295E, 7144590N).

The thickness of the volcanic-dominated lower Bouvette Formation in the northern part of the area ranges from 700 to 1200 m. It is thickest near Ervin Creek where basalt reaches its maximum thickness of nearly 300 m. West of Castle Mountain the absence of basalt, basalt breccia and volcanic-derived conglomerate reduces the total thickness. The lower Bouvette sits unconformably on the Gillespie Lake Group (Fig. 2). The upper contact with the upper Bouvette is a disconformity marked in places by a boulder conglomerate (Cobbett, 2020).

South of Carpenter Creek in the east-central part of the map area, rocks that have been included in the lower Bouvette Formation are dominantly clastic with some volcanic intervals and dolostone (Fig. 8a).

The lowest part of the stratigraphy comprises an orange weathering, beige fresh, carbonate breccia comprising pebble to boulder sized clasts of carbonate and siliciclastic rocks in a calcareous sandy matrix (Fig. 8b). Above this lies a maroon weathering and fresh, sandy, matrix-supported volcanic breccia comprising subangular clasts of carbonate and quartz surrounded by a matrix of subangular quartz grains and euhedral feldspar (altered to sericite) crystals that commonly have concentric zoning (Fig. 8c). This unit grades into a green weathering and fresh, volcanic-derived conglomerate comprising rounded clasts of basalt in a volcanic-derived sandstone matrix (Fig. 8d).



**Figure 8.** Lower Bouvette stratigraphy exposed southeast of Carpenter Creek. **(a)** A sequence of volcanic conglomerate and sandstone with minor basalt flows (exposed in the dark grey cliff in the middle of the photograph) overlain by grey massive dolostone and underlain by orange-brown weathering sandy breccia and carbonate breccia (497778E, 7150096N). **(b)** Orange weathering carbonate conglomerate comprising clasts of carbonate floating in a sandy dolomitic matrix (494175E, 7148144N). **(c)** Photo micrograph of maroon weathering, sandy breccia. Photo shows zoned feldspar crystals in a matrix of smaller lithic and volcanic grains (493756E, 7148866N). **(d)** Volcanic conglomerate comprising volcanic clasts in a sandy matrix (495445E, 7148298N). Figure continued on next page.

Green weathering and fresh, medium-bedded, coarse-grained, volcanic-derived sandstone comprise the top of very thick beds of conglomerate and is commonly cross-bedded. Locally interbedded with the volcanic conglomerate are basalt flows. The lowermost flow has feldspar phenocrysts and two flows higher up in the succession are aphanitic (Fig. 8e). Rarely, basalt flows are directly overlain by basalt breccia comprising angular clasts of basalt in a glassy to basaltic matrix or volcanic breccia comprising irregular shaped, vesicular clasts ranging in size from 0.5–5 cm with interstitial calcite (Fig. 8f).

Above the volcanic and volcanoclastic rock units is a single thick bed of beige weathering, quartz-rich, fine-grained sandstone that is overlain by beige weathering, grey fresh, thick-bedded to massive dolostone (Fig. 8a).

Locally the two breccia units are absent, and the volcanic-derived conglomerate sits instead on, (1) orange to pink weathering, thick-bedded dolostone,

or (2) orange weathering, medium-bedded dolostone interbedded with beige-brown weathering, lithic, pebble conglomerate comprising well-rounded clasts of quartz arenite, chert and siltstone (Fig. 8g). Maroon weathering sandy siltstone rarely occurs within this part of the stratigraphy.

South of Carpenter Creek, the thickness of the volcanic strata, including volcanic-derived conglomerate and basalt, ranges from 150 to 200 m. The orange carbonate conglomerate ranges in thickness from 0 to 20 m and is exaggerated on the cross section on Figure 2. The maroon sandy breccia that occurs locally between the orange carbonate conglomerate and the volcanic rocks ranges in thickness from 0 to 10 m. The contact with the underlying dark weathering sedimentary rocks is not conformable but this is difficult to confirm in outcrop because all strata is relatively flat lying where the volcanic rocks are exposed.



### Ordovician to Devonian upper Bouvette Formation (ODBud)

Across the entire northern part of the map area, the youngest rocks belong to the upper Bouvette Formation (ODBud). Upwards of 500 m of limestone and dolostone crop out above the lower Bouvette tuff unit (COBlT). Light to dark grey weathering and fresh, thin to thick-bedded, variably fossiliferous limestone and dolostone make up many ridge tops, including those of Castle Mountain (Fig. 9a). Common fossils include corals, crinoids and bivalves (Fig. 9b).

The lower and upper Bouvette stratigraphy is repeated in a band parallel to the Dawson thrust, directly north of the Beaver River valley, where it unconformably overlies Proterozoic rocks (Fig. 2).

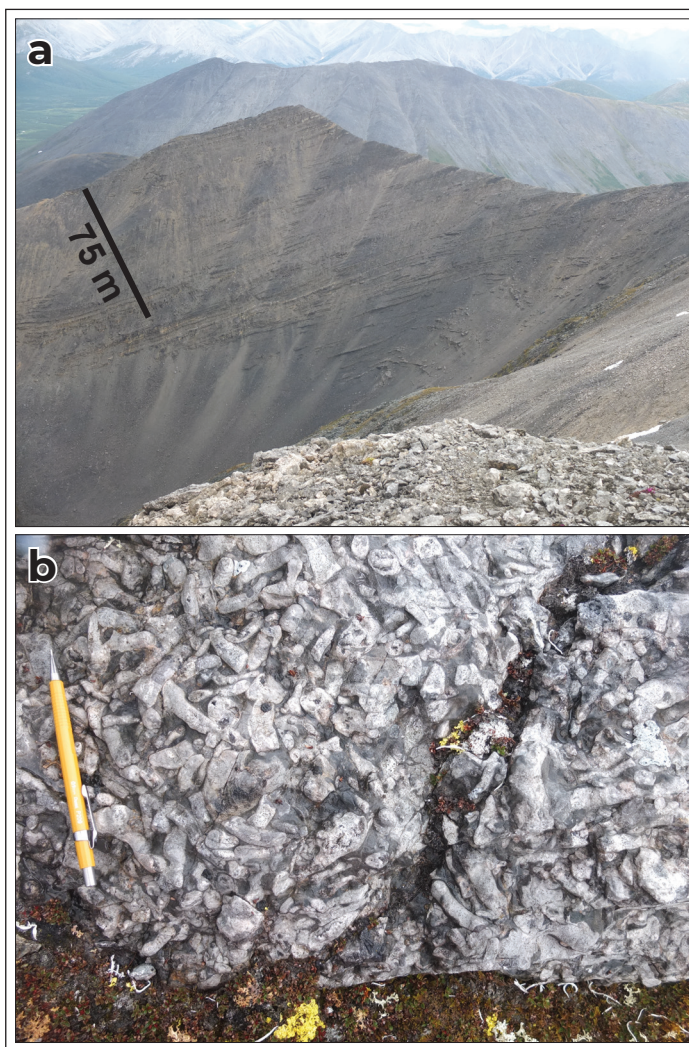
The upper Bouvette Formation is separated by a disconformity from the lower Bouvette and is marked by the first occurrence of fossiliferous carbonate above the volcanic and clastic rocks. The top of the Bouvette Formation is not exposed in the map area.

### Stratigraphy south of the Dawson Thrust fault

Two groups of rocks were mapped south of the Dawson thrust. Near Sullivan and McKay hills, volcanic and volcanoclastic rocks are interbedded with fine-grained siliciclastic rocks. On the southern ends of the north-south trending ridges, south of the volcanic rocks, are exposures of Hyland Group shale, quartz grit and limestone.

The Hyland Group within the mapped area comprises maroon, green, grey, and brown shale (PCH). Brown weathering, coarse-grained, quartz-rich sandstone occurs as metre-scale interbeds that occur locally within the shale. Stratigraphically above the shale and sandstone is light grey weathering, medium-bedded limestone (PCHl). In one location, the limestone is overlain by dark weathering, dark grey fresh, thin-bedded siltstone interbedded thickly with dark grey quartz arenite, but these rocks are grouped with the shale unit (PCH) in Figure 2.

In fault contact with the Hyland Group rocks, volcanic and sedimentary rocks crop out along north-south



**Figure 9.** Upper Bouvette dolostone and limestone. (a) Ridge tops comprising upper Bouvette interbedded limestone and dolostone. (b) Coral fossils typical of parts of the upper Bouvette stratigraphy (493306E, 7153555N).

trending ridges that comprise Sullivan and McKay hills. A stratigraphic column is difficult to construct with confidence due to folding and lack of regular upright bedding indicators. Two volcanic horizons are separated by brown shale and siltstone. The lower volcanic horizon is dominated by green weathering and fresh variably calcareous volcanic-derived conglomerate comprising well-rounded clasts of basalt and volcanoclastic sandstone in a sandy or crystal-rich matrix (Fig. 10a). Locally, basalt breccia forms lenses up to 200 m thick (Fig. 10b). The upper volcanic horizon includes pillow basalt, basalt breccia and pillow-basalt breccia.

Pillow basalt forms beds that are several metres to tens of metres thick and contains rare limestone lenses with coral fossils (Fig. 10c,d). Spatially associated with the pillow basalt and basalt breccia is a highly calcareous volcanic rock characterized by hexagon shaped vesicles(?) that are filled with calcite and are surrounded by glassy material, (Fig. 10e) which crops out on the main ridge between Sullivan Hill and McKay Hill. Included in the upper volcanic horizon is interbedded green-grey weathering, thin-bedded mudstone, calcareous volcanic-derived sandstone and volcanic-derived conglomerate. The conglomerate is composed of lapilli-sized clasts in a fine-grained matrix. The volcanic rocks are overlain by, and possibly partially interbedded with, brown weathering, lithic conglomerate with varying amounts of volcanic detritus, shale, and dark grey weathering, banded chert. Milky-white quartz veins are exposed along a ridge southwest of McKay Hill where gabbro and shale exhibit orange weathering near the veins.

The lower volcanic horizon is approximately 200 m thick and the upper volcanic horizon is up to 150 m thick; however, because the volcanic horizons are lenticular, they vary in thickness over a few kilometers (Fig. 10f). The presence of coral-bearing limestone (Fig. 10d) within the basalt constrains the age of the volcanic rocks to Middle Ordovician to Permian based on the range of ages of fossil in the Cordillera (Nelson, 1975).

## Intrusive Rocks

### Hart River intrusions (mPHRg)

The Gillespie Lake Formation is extensively intruded by gabbro sills and dikes. The gabbro is grey-brown weathering, green-grey fresh, medium to coarse-grained and is commonly chlorite-altered. The gabbro comprises sills up to 2 km long, and dikes that can be up to 200 m thick. Two samples of the gabbro from Carpenter Ridge were dated at  $1385.8 \pm 1.9$  Ma and  $1383.0 +5.9/-5.2$  Ma (Abbott, 1997).

### Upper Ordovician Porphyritic gabbro (uOp)

Between Castle Mountain and Carpenter Creek, in the northern quarter of the map area, the silty limestone unit (EOBlsl) is intruded by two porphyritic sills.

Similar sills are also hosted by the silty limestone unit just north of Beaver River. The sills only occur where basalt is part of the lower Bouvette stratigraphy (Fig. 2). The sills comprise fine-grained, pyroxene-phyric gabbro in most areas but near the cores of larger sills, they consist of medium-grained pyroxene-bearing gabbro. A metre thick, aphanitic dike cuts through the silty limestone near Ervin Creek and is traced to the base of the volcanic rocks (Fig. 7a).

### Gabbro of unknown age (OTg)

Several gabbro bodies intrude into the Hyland Group rocks. These are grey-green weathering, coarse-grained, pyroxene gabbro that form 10 to 20 m thick bodies, which are oriented parallel to the main structural fabric. Similar bodies intrude into the Road River Group shales near Sullivan and McKay hills, where they are locally associated with pyroxenite. The ultramafic bodies are orange weathering, medium to coarse-grained, and primarily comprise clinopyroxene.

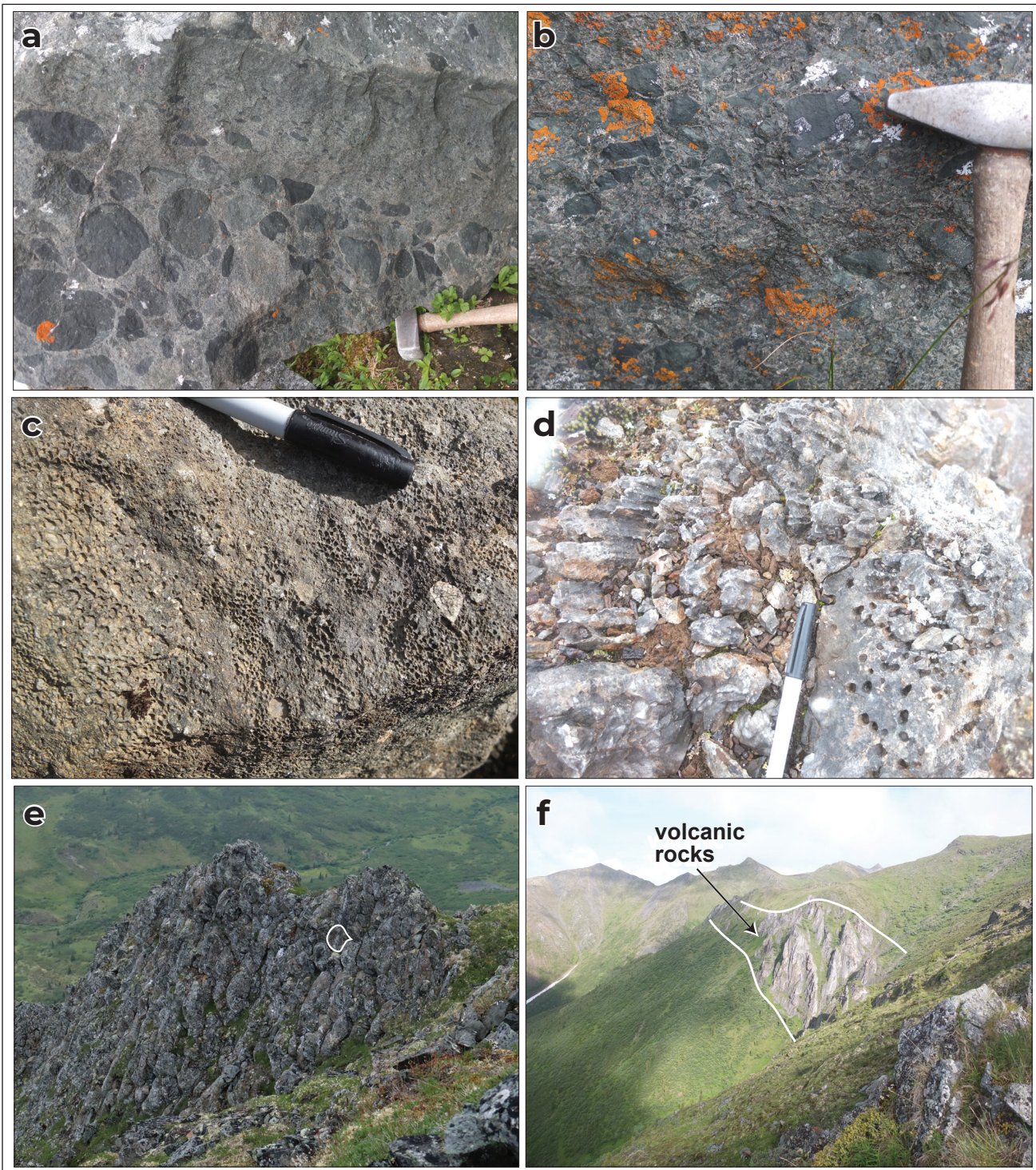
### Feldspar porphyritic sills and dikes

Southeast of Carpenter Creek, several occurrences of feldspar-phyric diorite are observed both cutting the stratigraphy and intruding along bedding. However, these bodies are too small (1–5 m thick) to be included as separate units on the map. The diorite is a brown weathering, variably altered, fine-grained, feldspar  $\pm$  pyroxene-phyric diorite.

## Structure

### North of the Dawson fault

Proterozoic rocks exposed across the central part of the map area were deformed prior to the deposition of overlying Paleozoic strata. A very clear angular unconformity exists between the two successions. For example, in Figure 5, near vertical beds that belong to Gillespie Lake siltstone are overlain by flat-lying lower Bouvette Formation. Folding and faulting was not directly observed in the Proterozoic strata, so the structures responsible for the steep bedding orientations remains uncertain.



**Figure 10.** Volcanic rocks at McKay Hill, south of the Dawson Thrust fault. **(a)** Agglomerate comprising rounded volcanic rocks in a calcareous, sandy matrix (481587E, 7139702N). **(b)** Mafic tuff breccia comprising angular clasts of basalt in a devitrified glass matrix (484347E, 7138301N). **(c)** Very calcareous volcanic rock comprising hexagonal shaped vesicles filled with calcite with minor white weathering, angular clasts (478807E, 7138037N). **(d)** Limestone with fasciculate coral fossils that have been replaced by rusty weathering sulphides (479453E, 7137976N). **(e)** Ridge comprised of pillow basalt that is approximately 10 m high. Pillows clearly show bottoms and tops, as highlighted by the white outline indicating this sequence of rocks young to the southwest (476325E, 7138362N). **(f)** Looking northwest at McKay Hill, where light grey weathering cliff-forming rocks comprise a tapering lens of pillow basalt.

A buried fault follows the trace of Carpenter Creek and accommodates the placement of upper Proterozoic rocks at a similar level as the Gillespie Lake Group rocks (Fig. 2). However, because the age of the strata southeast of Carpenter Creek is unknown, the nature of movement along that fault is uncertain.

North of the Dawson thrust, Paleozoic rocks are openly folded with fold axial traces plunging gently west-northwest. East-west striking normal faults cut through Castle Mountain stratigraphy offsetting rocks by as much as 300 m. One of the more significant faults in the northern part of the map area has dropped the stratigraphy in the northeast corner down, so that much of lower Bouvette Formation remains buried.

### **South of the Dawson fault**

A strong structural trend exists south of the Dawson thrust where most foliation and bedding strikes west-northwest/east-southeast. Foliation dips between 80 and 89° and is well-developed in the shale but is not commonly observed in the volcanic rocks and gabbro. Several tight regional folds follow the structural trends and locally repeat the stratigraphy. A right-lateral strike-slip fault has offset these strata by several hundred metres near McKay Hill.

The Hyland Group is in fault contact with the volcanic strata along a moderately south-southwest dipping thrust fault. The fault was drawn at the first occurrence of maroon and green shale.

## **Discussion**

### **Stratigraphic relationships**

The map area is unique because of the igneous rocks exposed here. Based on stratigraphic position and crosscutting relationships, there are at least three distinct episodes of magmatism, possibly as many as five. These are represented by (1) the Mesoproterozoic Hart River gabbro bodies, (2) the volcanic and volcanoclastic rocks in the lowest part of the lower Bouvette Formation, and (3) the Ordovician volcanic rocks exposed on both sides of the Dawson thrust fault (*i.e.*, the upper parts of the lower Bouvette near Castle Mountain and Ervin Creek and the volcanic rocks exposed at McKay Hill).

The feldspar-porphyrific rocks that occur as dikes and sills southeast of Carpenter Creek intrude and are therefore younger than the older lower Bouvette Formation volcanic rocks with no upper age constraint. Based on the current age constraints for these rocks, they could represent a fourth magmatic episode. The gabbro that intrudes the Dawson fault hangingwall rocks intrudes into the Road River Group rocks constraining its age to younger than Middle Ordovician, suggesting that these rocks could also represent a temporally distinct magmatic episode. The wide valley that the Beaver River partially occupies may represent a long-lived basement structure that facilitated the migration of magma to and near the surface.

The lack of gabbro in the upper Proterozoic rocks, south of Carpenter Creek, is interpreted to indicate that the younger succession unconformably overlies Gillespie Lake rocks, as shown on the cross sections in Figure 2. However, because the Carpenter Creek fault separated the two successions, this could not be verified.

### **Significance of volcanic facies**

The basaltic rocks and sills in the northeastern part of the map area (near Ervin Creek, Fig. 2) represent the thickest accumulation of volcanic rocks in this part of the stratigraphy. The lens shaped mound of volcanic-derived conglomerate that sits below the basalt (Fig. 7a,b) is interpreted to be a block and bomb tuff based on the shape and size of the clasts and the lack of a lithic component (*i.e.*, the entire lens comprises volcanic-derived material). The only dike that was confidently identified in the northern part of the map area is right below the block and bomb tuff, where a metre-wide, steeply dipping, aphanitic, mafic dike was observed cutting through the silty limestone unit trending into (but not cutting) the overlying tuff and basalt flows (Fig. 7a). Block and bomb tuffs are vent-proximal facies because the large size of the bombs requires them to be deposited quickly after they are ejected (Head and Wilson, 2003). Feeder dikes are typically preserved near vents, and basalt flows are considered vent-proximal facies; however, during effusive eruptions that are typical of basaltic compositions, flows can spread out laterally many kilometres from a vent (*e.g.*, Cas and Wright, 2012).

North of Beaver River, the amoeboid-shaped limestone clasts that occur locally in basalt are interpreted to be formed from basalt flowing into unconsolidated limey sediments. This indicates that the fossils found in some of the limestone clasts directly date the age of the eruptions. Cross-bedded, volcanic derived sandstone is interpreted to form from pyroclastic surges that sort ash to lapilli-sized volcanic fragments during transport (e.g., Cas and Wright, 2012).

The bedded volcanic-derived siltstone and sandstone that occur adjacent to the block and bomb tuff are interpreted to be syn-eruptive facies. Ash and lapilli ejected during explosive eruptions were sorted during transport through air or water shortly after the block and bomb tuff was deposited resulting in well-bedded deposits. These pyroclastic rocks that occur as the basal volcanic unit near Ervin Creek suggest early eruptions may have been explosive, followed by more effusive eruptions represented by the basalt flows above the tuffaceous rocks. Also, in the northeastern part of the map area, discontinuous limestone in basalt represents a break in volcanism (Fig. 7c). The limestone conformed to the irregular shape of the top of the underlying flow.

The volcanic-derived conglomerate that occurs near the base of the Bouvette Formation is interpreted to be reworked deposits from collapse of a steep volcanic edifice. The well-rounded nature of clasts suggest they have been transported. Further, the general fining upwards of the beds into cross-bedded volcanic-derived sandstone indicated sorting during transport (e.g., Cas and Wright, 2012). Rare volcanic breccia that occurs near the top of basalt is interpreted to be a flow-top breccia (Fig. 8f) that formed from fragmenting of a vesicular basalt rind (Cas and Wright, 2012).

## Mineralization

Mineralization at McKay Hill is associated with milky-white quartz veins and orange weathering surface alteration of gabbro. Veins and mineralization are interpreted to be linked to late strike-slip faulting (Blackburn, pers. comm.). Competency contrasts between rigid gabbro bodies and shale are important controls for vein growth at McKay Hill because they undergo brittle deformation during faulting, allowing

space for fluids (Blackburn, 2010). Volcanic rocks are spatially associated with the mineralization at McKay Hill but it is unclear whether they are an important control for mineralization.

Little is known about the mineralization at Grey Copper Hill but historical trenches were dug parallel to the contact between the Bouvette Formation and the underlying Pinguicula Group suggesting the unconformity between these two formations is a control for mineralization.

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