



**PREVIOUS MAPPING**  
The Carpp Ridge 7.5' quadrangle and east adjacent Storm Lake 7.5' quadrangle were mapped at 1:24,000 scale by Lukke and Wallace (1992). The Carpp Ridge 7.5' quadrangle was re-mapped by the MBMG at 1:24,000 scale (Lonn, unpublished mapping, 2008), with considerable revisions made to the structural interpretation of Lukke and Wallace (1992). Carpp Ridge is included in geologic maps of the Georgetown Thrust area (Poulet, 1956; 1:48,000 scale), the Anaconda-Pintar wilderness area (Wallace and others, 1992; 1:50,000 scale), and the Phillipsburg 30' x 60' quadrangle (Lonn and others, 2008; 1:100,000 scale). It is further included in the classic Emmons and Calkins (1913) 1:125,000 scale map of the Phillipsburg area. Maps of adjacent and nearby areas include the Kelly Lake 7.5' quadrangle (Lonn and McDonald, 2004; 1:24,000 scale), the Long Peak 7.5' quadrangle (Hilbert and Lonn, 2017; 1:24,000 scale), the southern half of the Warren Peak 7.5' quadrangle and the northern half of the Pintar Lake 7.5' quadrangle (Howlett and others, 2020; 1:24,000 scale), and the Dillon 1' x 2' quadrangle (Ruppel and others, 1993; 1:250,000 scale).

**METHODS (U-Pb Geochronology)**  
Five samples were collected from plutons and dikes for U-Pb zircon geochronology. Three samples (21CR12, 46.009, -113.439; 21CR15, 46.027, -113.397; 21CR33, 46.035, -113.413) were collected from cross-cutting dike and granodiorite in the southern half of the quadrangle, and another sample was collected from a biotite monzonitic stock (Rmg, 21CR16, 46.003, -113.420). An additional sample was collected from a highly foliated biotite-hornblende stock (Rgd, 21CR35, 45.992, -113.441) in the northern half of the Warren Peak 7.5' quadrangle. We separated zircons from bulk samples using standard rock crushing techniques, a Wilfly table, Franz magnetic separator, and heavy liquid at Montana State University. For each sample, 50 high quality zircons were mounted alongside SLmix, R33, and FC zircon standards. Mounted zircons were polished to a depth of ~20 µm and sent to the Arizona Laser-Corion Center at the University of Arizona for imaging and analysis. Cathodoluminescence (CL) and backscattered electron (BSE) images were taken of each mount using a Hitachi 3400N SEM and a Gatan CL2 detector system. BSE images were used to target individual zircons for isotopic analysis and specific age domains in each zircon were identified using CL images. A Photon Machines Analyte G2 Excimer excimer equipped with He/Ne excitation cell was used to laser ablate each zircon to a spot diameter of 20 microns and a depth of 10 microns for ~10 seconds following methods outlined by Gehrels and others (2008). Ablated material was transferred in helium to the ion source of an attached Element2 HR single-collector ICP-MS, and signal intensities for U, Th, Pb, and Hg isotopes were measured using an SEM. We reduced data using AgeCalcML (<https://www.kurtandell.com/agecalcml/>) following procedures outlined by Gehrels and others (2008).

**GEOLOGIC ADVANCES**  
S<sub>1</sub> bedding-parallel transposition fabrics and faults that attenuate the Missoula-Piegan Group section in the footwall of the Georgetown Thrust are axial planar to F<sub>1</sub> west-vergent parasitic folds in the hinge of the FRA (Figure 2A, 3). Rare shear-sense indicators suggest top-to-NW motion, consistent with NW-vergent F<sub>1</sub> in the FRA. Bedding-parallel faults originally interpreted as east-of-sequence thrusts (Lukke and Wallace, 1992) and low-angle detachment faults (Lonn and McDonald, 2004; Lonn and McDonald, 2009) are reinterpreted as NW-directed faults and thrusts related to F<sub>1</sub> folding, although they could also be passive surfaces related to ductile flow of incompetent argillites in the Piegan and Missoula Groups. Given these observations, it is highly likely that extension in the upper limb of the FRA, at least locally, attenuated the Belt-Palozozo section. S<sub>1</sub> fabrics are refolded by F<sub>2</sub> upright folds associated with the gently N-plunging Rock Creek Anticline (RCA), and parasitic folds strongly suggest that this structure is also west-vergent (Fig. 2A, 3). The RCA folds the Georgetown Thrust and likely refolds the FRA at depth. New U-Pb zircon dates from cross-cutting intrusions indicate that folding is Late Cretaceous in age, perhaps contemporaneous with development of the ~75–74 Ma Lake of the Hot Shear Zone (LSZ) (Grove, 2006) on the basis of similar structural styles. Regional map patterns strongly suggest that the FRA is a kilometer-scale fold involving the entire Belt Supergroup, and that it may represent the southern sub-dome of a larger dome-gneiss dome centered around the LSZ. West-vergent folding may therefore be decoupled from east-vergent regional tectonics and kinematics linked to gneiss doming. This dome may have formed in response to local decompression of mid-crustal rocks in the AMCC footwall documented by Groves (2006) and Foster and others (2010), perhaps driven by delamination of lithospheric mantle (Wells and Hoisch, 2008) or across-faulting beneath the Cordilleran magmatic arc of SW Montana (DeCelles and others, 2009).

**GEORGETOWN THRUST FOOTWALL**  
The footwall of the Georgetown Thrust in the Carpp Ridge 7.5' quadrangle consists of a greenschist- to lower amphibolite facies section of Cambrian-Mississippian shelf platform and Mesoproterozoic Belt Supergroup strata intruded by a series of Eocene dikes and plutons. NW-dipping S<sub>1</sub> fabrics are particularly well-developed in Piegan Group strata along the crest of the Anacostia Range and often bounding and transposing original bedding. White F<sub>1</sub> folds are well developed in the Carpp Ridge area as they are in the FRA hinge. S<sub>1</sub> fabrics are axial planar to NW-vergent isoclinal folds that are sub-parallel to the original bedding (Fig. 3). A much larger NW-vergent F<sub>1</sub> fold, the Cutaway Recumbent Anticline (CRA) is visible in a cliff face along the HI-Line trail in the southeastern part of the quadrangle (Fig. 4). The lower limb of the fold roots into a shear zone, the Cutaway Nappe Thrust (CNT), that is sub-parallel to the S<sub>1</sub> fabric. Up-section in the Missoula Group, along the crest of the Anacostia Range, S<sub>1</sub> fabrics are well-developed in the Snowship Formation. Much of the Snowship Formation and the overlying Shepard Formation, however, are omitted along a bedding-parallel fault that juxtaposes quartzite of the Snowship Formation against the Snowship. While the fault surface is not well-exposed along the ridge, Lukke and Wallace (1992) observed shear zones associated with this fault in the scarp above Spruce Lake. Given its parallelism with the S<sub>1</sub> fabric, we interpret this fault as the Sawed Cabin Fault (SCF), a re-interpretation of the Sawed Cabin Detachment of Lonn and McDonald (2004). The SCF may be a passive surface that accommodated ductile flow of incompetent Piegan and Snowship strata between more competent quartzites of the overlying Mount Shields Formation and underlying Ravalli Group, perhaps analogous to stretching faults of Means (1989). East of Carpp Ridge, the Piegan-Ravalli contact is also a shear zone, perhaps related to S<sub>1</sub> axial planar cleavage is well-developed in argillites of the Mount Shields Formation in the core of the hills, where it is often at a high-angle to bedding. The orientation of S<sub>1</sub> changes from SE-dipping on the western limb of this fold to NW-dipping on the eastern limb. Several parasitic F<sub>1</sub> folds with gently SW-plunging hinge lines are well-exposed in the Dexter Basin corrie on the western limb of the RCA (Fig. 2B, 5).

New U-Pb zircon dates (Figure 6) from five cross-cutting dikes and plutons in the Georgetown Thrust footwall help to constrain the age of deformation in the field area. A sample from an extensive, undeformed granodiorite dike (21CR33) that crosscuts the RCA yielded an age of 52.87 ± 0.12 Ma. A smaller dike dike (21CR15) observed cross-cutting S<sub>1</sub> fabrics in the Piegan Group yielded an age of 49.28 ± 0.14 Ma. A sample from the biotite-hornblende granodiorite stock (Rgd, 21CR35) collected in the northern half of the Warren Peak 7.5' quadrangle yielded an age of 51.87 ± 0.12 Ma. Interestingly, the stock is locally foliated in the hinge of the FRA, and this foliation is sub-parallel to the S<sub>1</sub> fabric. While this initially suggested a syn-kinematic relationship between the FRA and the granodiorite stock, it is non-foliated throughout Carpp Ridge and actually crosscuts S<sub>1</sub> fabrics in the southeastern portion of the quadrangle. Therefore, this foliation may represent local reactivation of the FRA during AMCC extension. A sample from a dike intruding the biotite-hornblende granodiorite (21CR12) yielded an age of 51.85 ± 0.08 Ma, and may be comagmatic with 48.91 ± 0.13 Ma monzonitic stock (Rmg, 21CR36) that intrudes Rgd. While no upper bound on the age of deformation was identified in the Carpp Ridge quadrangle, similarities in structural style between the FRA and the ~75–74 Ma LSZ suggest that the two may have developed contemporaneously.

**GEORGETOWN THRUST HANGING WALL**  
The hanging wall of the Georgetown Thrust in the Carpp Ridge 7.5' quadrangle consists of a west-dipping panel of lightly metamorphosed Piegan-Missoula Group strata. Bedding-parallel fabrics, including shear zones and rootless isoclines, are present in Piegan strata, however, to what extent they are related to deformation of the Georgetown Thrust versus subsequent folding is unclear. S<sub>1</sub> cleavage at a high angle to bedding was identified in Piegan strata in the northeastern part of the quadrangle.

A bedding-parallel normal fault mapped by Lonn and others (2003) between the Snowship and Mt. Shields formation in the Georgetown hanging wall does not, and is clearly a conformable contact. Further, strata originally assigned to the Mt. Shields and Bonner formations by Lonn and others (2003) are assigned to an informal unit referred to as the Missoula Quartzite. This sequence of sub-arcose, grading upwards into quartz arenites is much coarser-grained than equivalent Missoula Group strata east of the Georgetown Thrust, leading us to interpret them as a transitional sequence between the recently recognized Lemhi subbasin of the Belt Supergroup (Barnhorst and others, 2016) and more distal Belt strata to the east.

**DESCRIPTION OF MAP UNITS**

**Qal** Alluvium (Holocene)—Modern stream and wetland deposits. Thickness likely less than 30 m (100 ft).

**Qls** Landslide deposits (Holocene)—Mixture of unsorted, unstratified boulders and mud related to mass wasting. Notable examples occur around Carpp Lake and on the western end of Carpp Creek. Thickness likely less than 60 m (200 ft).

**Qgk** Glacial till and kame deposits (Pleistocene)—Glacial till consists of unsorted, unstratified mixtures of clay, silt, sand, gravel, and sub-rounded boulders deposited by alpine glaciers. Kames consist of moderately well-sorted, well-sorted, well-sorted to sub-rounded sand, pebbles, and boulders deposited by streams marginal to glaciers. Thickness may be as much as 120 m (400 ft).

**Qgk** Glacial kame deposits (Pleistocene)—Moderately well-sorted, well-sorted, rounded to sub-rounded sandy pebbles, cobbles, and boulders deposited by streams marginal to glaciers. Thickness may be as much as 60 m (200 ft).

**Ngg** Neogene gravels (Pliocene-Miocene?)—Moderately to poorly sorted, poorly stratified, rounded to sub-rounded sandy pebbles, cobbles, and boulders. Occurs along the Meadow Creek drainage and around McDougal Gulch. Thickness may be as much as 120 m (400 ft).

**Rmg** Biotite monzonitic stock (Eocene)—Porphyritic, non-foliated biotite monzonitic composed of coarse-grained quartz, orthoclase perthite, plagioclase, and minor microcline phenocrysts in a medium-grained plagioclase and quartz-rich groundmass. Orthoclase phenocrysts are sub-euhedral, with long axes measuring up to 1 inch, and plagioclase phenocrysts display considerable sericitic alteration. U-Pb zircon age of 48.91 ± 0.13 Ma obtained from sample 21CR36 collected from the eastern flank of the Maloney Basin.

**Rgd** Granodiorite and dike dikes (Eocene)—Porphyritic, non-foliated biotite granodiorite and dike composed of coarse-grained quartz, orthoclase perthite, plagioclase, and minor microcline phenocrysts. Microcline phenocrysts are variable in occurrence, with some dikes containing more than others. Dacite groundmass consists of aphanitic quartz and plagioclase, and rims of smaller quartz grains around quartz phenocrysts are in optical continuity with phenocrysts. Plagioclase phenocrysts display considerable sericitic alteration. U-Pb zircon ages were obtained from three dikes in the southern part of the quadrangle: 51.85 ± 0.08 Ma (sample 21CR12), 49.28 ± 0.14 Ma (sample 21CR15), and 52.87 ± 0.12 Ma (sample 21CR33). Likely comagmatic with qg and ang.

**Rmg** Biotite-hornblende granodiorite stock (Eocene)—Medium to fine-grained equigranular biotite-hornblende granodiorite composed of quartz, plagioclase, microcline perthite, biotite, and minor hornblende. Plagioclase phenocrysts are common and some display complex zoning. Non-foliated in the Carpp Ridge quadrangle, however, in the hinge of the Fishtrap Recumbent Anticline south of the quadrangle, this stock has a weakly-moderately developed foliation sub-parallel to wall rocks. In foliated samples, quartz grains have been recrystallized into foliation-parallel zones of subgrains. Biotite "ribbons" occur within subgrain zones, often in alignment with quartz and plagioclase porphyroclasts. Quartz porphyroclasts often display undulatory extinction. U-Pb zircon age of 51.87 ± 0.11 Ma obtained from sample 21CR35 collected below the quadrangle's southern boundary.

**Mm** Madison Group (Mississippian)—Well-bedded, grey fossiliferous limestone containing abundant crinoids, hyzozoids, and brachiopods. May correspond to the Mission Canyon Formation. Approximately 700 m (2,300 ft) thick.

**Dm** Jefferson and Maywood formations, undivided (Middle-Upper Devonian)

**Dm** Jefferson Formation (Upper Devonian)—Dark grey massive dolostone interbedded with light grey limestone. Alternating dark and light beds give it a striped appearance. Poorly exposed in the quadrangle. Maximum thickness is approximately 720 m (2,360 ft).

