



Kilometer-scale recumbent folding, tectonic attenuation, and rotational shear in the western Anaconda Range, southwestern Montana, USA

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ABSTRACT

The Eocene Anaconda metamorphic core complex is the most recently documented metamorphic core complex in the North American Cordillera. While much work has focused on constraining the nature and timing of core complex extension, earlier deformation preserved in its footwall is not as well understood. The Anaconda metamorphic core complex footwall contains an anomalously thin, lower- to uppermost-amphibolite-facies section of Mesoproterozoic Belt Supergroup and Paleozoic metasedimentary strata. While the tectonic nature of this thinning is generally accepted, the mechanisms behind it remain enigmatic. Previous workers have hypothesized that footwall strata were attenuated along the upper limb of the Late Cretaceous Fishtrap recumbent anticline, a kilometer-scale, NW-vergent, recumbent fold exposed throughout the west-central metamorphic core complex footwall. New geologic mapping in the west-central Anaconda Range better constrains the nature and timing of tectonic attenuation in this structurally complex area. Two generations of folds were recognized: (1) F_1 recumbent isoclines associated with the Fishtrap recumbent anticline and (2) F_2 W-vergent asymmetric folds associated with map-scale N-plunging folds. F_1 folds, axial planar S_1 transposition fabrics, and bedding-parallel faults and shear zones boudinage, transpose, and omit strata of the Belt Supergroup. We suggest that the Fishtrap recumbent anticline tectonically attenuated the Belt Supergroup through Paleozoic section of the west-central Anaconda metamorphic core complex footwall, and we propose that it is a kilometer-scale, regionally significant structure. We further propose that the fold may have developed in response to rotational shear and sinistral transpression along the Lewis and Clark Line, which was further driven by accretion of outboard terranes along the western margin of North America during Late Cretaceous time.

1. INTRODUCTION

Cordilleran metamorphic core complexes of western North America (Fig. 1) represent focal points of high-magnitude extension in Earth's crust following prolonged Jurassic–Paleogene orogenesis (e.g., Davis and Coney, 1979; Crittenden, 1980; Wernicke, 1981). First recognized in the North American Cordillera, these features are characterized

by domal uplifts consisting of a highly metamorphosed footwall, a mylonitic shear zone crosscut by a low-angle detachment fault, and an unmetamorphosed hanging wall (Coney, 1980). Exhumed footwall rocks of North American Cordilleran core complexes often record Mesozoic deformational histories that predate core complex extension, providing natural laboratories in which to study midcrustal conditions in the hinterland (e.g., Armstrong and Hansen, 1966; Armstrong, 1982; Coney and Harms, 1984; Spencer and Reynolds, 1990;

Platt et al., 2015; Wrobel et al., 2021). While much study has focused on the mechanics of core complex extension in this orogen, comparatively little work has been done on the nature and timing of pre-extensional deformation related to orogenesis. Crustal thickening and magmatism associated with contraction preconditioned the Cordilleran crust for subsequent core complex extension and exhumation (e.g., Coney and Harms, 1984; Spencer and Reynolds, 1990; Howlett et al., 2021; Wrobel et al., 2021); therefore, understanding pre-extensional deformation is critical to (1) better understand midcrustal behavior during orogenesis and (2) elucidate the processes that drive high-magnitude extension in orogens.

Previous studies of Cordilleran metamorphic core complex footwalls have documented deformation more characteristic of midcrustal levels, yet this has been explained in terms of both pre-core complex contraction and syn-core complex extension. In the footwall of the Ruby Mountains–East Humboldt metamorphic core complex of eastern Nevada, recumbent folding and extreme stratal attenuation have been interpreted in terms of both midcrustal flow during core complex extension and thrust-subparallel distributed ductile thinning during Late Cretaceous decompression (MacCready et al., 1997; Long and Kohn, 2020). In the footwall of the northern Snake Range metamorphic core complex of eastern Nevada, Late Cretaceous regional-scale recumbent folding and deep-seated thrusting roughly coincided with burial and amphibolite-facies metamorphism of footwall strata (Miller and Gans, 1989; Wrobel et al., 2021).

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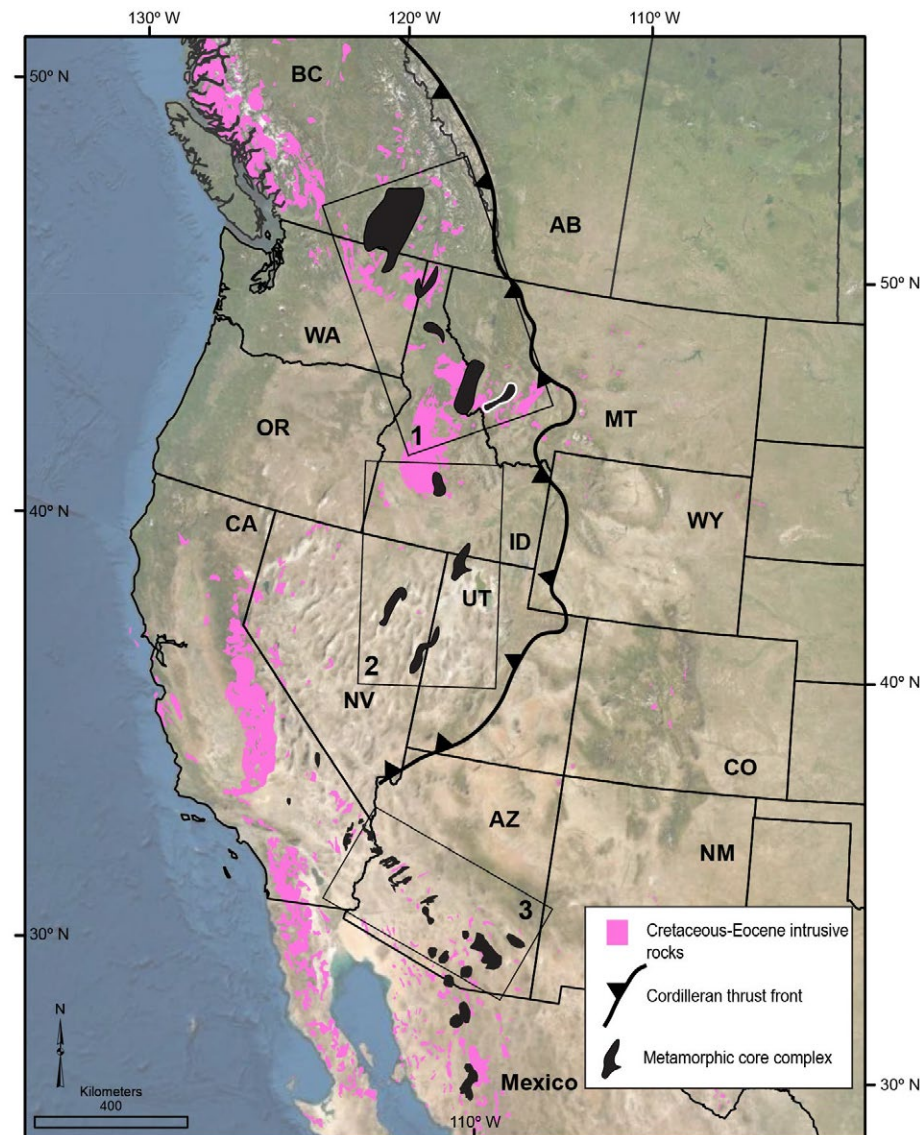


Figure 1. Tectonic map of the western United States, modified from Howlett et al. (2021), showing distribution of metamorphic core complexes in relation to Cretaceous–Eocene intrusive rocks and the Cordilleran thrust front. Metamorphic core complex with white outline—Anaconda metamorphic core complex. Rectangles 1–3 outline the northern, central, and southern Cordilleran metamorphic core complex belts, respectively. Base map is satellite imagery from Esri/National Oceanic and Atmospheric Administration (NOAA). State/province abbreviations: AB—Alberta; BC—British Columbia; AZ—Arizona; CA—California; CO—Colorado; ID—Idaho; MT—Montana; NM—New Mexico; NV—Nevada; OR—Oregon; UT—Utah; WA—Washington; WY—Wyoming.

This episode of crustal thickening likely primed the northern Snake Range metamorphic core complex for high-magnitude Cenozoic extension (Wrobel et al., 2021). Furthermore, studies in and around the Shuswap metamorphic core complex of south-eastern British Columbia have documented both migmatite-cored gneiss domes associated with diapiric flow of midcrustal rocks during core complex extension as well as various Mesozoic contractional features such as the Monashee décollement and the Selkirk allochthon (Brown et al., 1992; Norlander et al., 2002; Gibson et al., 2008).

Many of the features described in the previous paragraph are present in the footwall of the Anaconda metamorphic core complex of southwestern Montana, the most recently documented metamorphic core complex in the North American Cordillera (Figs. 1 and 2; Lonon et al., 2003; O'Neill et al., 2004). Like other Cordilleran core complexes, most work in the Anaconda metamorphic core complex has focused on determining the nature and timing of core complex extension (e.g., Grice et al., 2004; Foster et al., 2010; Howlett et al., 2020, 2021), with less emphasis on pre-extensional deformation in the exhumed footwall. The Anaconda metamorphic core complex footwall consists of an extremely attenuated package of lower- to uppermost-amphibolite-facies Mesoproterozoic Belt Supergroup and Paleozoic passive-margin strata intruded by voluminous Cretaceous–Paleogene plutons. In total, the Belt Supergroup section exposed in the western Anaconda metamorphic core complex footwall is 4000 m thick, compared to 6100 m west of the regionally extensive Late Cretaceous Georgetown thrust (Figs. 2 and 3; Lonon et al., 2003). In addition, strata of the Mesoproterozoic Missoula Group have been thinned from ~3000 m to ~60–500 m in the same area (Emmons and Calkins, 1913; Poulter, 1956; Csejter, 1968; Heise, 1983; Lonon and McDonald, 2004). Much of this attenuation appears to be tectonic in nature, facilitated by bedding-parallel faults and shear zones that flatten, boudinage, transpose, and omit parts of the section (Lidke and Wallace, 1992; Wallace et al., 1992; Lonon et al., 2003; Lonon and McDonald, 2004; Lonon and Lewis, 2009).

Previous workers have speculated that the Fishtrap recumbent anticline, an anomalously

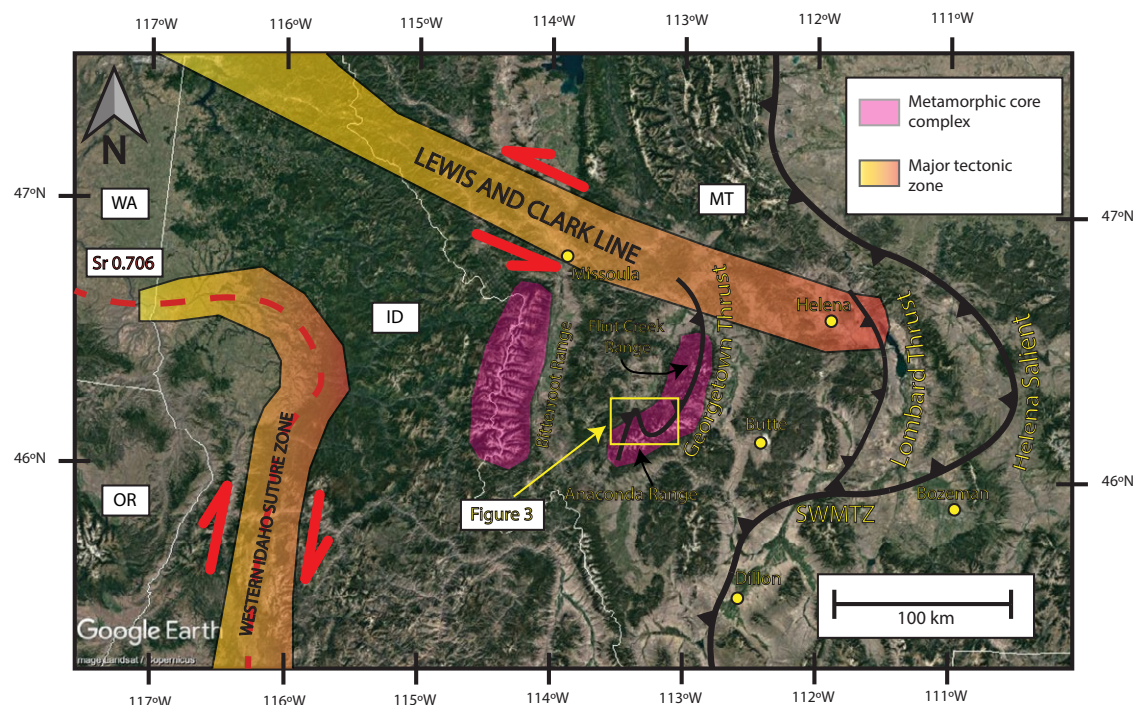


Figure 2. Tectonic map of the Montana-Idaho-Washington-Oregon Cordillera, outlining major tectonic features mentioned in text. SWMTZ—Southwest Montana transverse zone. Imagery sourced from Google Earth. Used with permission. See Figure 1 caption for state abbreviations.

NW-vergent recumbent fold visible in mountainsides throughout the west-central Anaconda Range, attenuated the Belt Supergroup through Paleozoic section along its upper limb. There has been no attempt in the literature to relate attenuation to recumbent folding during contractional deformation, and exposures of the fold hinge and overturned limb in the southeastern Anaconda Range have led some workers to speculate that the Fishtrap recumbent anticline is a structure of regional significance, perhaps related to the ca. 75–74 Ma Lake of the Isle shear zone (Grice et al., 2004; Kalakay et al., 2014) in the eastern Anaconda metamorphic core complex footwall (Fig. 3). Cross-cutting relationships with Eocene and Cretaceous magmatic rocks strongly suggest that the Fishtrap recumbent anticline developed during Late Cretaceous time (Lonn et al., 2003; Grice et al., 2004; Kalakay et al., 2014; Neal et al., 2023), perhaps contemporaneously with the Lake of the Isle shear zone

and other elements of the Helena salient of the Cordilleran retroarc fold-and-thrust belt (Fig. 2).

In this contribution, we tested the hypothesis that recumbent folding was the driving mechanism behind attenuation of the Belt Supergroup through Paleozoic section in the western Anaconda metamorphic core complex footwall. The study area (Figs. 3 and 4), located in the west-central Anaconda Range just south of Philipsburg, Montana, is host to an extremely attenuated, ~230-m-thick Mesoproterozoic Missoula Group section (Lonn and Lewis, 2009) in the footwall of the Georgetown thrust, and it provides excellent exposures of the Fishtrap recumbent anticline hinge. Much of the deformation in this area has been attributed to development of the Georgetown thrust and series of NNE-plunging upright folds (e.g., Lidke and Wallace, 1992; Lonn et al., 2003); however, mesoscopic W-vergent folds in adjacent areas suggest that Fishtrap recumbent anticline-related deformation is

underappreciated. High-resolution geologic mapping in the study area was conducted at 1:24,000 scale to (1) document mesoscale structural fabrics to determine structural style and kinematics and (2) determine whether an axial planar relationship exists between bedding-parallel transposition fabrics and the Fishtrap recumbent anticline. Our results suggest that the Fishtrap recumbent anticline attenuated Belt Supergroup through Paleozoic strata along its upper limb during Late Cretaceous time and that map-scale bedding-parallel faults and shear zones originally mapped as thrusts (Lidke and Wallace, 1992; Wallace et al., 1992) and detachments (Lonn et al., 2003; Lonn and McDonald, 2004; Lonn and Lewis, 2009) are related to development of the Fishtrap recumbent anticline. Further, we propose a conceptual model integrating the Fishtrap recumbent anticline and the Lake of the Isle shear zone, and we attempt to explain anomalous opposite vergence in terms of far-field stresses

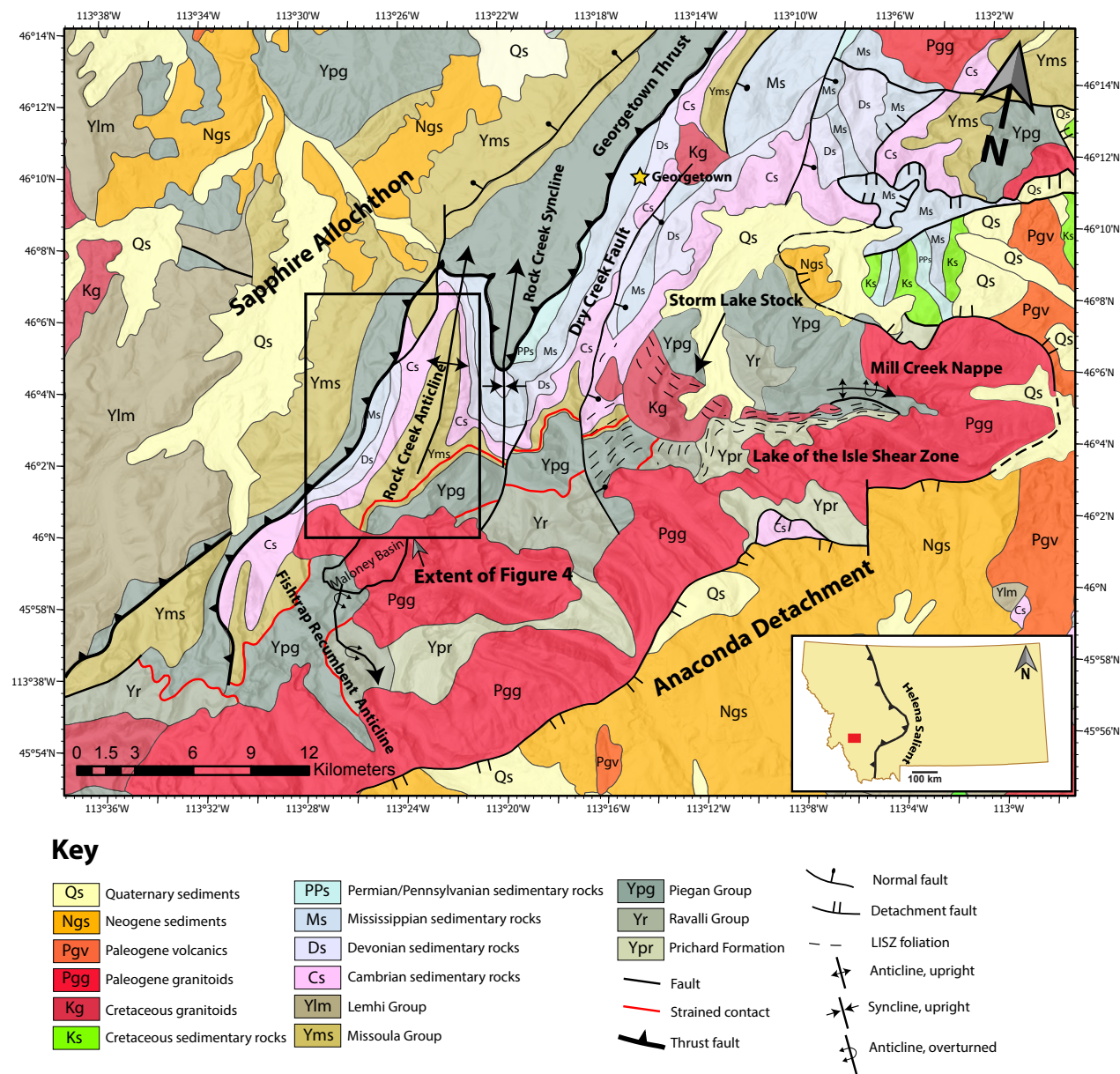


Figure 3. Regional geologic map of the Anaconda metamorphic core complex footwall. Red rectangle in inset shows location of Figure 3 relative to the Helena salient. Black-outlined rectangle in main panel shows location of the study area. The footwall consists of complexly deformed Mesoproterozoic–Mesozoic metasedimentary strata intruded by Late Cretaceous–Eocene plutons. Strained contacts and bedding-parallel faults are outlined in red. LISZ—Lake of the Isle shear zone. Bedrock geology data are sourced from the Montana Bureau of Mines and Geology, Wallace et al. (1992), and Kalakay et al. (2014). Base map and hillshade are sourced from Esri/National Oceanic and Atmospheric Administration (NOAA).

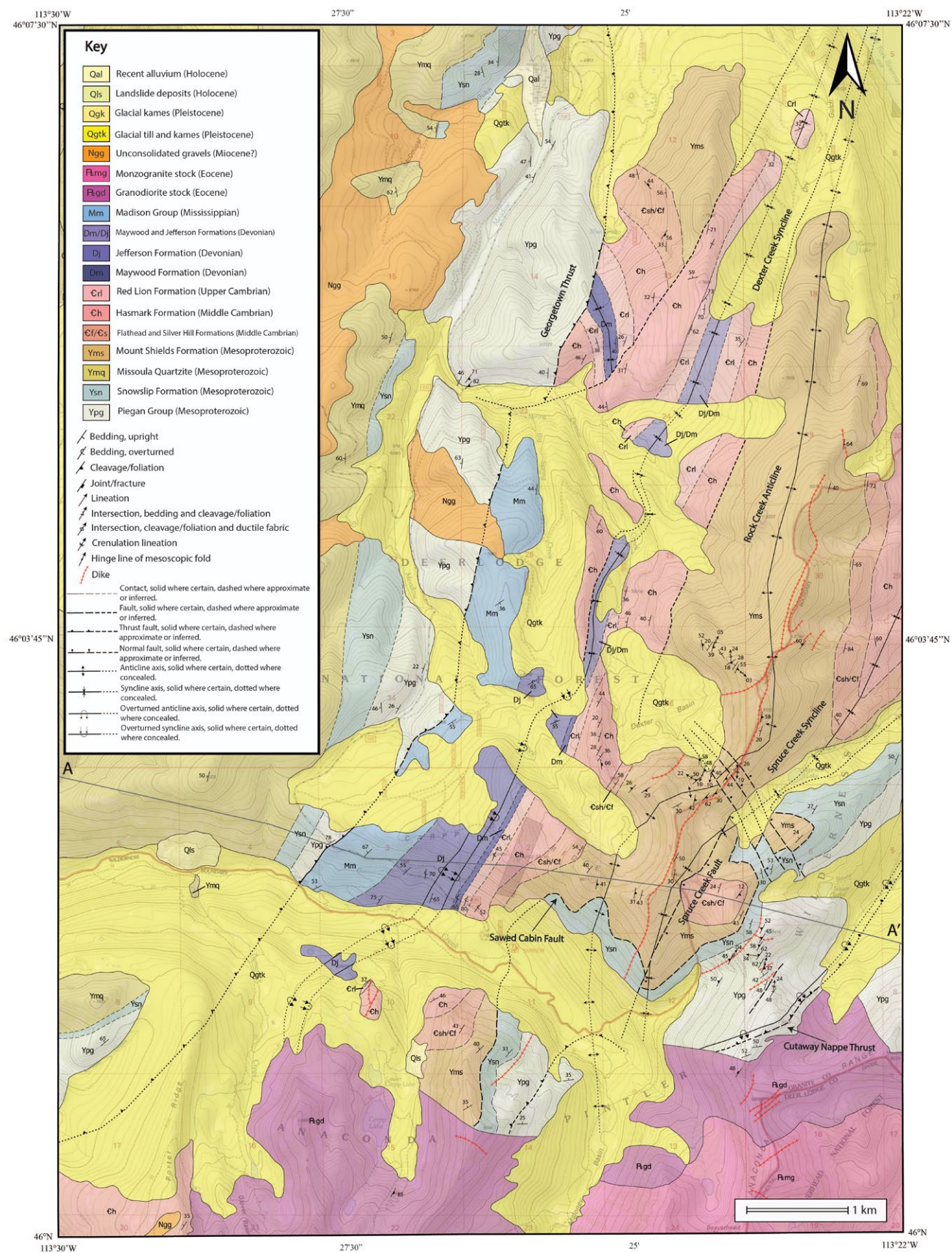


Figure 4. Geologic map of the field area in the west-central Anaconda metamorphic core complex at 1:24,000 scale. Line A-A' corresponds to cross section in Figure 13. Base map is sourced from U.S. Geological Survey (2020).

transmitted by terrane accretion into the Helena salient (Gray et al., 2022).

2. GEOLOGIC SETTING

The Anaconda metamorphic core complex is situated within the Helena salient, a forelandward-convex bend in the U.S. Cordilleran retroarc fold-and-thrust belt inherited from the earlier Helena embayment of the Mesoproterozoic Belt Supergroup (Fig. 1 and 2; Harrison et al., 1974). It is bounded to the north by the Lewis and Clark Line (Fig. 2), a regionally significant zone of strike-slip, dip-slip, and oblique-slip faulting that has been intermittently active since at least middle Proterozoic time (Hobbs et al., 1965; Weidman, 1965; Harrison, 1972; Harrison et al., 1974; Bennett and Venkatakrishnan, 1982; Wallace et al., 1990; Phillipone and Yin, 1994; Yin and Oertel, 1995; Sears and Hendrix, 2004), and to the south by the Southwest Montana transverse zone (Fig. 2), an extensive lateral ramp system separating thin-skinned thrust sheets of the Helena salient from basement-involved structures to the south (Schmidt and O'Neill, 1982; O'Neill et al., 1990; Schmidt et al., 2014). Major structural features within the Helena salient include the Late Cretaceous Lombard thrust (Fig. 2), the leading thrust fault of the salient, and the Late Cretaceous Georgetown thrust (Fig. 2). West of the Helena salient, intrusive igneous and high-grade metamorphic rocks of the Idaho Batholith and surrounding region are exposed in the footwall of the Bitterroot metamorphic core complex (Fig. 2; Hyndman et al., 1980), representing a major transition from foreland to hinterland elements of the northern U.S. Cordillera. Further west, the Western Idaho suture zone and the Sr 0.706 isopleth (Fig. 2) structurally and geochemically demarcate the boundary between Precambrian North American lithosphere and late Paleozoic to Mesozoic intra-oceanic terranes accreted during Late Cretaceous time (Hamilton, 1976; Armstrong et al., 1977; Jones et al., 1977; Vallier et al., 1977; Fleck and Criss, 1985, 1988; Lund and Snee, 1988; Snee et al., 1995).

The Anaconda metamorphic core complex consists of an unmetamorphosed hanging wall, a mylonitic shear zone crosscut by a low-angle

detachment fault, and a lower- to uppermost-amphibolite-grade footwall (Fig. 3). The hanging wall is characterized by detached blocks of Mesoproterozoic–Mesozoic rock covered by Cenozoic syntectonic and posttectonic clastic, volcanoclastic, and volcanic strata (O'Neill et al., 2004; Foster et al., 2010). It is separated from the footwall by the Anaconda detachment, a SE-dipping, 300–500-m-thick zone of lower- to middle-greenschist-facies mylonite, cataclasite, and breccia (Foster et al., 2007, 2010). Mineral lineations documented in the Paleocene Pintler Creek Batholith and surrounding metasediments near the detachment suggest that extension was likely directed NW-SE (Kalakay et al., 2003; O'Neill et al., 2004; Foster et al., 2007). Biotite $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages from rocks of the Anaconda metamorphic core complex footwall get younger to the east toward the detachment and define an exhumed partial retention zone, suggesting that core complex extension likely began ca. 53 Ma (Foster et al., 2010). Further, zircon (U-Th)/He data from the Pintler Creek Batholith suggest a phase of rapid cooling from ca. 60 Ma to 45 Ma associated with ambient cooling and initial exhumation, followed by a second phase of slower cooling from ca. 45 Ma to 25 Ma associated with footwall unroofing (Howlett et al., 2021). This extension was likely synchronous with the Bitterroot metamorphic core complex, on the basis of similar cooling histories, which has led some to suggest that the Anaconda and Bitterroot core complexes are an integrated extensional system (Foster et al., 2007, 2010).

In the Anaconda and Flint Creek ranges (Figs. 2 and 3), the footwall is characterized by complexly deformed Mesoproterozoic Belt Supergroup, Paleozoic passive margin, and Lower Cretaceous continental strata. For the purposes of this study, we consider the western edge of the Anaconda metamorphic core complex footwall to be the Georgetown thrust (Figs. 2 and 3), consistent with previous work in the region (Lonn et al., 2003; Lonn and Lewis, 2009; Lonn and Johnson, 2010). This structure separates highly attenuated, lower- to uppermost-amphibolite-facies Mesoproterozoic–Paleozoic strata to the west from lightly deformed, unmetamorphosed Mesoproterozoic strata of the Sapphire allochthon (Fig. 3). Anaconda complex

footwall strata have been tectonically attenuated by bedding-parallel faults and shear zones that omit parts of the section (Lonn et al., 2003; Lonn and Lewis, 2009; Lonn and Johnson, 2010). In the Lake of the Isle shear zone of the eastern Anaconda Range, ca. 75–74 Ma bedding-parallel gneissic foliation, boudinage, and isoclinal folding severely attenuate Mesoproterozoic and Paleozoic strata (Grice et al., 2004; Kalakay et al., 2014). In the western Anaconda Range, the Belt Supergroup is host to highly strained contacts and bedding-parallel faults that clearly omit section, as well as strain-partitioned zones of ductile shear containing prominent bedding-parallel transposition fabrics (Lonn et al., 2003; Lonn and McDonald, 2004). The deformational character of the Mesoproterozoic Missoula Group–Piegian Group contact (Fig. 3) is locally variable; at some localities, it is expressed as a brittle fault that omits section, and in others, it is expressed as a severely attenuated gradational contact with no clear stratigraphic discontinuity (Lonn and McDonald, 2004). The Mesoproterozoic Piegian Group–Ravalli Group contact (Fig. 3) is also strained in a similar manner. The attenuated section and associated structures in the Anaconda and Flint Creek Ranges are further folded by the NW-vergent Fishtrap recumbent anticline as well as series of NNE-plunging upright folds that fold the Georgetown thrust (Csejtey, 1968; Flood, 1974; Wiswall, 1976; Heise, 1983; Baken, 1984; Lidke and Wallace, 1992; Wallace et al., 1992; Lonn et al., 2003). The age of this deformation is roughly Late Cretaceous in age based on crosscutting plutons throughout the Anaconda complex footwall (Lidke and Wallace, 1992; Wallace et al., 1992; Lonn and McDonald, 2004). All aforementioned structures are cut by series of NE-striking high-angle normal faults that offset middle to late Eocene intrusive rocks (Wallace et al., 1992).

Three phases of metamorphism have been recognized throughout the footwall of the Anaconda metamorphic core complex: (1) Late Cretaceous high-pressure metamorphism related to thrust-driven burial, (2) Late Cretaceous amphibolite-facies metamorphism related to tectonic attenuation, and (3) a subsequent thermal event associated with the intrusion of Late Cretaceous–Eocene plutons. In the Lake of the Isle shear zone, metapelites

of the Mesoproterozoic Ravalli Group contain kyanite-bearing assemblages that suggest Barrovian, high-pressure metamorphism, perhaps related to emplacement of the Late Cretaceous Sapphire allochthon (Grice et al., 2004; Kalakay et al., 2014). Similar assemblages have been observed in metasedimentary strata of the Lower Cretaceous Kootenai Formation in the Flint Creek Range (Buckley, 1990). Peak pressures are estimated to have occurred around 7–8 kbar, based on reconstructed thicknesses of the Sapphire allochthon; however, no thermobarometry is available to constrain this estimate (Grice et al., 2004; Sears and Hendrix, 2004; Kalakay et al., 2014). Kyanite-bearing assemblages in the Lake of the Isle shear zone are overprinted by high-temperature, low-pressure cordierite-bearing assemblages. Cordierite-bearing, migmatitic paragneisses of the Mesoproterozoic Prichard Formation record temperatures and pressures of ~750–825 °C and ~3.2–5.3 kbar, based on thermobarometry, indicating uppermost-amphibolite-facies conditions (Grice et al., 2004; Kalakay et al., 2014). Field relationships suggest that this metamorphism accompanied tectonic attenuation and partial melting in the Lake of the Isle shear zone, and it has been dated to ca. 75–74 Ma based on deformed and crosscutting intrusions (Grice et al., 2004; Kalakay et al., 2014). In the west-central Anaconda Range, around the Fishtrap recumbent anticline, biotite-muscovite metapelites and diopside-tremolite calc-silicate schists of the Belt Supergroup are estimated to record temperatures and pressures of 550–650 °C and ~2–4 kbar, suggesting middle- to lower-amphibolite-facies conditions (Flood, 1974; Wiswall, 1976). While no thermobarometric or timing constraints exist for these mineral assemblages, they developed synchronously with Fishtrap recumbent anticline-related fabrics (Flood, 1974; Wiswall, 1976). Relative to the Anaconda detachment (Fig. 3), amphibolite-facies metamorphism in the Anaconda metamorphic core complex footwall decreases in intensity from E to W, from uppermost-amphibolite facies in the Lake of the Isle shear zone to middle to lower amphibolite facies around the Fishtrap recumbent anticline. West of the Georgetown thrust, on the eastern edge of the Sapphire allochthon, strata of the Belt Supergroup have been metamorphosed

to greenschist facies (Lonn et al., 2003). Subsequent metamorphism associated with Late Cretaceous to Eocene plutons in the Anaconda metamorphic core complex is generally restricted to small contact aureoles and is estimated to have occurred at temperatures and pressures of ~550–700 °C and ~1–3 kbar (Wallace et al., 1992). These rocks are further overprinted by greenschist-facies mylonites of the Anaconda detachment.

Voluminous magmatism affected the Anaconda metamorphic core complex footwall during Late Cretaceous to Eocene time. Cretaceous magmatism was coincident with inboard migration of the Cordilleran magmatic arc into the retroarc fold-and-thrust belt, resulting in fault-controlled emplacement of notable SW Montana intrusive suites such as the Boulder and Pioneer Batholiths (Kalakay et al., 2001; Lageson et al., 2001). In the Flint Creek Range, this magmatism is represented by the granodioritic-monzogranitic Philipsburg Batholith, Mount Powell Batholith, and Royal Stock (Allen, 1966; Csejtey, 1968; Lonn et al., 2003; Elliott et al., 2013). U-Pb zircon ages calculated from the bimetallic stock and Dora Thorn pluton of the composite Philipsburg Batholith are 72.4 Ma and 69.48 Ma, respectively (Gray et al., 2022). The Philipsburg Batholith intrudes along a ramp on the Georgetown thrust, and based on paleomagnetic fabric data, the batholith's emplacement postdated movement on the fault (Naibert et al., 2010). U-Pb zircon ages calculated from two plutons of the composite Mount Powell Batholith are 64.5 Ma and 71.2 Ma, and the batholith is crosscut by Anaconda metamorphic core complex-related detachment faults (Elliott et al., 2013; Gray et al., 2022). A 66.4 Ma fission-track age exists for the Royal Stock (Baty, 1973).

Several Late Cretaceous to Eocene intrusive suites are exposed in the Anaconda Range. The nonfoliated, granodioritic Storm Lake Stock (Fig. 3), east of the Lake of the Isle shear zone, is 74.6 Ma based on U-Pb zircon geochronology (Grice et al., 2004; Kalakay et al., 2014). To the southwest, two-mica granites of the Pintler Creek Batholith have U-Pb zircon ages of 60.8 Ma and 62.7 Ma (Howlett et al., 2021). The Hearst Lake plutonic suite, consisting mostly of two-mica granite, granodiorite, and dacite throughout the Anaconda Range, is

ca. 53–50 Ma based on U-Pb geochronology (Foster et al., 2007; Neal et al., 2023). This suite was emplaced roughly coeval with the Eocene Lowland Creek volcanic field west of Butte, Montana, which was active from 52.9 Ma to 48.6 Ma (Dudás et al., 2010), and synchronous with calc-alkaline Kamloops-Absaroka-Challis magmatism. Currently, no geochemical data exist for Eocene intrusive rocks in the Anaconda Range, making correlation with the Lowland Creek volcanic field uncertain.

3. METHODS

We conducted geologic mapping in the study area at 1:24,000 scale using the StraboSpot 2 iPad app (<https://strabospot.org/>) to document meso-scale structural fabrics, determine relationships between fabrics, and determine overall structural style. Representative hand samples were collected from each lithology to assist with unit descriptions, and thin sections were obtained to assist with unit identification and determination of fabric relationships. Several samples were collected from crosscutting dikes and intrusions of the Hearst Lake plutonic suite for U-Pb geochronology, the results of which were reported in Neal et al. (2023). We used structural data collected in the field to construct an E-W-oriented cross section to illustrate our interpretation of structural style and kinematics. Map units presented in Figure 4 are described further in Figure S1.¹

4. RESULTS

4.1 Structural Geology

The study area is located mostly within the U.S. Geological Survey Carpp Ridge 7.5 min quadrangle (U.S. Geological Survey, 2020; Figs. 2 and 3), extending past the quadrangle's southern boundary (46.0°N) to the southern headwall of the

¹Supplemental Material. Figure S1: Detailed descriptions of map units presented in Figure 4. Please visit <https://doi.org/10.1130/GEOS.S.24053199> to access the supplemental material, and contact editing@geosociety.org with any questions.

Maloney Basin (Fig. 3). It hosts two distinct stratigraphic sections separated by the Late Cretaceous Georgetown thrust (Fig. 4). The Georgetown footwall section features upright, complexly deformed Mesoproterozoic Belt Supergroup–Paleozoic strata characteristic of the Anaconda metamorphic core complex footwall, while the hanging wall features an upright, lightly folded, greenschist-facies section of the Mesoproterozoic Piegan and Lemhi Groups (Fig. 4). Metamorphic grade in the footwall section increases from greenschist facies in the NW to lower to middle amphibolite facies in the SE, corresponding to deeper levels of exposure toward the Anaconda detachment. Phyllites of the Mesoproterozoic Mount Shields Formation located in Dexter Basin (Fig. 4) contain minor muscovite assemblages, and calc-silicates of the Mesoproterozoic Piegan Group in the extreme southeastern study area (Fig. 4) contain tremolite-diopside assemblages. This metamorphism is equivalent to Late Cretaceous high-temperature, low-pressure metamorphism documented to the south and east around the Fishtrap recumbent anticline and Lake of the Isle shear zone (Flood, 1974; Wiswall, 1976; Grice et al., 2004; Kalakay et al., 2014). The prior phase of high-pressure metamorphism was not recognized.

Four phases of deformation were identified in the study area: (1) thrusting along the Georgetown thrust; (2) development of S_1 transposition fabrics, bedding-subparallel faults and shear zones, and F_1 NW-vergent recumbent folds associated with the Fishtrap recumbent anticline; (3) development of an S_2 foliation and F_2 W-vergent folds associated with map-scale N-plunging folds; and (4) high-angle faults that cut across all previous structures (Fig. 4). High-angle faults are beyond the scope of this paper and will not be discussed further. Field evidence strongly suggested that S_1 transposition fabrics are axial planar to the NW-vergent Fishtrap recumbent anticline and that bedding-parallel faults and shear zones are associated with S_1 transposition fabrics.

4.1.1 Georgetown Thrust

The Late Cretaceous Georgetown thrust cuts up section from N to S, from Cambrian to

Mississippian strata (Fig. 4). In the southern part of the field area (coordinates: 46.0406°N, 113.4606°W), strata of the Mesoproterozoic Piegan Group are juxtaposed against the Mississippian Madison Group. Piegan Group strata within meters of the Georgetown thrust appear highly flattened and sheared, although the component of flattening related to thrusting versus subsequent deformation is unclear. At this locality, the fault dips 78°NW, exceeding the typical inclination of a thrust fault. Assuming that there are no underlying thrust ramps causing this rotation, the steepness of the Georgetown thrust is related to subsequent F_2 folding. Prior mapping to the east and north of the study area showed that the thrust is folded by the N-plunging F_2 Rock Creek anticline and east-adjacent Rock Creek syncline (Fig. 3; Emmons and Calkins, 1913; Poulter, 1956; Lidke and Wallace, 1992; Wallace et al., 1992; Lonn et al., 2003). Small, rootless isoclinal and bedding-parallel strain fabrics like those observed in the footwall were also observed in Piegan Group strata of the Georgetown hanging wall; however, their relationship to S_1 transposition fabrics and F_1 folding is unclear. Interactions between the Georgetown thrust and the Fishtrap recumbent anticline have never been observed, perhaps due to intervening plutons and glacial deposits, although it is reasonable to infer that it is folded by the Fishtrap recumbent anticline at depth based on its relationship with subsequent F_2 folding.

4.1.2 F_1 Folding

F_1 recumbent folds and axial planar S_1 transposition fabrics are well developed in mechanically incompetent, lower- to middle-amphibolite-facies metasediments of the Mesoproterozoic Piegan Group, Mesoproterozoic Snowslip Formation of the basal Missoula Group, and Cambrian Hasmark Formation in the southern study area (Figs. 5, 6C, 6D, and 6F). Typically, S_1 fabrics dip moderately NW, exhibit moderately WNW-plunging bedding-fabric intersection lineations, and occur at a <30° angle to bedding (Figs. 6A and 6B). Rare kinematic indicators suggest sinistral, top-to-the-NW-directed shear (Fig. 6). S_1 fabrics are subparallel to

map-scale bedding-parallel faults and shear zones, as well as axial planar to recumbent F_1 folds that were observed exclusively in the Mesoproterozoic Piegan Group, although they also occur in the Mesoproterozoic Ravalli Group and Prichard Formation just south of the study area (Flood, 1974; Wiswall, 1976). F_1 folds and axial planar fabrics are all associated with the Fishtrap recumbent anticline.

S_1 transposition fabrics and F_1 folding. S_1 fabrics are well developed in the Mesoproterozoic Piegan Group along the crest of the Anaconda Range in the southeastern study area (Figs. 5, 6C, and 6D). Strain partitioning is apparent throughout the unit; at some localities, bedding is lightly transposed, and at others, it has been completely transposed by S_1 . Three notable exposures on the southeastern ridgeline display a prominent strain gradient and help to elucidate the mechanisms of fabric development. At locality 1 (Fig. 5, coordinates: 46.0257°N, 113.3955°W), S_1 fabrics are weakly developed in rhythmically interbedded quartzite and calc-silicate schist. To the southeast, at locality 2 (Fig. 5, coordinates: 46.0194°N, 113.3978°W), series of NNW-vergent F_1 rootless isoclinal and boudinage interbedded quartzite and calc-silicate schist (Fig. 6C). These folds feature highly attenuated lower limbs that root into a prominent cataclastic zone displaying moderately developed S_1 fabrics. Further southeast, at locality 3 (Fig. 5, coordinates: 46.01827°N, 113.3989°W), calc-mylonites exhibit completely developed S_1 fabrics oriented 258/38° that have obliterated original bedding. Quartzite beds are severely attenuated and boudinaged while calc-mylonites are completely transposed.

Several other localities in the Mesoproterozoic Piegan Group of the southeastern study area further elucidate the general geometry and kinematics of S_1 fabrics. At locality 4 (Fig. 5, coordinates: 46.0285°N, 113.4014°W) in the Carpp Creek cirque, S_1 fabrics in calc-mylonites are typically oriented 212/50°. The angle between bedding and S_1 in this area is around 10°–20°, and average bedding- S_1 intersection lineations plunge 43° toward 277. A single sigma porphyroclast associated with S_1 showed apparent sinistral, top-to-the-NW kinematics (Fig. 6D); however, transport lineations are poorly developed.

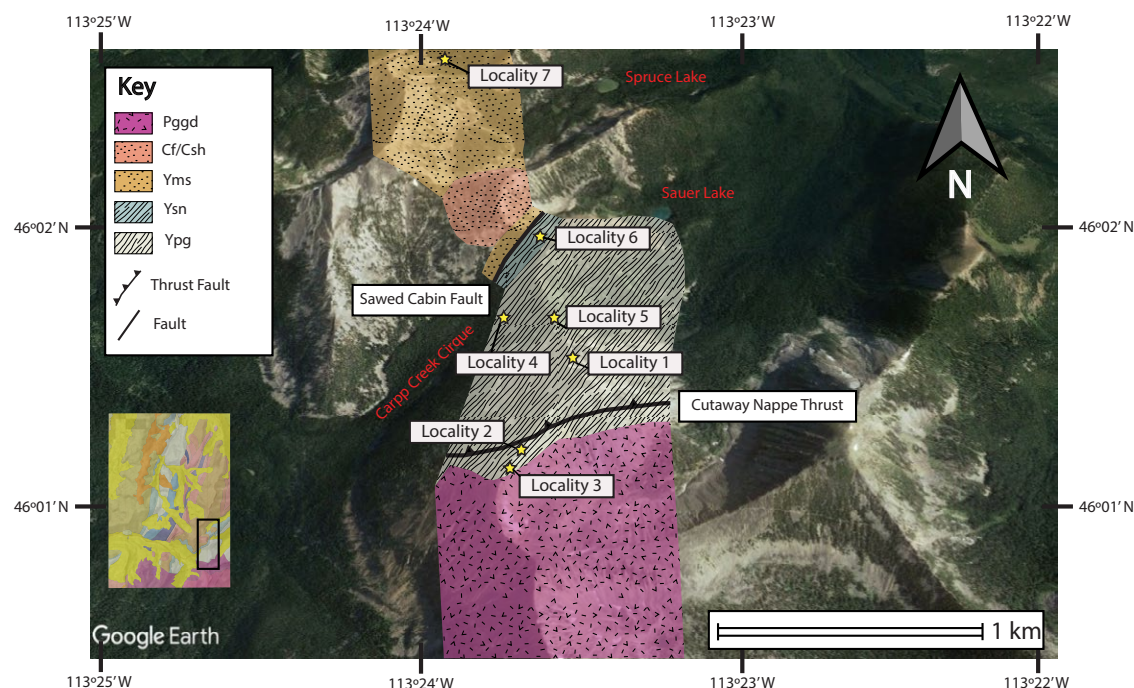


Figure 5. Strip map of the Anaconda Range in the southeastern field area showing S_1 localities discussed in text. See Figures 3 and 4 for unit abbreviations. Imagery sourced from Google Earth. Used with permission.

At locality 5 (Fig. 5, coordinates: 46.0286°N, 113.3971°W), the angle between bedding and S_1 in interbedded quartzites and calc-silicate schists is between 05° and 20°, and average bedding- S_1 intersection lineations plunge 34° toward 278. Examples of bedding-parallel boudinage and shortening are pervasive throughout interbedded quartzites and calc-silicate schists of this area.

S_1 fabrics were also observed in the Mesoproterozoic Snowslip and Mount Shields Formations in the southeastern and east-central study area, respectively. At locality 6 (Fig. 5, coordinates: 46.0317°N, 113.3967°W), just above its contact with the Mesoproterozoic Piegan Group, S_1 fabrics oriented 208/28° at a 28° angle to bedding were documented in phyllites of the Snowslip Formation. Calculated bedding- S_1 intersection lineations plunge 10° toward 009. The slight increase in angle between bedding and S_1 in the Mesoproterozoic Snowslip Formation compared to the Mesoproterozoic Piegan Group is likely related to rheological

differences between quartzofeldspathic-rich and carbonate-rich lithologies of the respective units. At locality 7 (Fig. 5, coordinates: 46.04703°N, 113.4064°W), S_1 fabrics in phyllites of the Mount Shields Formation are oriented 229/50°. Original bedding is indiscernible at this locality; however, phyllites appear to be moderately crenulated (Fig. 6E). On average, crenulation lineations plunge 24° toward 302 (Fig. 6E), subparallel to bedding- S_1 intersection lineations.

The S_1 fabrics were not abundantly observed in the Paleozoic section throughout the study area, perhaps due to most of the section being located at higher structural levels and lower metamorphic grades. At lower- to middle-amphibolite-facies conditions in the extreme southwestern portion of the study area (Fig. 4), calc-mylonites of the Cambrian Hasmark Formation exhibit considerable bedding-subparallel boudinage (Fig. 6F). While the orientations of structural fabrics were difficult to discern in these rocks, their proximity to

Mesoproterozoic Piegan Group strata pervasively deformed by S_1 strongly suggests that boudinage was related to development of the S_1 fabric.

At the southernmost edge of the study area, the hinge zone of the Fishtrap recumbent anticline is spectacularly exposed in the face of an unnamed peak east of Warren Peak (Figs. 7 and 8B). Here, the fold is cored by lower- to middle-amphibolite-facies calc-silicate schists and quartzites of the Mesoproterozoic Piegan Group. Series of parasitic S-folds on the upper limb of the Fishtrap recumbent anticline at this locality help to elucidate the axial planar relationship between S_1 and F_1 folding. The average attitude of S_1 axial planar fabrics is 200/20°, and hinge lines plunge 18° toward 236, subparallel to the calculated fold axis, which plunges 10° toward 231 (Fig. 8A). These folds exhibit a similar style of geometry with considerable hinge thickening and limb thinning. Unoriented thin sections of the Piegan Group from the hinge zone exhibit well-developed S_1 transposition fabrics defined

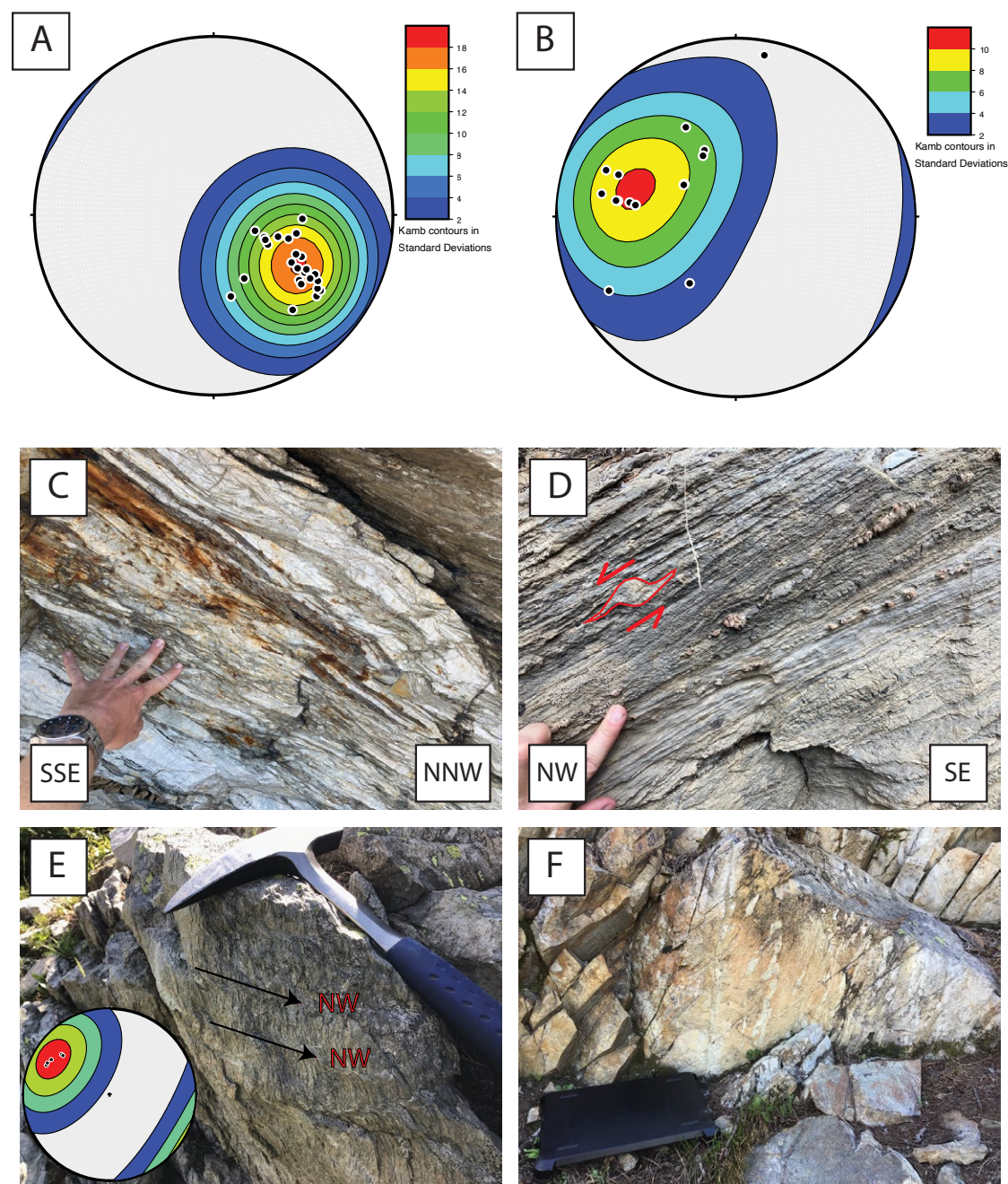


Figure 6. (A) Equal-area stereonet displaying predominantly NW-dipping S_1 transposition fabrics. (B) Equal-area stereonet displaying WNW-trending, moderately plunging bedding- S_1 intersection lineations. (C) NNW-verging F_1 rootless isocline in the Mesoproterozoic Piegan Group (locality 2, Fig. 5). The lower limb of the isocline is highly attenuated and underlain by a prominent cataclasite zone. (D) NW-directed sigma porphyroclast in highly boundinaged calc-mylonites of the Mesoproterozoic Piegan Group (locality 4, Fig. 5). (E) WNW-trending, shallowly plunging crenulation lineations subparallel to bedding- S_1 intersection lineations in phyllites of the Mesoproterozoic Mount Shields Formation (locality 7, Fig. 5). (F) Boudinage in the Cambrian Hasmark Formation in the southwestern study area, likely an expression of S_1 .

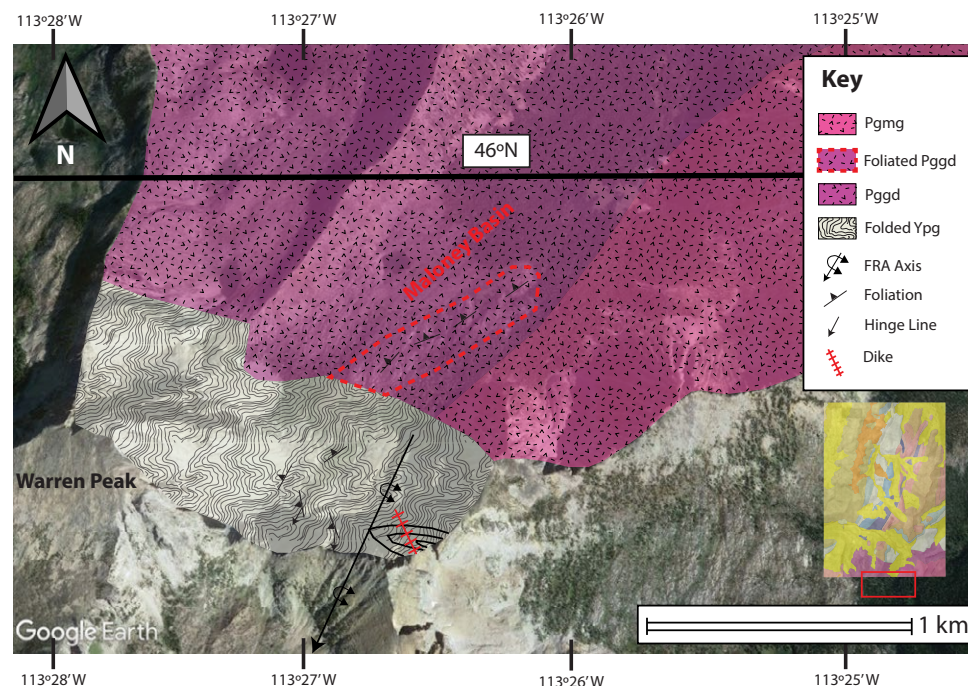


Figure 7. Simplified geologic map of the Maloney Basin south of the mapped study area depicting the F₁ Fishtrap recumbent anticline (FRA) hinge and SW-oriented fold axis. Dashed red line outlines approximate extent of foliated granodiorite. See Figures 3 and 4 for unit abbreviations. Imagery sourced from Google Earth. Used with permission.

by layers of fine-grained calcite that alternate with layers of aligned quartz grains displaying slight undulose extinction (Fig. 8C). While some of the calcite appears to have been dynamically recrystallized, it is difficult to discern due to the fine-grained nature of the original protolith. A tremolite sigma porphyroblast aligned with S_1 indicates that deformation and metamorphism were likely synchronous (Fig. 8C), consistent with previous observations in the area (Flood, 1974; Wiswall, 1976). Bedding at this locality is difficult to distinguish from S_1 transposition fabrics, but where it is distinguishable, the angle between bedding and S_1 is $\sim 50^\circ$, consistent with the structural position in the hinge of the Fishtrap recumbent anticline.

Interestingly, a 51.87 Ma biotite-hornblende granodiorite (Pggd in Fig. 4; Neal et al., 2023) intruding the Fishtrap recumbent anticline in the

southernmost study displays a weakly developed solid-state fabric subparallel to S_1 (Figs. 7, 8A, 8D, and 8E). It is subtle in outcrop, but where it is well exposed, it is defined by joint surfaces oriented $\sim 203/25^\circ$ (Figs. 7 and 8D). Aligned biotite and quartz porphyroclasts are discernible in outcrop; however, no shear sense indicators were apparent. The foliation is crosscut by a later set of steeply dipping joints. In thin section, these fabrics are clearly solid-state features and display prominent quartz phenocrysts surrounded by subgrains and “ribbon” biotite (Fig. 8D). Solid-state fabrics in the granodiorite are only present in the Fishtrap recumbent anticline hinge zone, and even in the hinge, they are weakly developed. Elsewhere in the study area, the granodiorite is nonfoliated.

Bedding-subparallel faults and shear zones. Two map-scale, bedding-subparallel faults and shear

zones were recognized in the study area: (1) the Cutaway nappe thrust and (2) the Sawed Cabin fault (Figs. 4 and 9). Both are localized in mechanically incompetent strata of the Mesoproterozoic Piegan Group and overlying basal Missoula Group in the southeastern study area, and both are subparallel to S_1 . While the Cutaway nappe thrust appears to thicken the Mesoproterozoic Piegan Group section, the Sawed Cabin fault clearly omits strata of the Mesoproterozoic Missoula Group. Both structures are folded around the hinge of the F₂ Rock Creek anticline in the southern field area (Fig. 4).

The Cutaway nappe thrust is prominently exposed in a cliff face best viewed from Cutaway Pass, just south of Sauer Lake (Figs. 4, 5, and 9A). Here, a subtle angular discontinuity is visible in bedding of the Mesoproterozoic Piegan Group (Fig. 9A). Above the discontinuity, bedding is oriented NE-SW, and below the discontinuity, it is oriented approximately E-W (Fig. 4). Due to precarious terrain, we were unable to investigate the fault surface; however, previous workers reported this feature to be highly strained and crenulated (Lidke and Wallace, 1992). Viewed from Cutaway Pass, bedding surfaces above the fault appear to fold and root into the fault, resembling a macroscopic, W-vergent drag fold (Fig. 9A). We refer to this fold as the F₁ Cutaway recumbent fold (Fig. 4). Similar bedding discordance observed at the type locality of the Cutaway nappe thrust at Cutaway Pass was also documented in the Mesoproterozoic Piegan Group on the western flank of the Maloney Basin in the extreme southern field area (Fig. 4), although the fault surface itself was not directly observed. While structural relations are obscured by intervening plutons and overlying glacial till, we infer that this bedding discordance represents a western extension of the Cutaway nappe thrust (Fig. 4), and that the structure is likely folded by the F₂ Rock Creek anticline.

The Sawed Cabin fault is a subtle bedding-parallel fault that follows the contact of the Mesoproterozoic Snowslip and Mount Shields Formations, both part of the basal Missoula Group. At its type locality along the crest of the Anaconda Range in the southern field area, just southeast of the Spruce Creek fault (Fig. 4), the fault has omitted

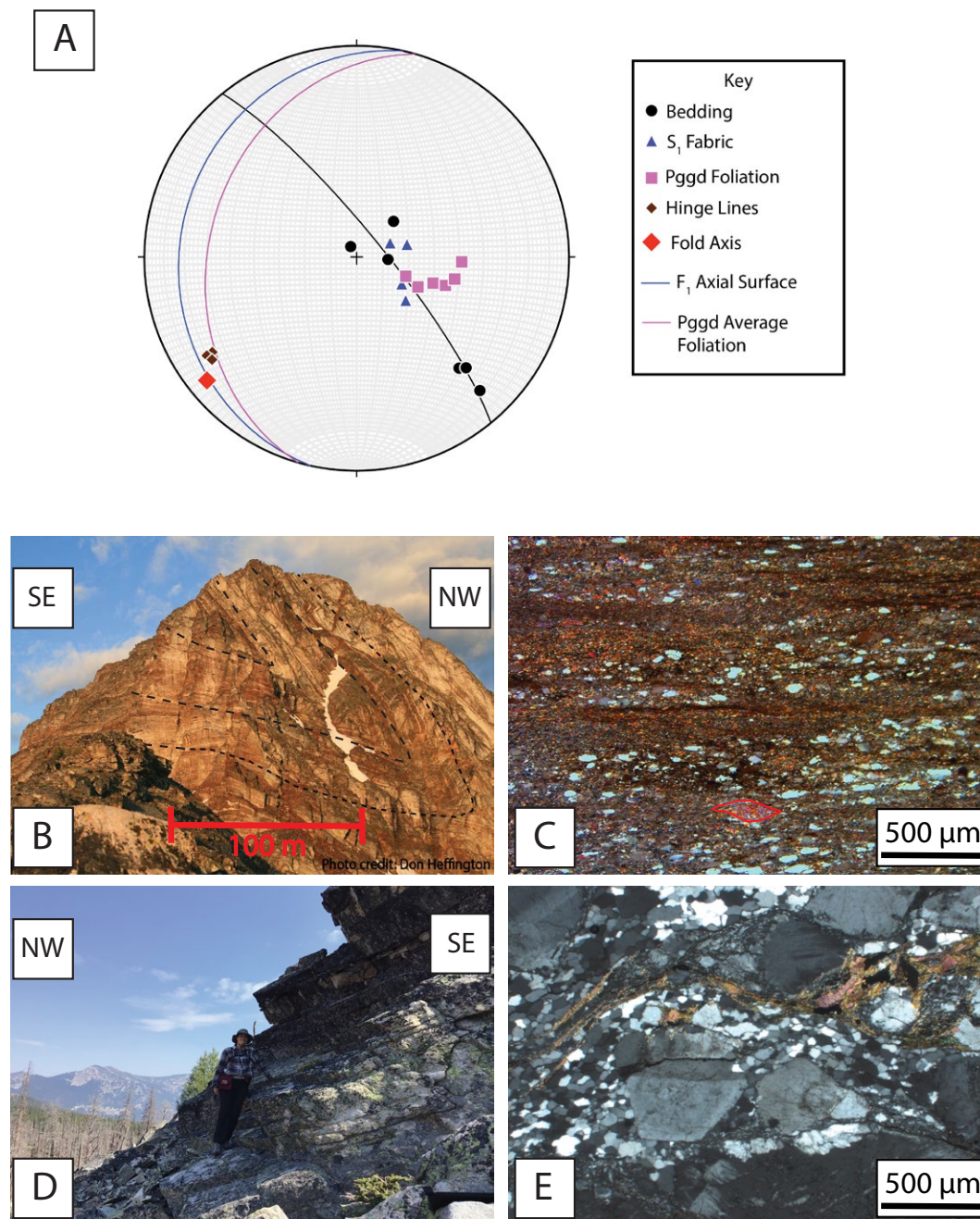


Figure 8. (A) Pi diagram showing data from parasitic S-folds in the F_1 Fishtrap recumbent anticline hinge. Fold axis plunges 10° toward 231. Hinge lines of smaller parasitic folds are subparallel to the calculated fold axis, and their axial surfaces are oriented $193/17^\circ$. Average foliation measured in the weakly foliated granodiorite (Pggd) is oriented $196/31^\circ$. See Figure 4 for unit abbreviations. (B) Hinge of the Fishtrap recumbent anticline in the Mesoproterozoic Piegan Group exposed on an unnamed peak southeast of Warren Peak (Figure 7). Photo credit: Don Heffington. (C) Thin-section photomicrograph of an unoriented, tremolite-bearing calc-mylonite from the Mesoproterozoic Piegan Group. Red-outlined tremolite sigma porphyroblast suggests metamorphism and development of S_1 fabrics were synchronous. (D) NW-dipping joint surfaces in granodiorite associated with weakly developed foliation subparallel to S_1 fabrics. (E) Thin-section photomicrograph of an unoriented granodiorite sample showing dynamically recrystallized quartz subgrains, quartz porphyroclasts, and "ribbon" biotite.

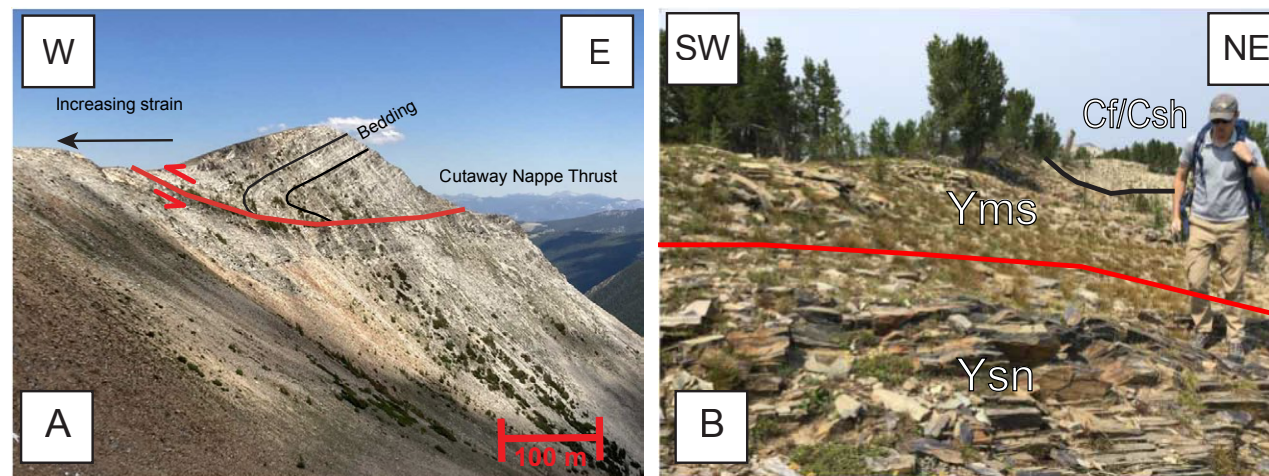


Figure 9. (A) Cutaway nappe thrust and associated F_1 Cutaway recumbent fold developed in the Mesoproterozoic Piegan Group on a cliff face in the south-eastern field area. Strata in the footwall of the structure are mylonitic, while strata in the hanging wall are moderately transposed. (B) Trace of the Sawed Cabin fault between the Mesoproterozoic Snowslip Formation (Ysn) and the Mesoproterozoic Mount Shields Formation (Yms), with the Cambrian Flathead and Silver Hill formations (Cf/Csh) in the background. The fault itself is not well-exposed at this locality; however, prominent shear zones were observed by Lidke and Wallace (1992) between the two units to the northeast around Spruce Lake (Figs. 4 and 5).

a considerable portion of the Mesoproterozoic Snowslip Formation and the entire overlying Mesoproterozoic Shepard Formation. Approximately 120 m above the base of the Snowslip Formation, maroon phyllites typical of the Snowslip Formation transition into quartzites typical of the Mount Shields Formation. The Sawed Cabin fault is not clearly exposed at this locality; however, due east in the cirque above Spruce Lake (Fig. 4), 1–10-m-thick shear zones are well developed in phyllites of the Snowslip Formation, and quartz veins in the overlying Mount Shields Formation terminate just above the fault (Lidke and Wallace, 1992). A type section of the Missoula Group in the John Long Mountains NW of the field area describes quartzites typical of the Mount Shields Formation occurring ~760 m above the base of the Snowslip Formation (Lonn and Lewis, 2009). Taking this into account, the basal Missoula Group in the study area has been thinned by ~85% along the Sawed Cabin fault. Map patterns indicate that the fault is folded by the F_2 Rock Creek anticline (Fig. 4).

4.1.3 F_2 Folding

Map-scale, N-plunging F_2 upright folds deform the entire section in the study area. Mesoscale F_2 folds with prominent axial planar S_2 foliation are well developed in greenschist-facies slates and phyllites of the Mesoproterozoic Mount Shields Formation and display prominent west-vergence. The F_2 folds and S_2 foliation deform F_1 rootless isoclinal and S_1 transposition fabrics in the Mesoproterozoic Piegan Group (Fig. 10C). The orientation of S_2 fabrics is predominantly controlled by their position on the map-scale F_2 Rock Creek anticline, with SE-dipping fabrics on the western limb and NW-dipping fabrics on the eastern limb (Figs. 4 and 10A). Bedding/ S_2 intersection lineations plunge shallowly to the NE and SW, consistent with Rock Creek anticline fold axis orientations (Fig. 10B), and fabrics occur at a 60°–80° angle to bedding.

S_2 foliation and F_2 folding. Relationships between S_1 and S_2 fabrics are well exposed in the hinge of the Fishtrap recumbent anticline.

Here, quartzite laminations in the Mesoproterozoic Piegan Group folded into F_1 rootless isoclinal and dismembered by S_1 have been subsequently modified by upright, mesoscale F_2 folds (Fig. 10C). Relationships between bedding, S_1 , and S_2 fabrics are also well exposed. At one notable locality in the Fishtrap recumbent anticline hinge, bedding in the Piegan Group is oriented 227/74°, S_1 is oriented 221/25°, and S_2 foliation is oriented 027/61°, crosscutting transposition fabrics. Due to this locality's structural position in the hinge of the Fishtrap recumbent anticline, S_1 occurs at an oblique angle to bedding. Bedding and S_1 define an intersection lineation plunging 03° toward 228, and bedding and S_2 define an intersection lineation plunging 22° toward 040. This is consistent with the orientation of macroscopic F_1 and F_2 fold axes from the Fishtrap recumbent anticline and Rock Creek anticline.

Relationships between S_2 fabrics and upright F_2 folds are most apparent in interbedded phyllites and quartzites of the Mesoproterozoic Mount Shields Formation along the rim of Dexter Basin

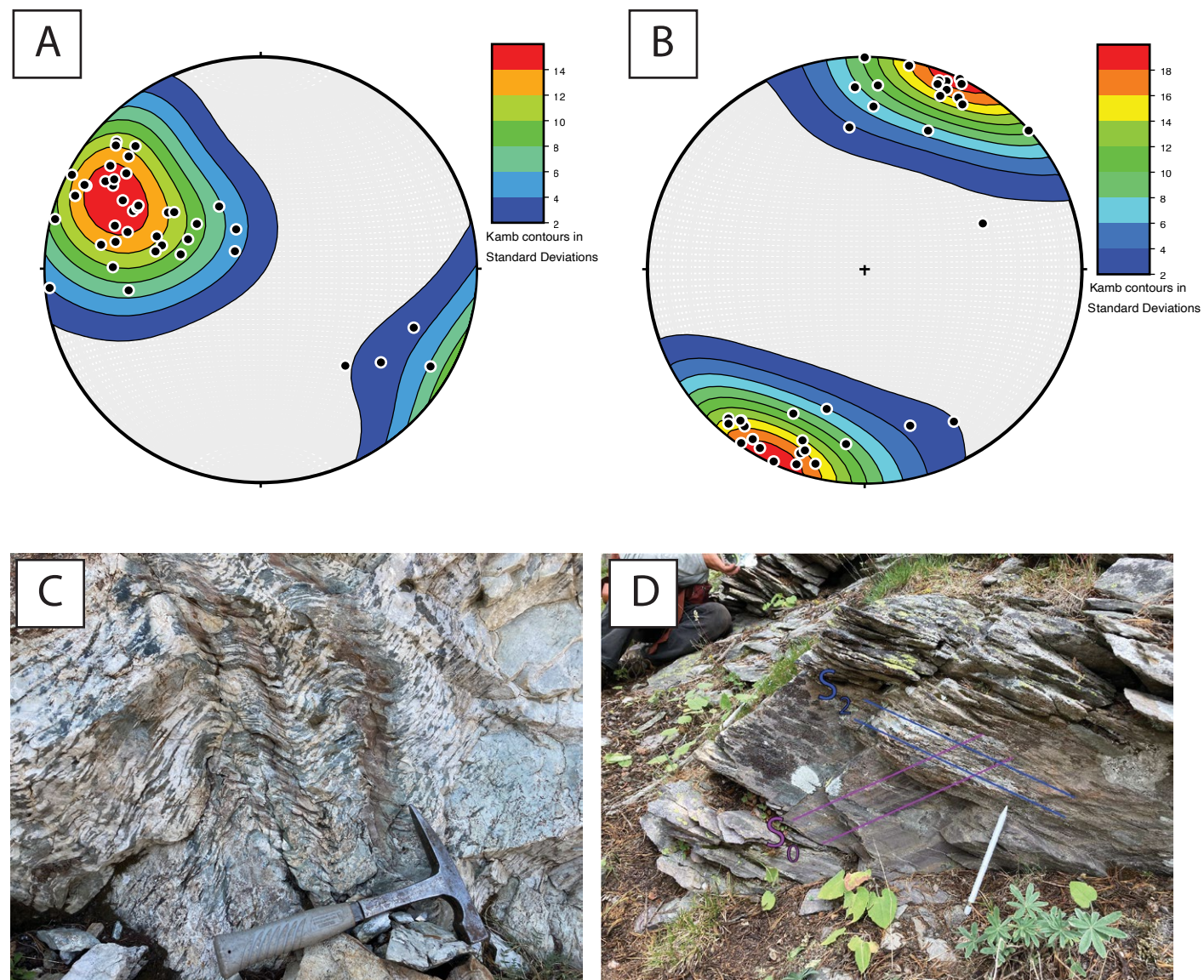


Figure 10. (A) Equal-area stereonet displaying predominantly SE-dipping S_2 foliation from the F_2 Rock Creek anticline. (B) Equal-area stereonet displaying gently plunging, NE- and SW-trending bedding- S_2 intersection lineations. (C) S_1 transposition fabrics and rootless isoclinal folds in the Mesoproterozoic Piegan Group refolded by upright F_2 folds. (D) Well-developed S_2 foliation in phyllites of the Mesoproterozoic Mount Shields Formation along the western limb of the Rock Creek anticline intersecting bedding (S_0) at a moderate angle.

(Fig. 11). An oblique transect across the hinge of the Rock Creek anticline in this area revealed a well-developed convergent foliation fan. On the western limb of the Rock Creek anticline, at locality 8 (Fig. 11, coordinates: 46.0598°N, 113.4030°W), S_2 is oriented 014/39° and intersects NW-dipping bedding at a high angle (Fig. 10D), suggesting that bedding is upright. The angle between bedding and S_2 is ~57°, and the bedding- S_2 intersection lineations plunge 007° toward 023. To the southeast, at locality 9 (Fig. 11, coordinates: 46.0592°N, 113.4013°W), S_2 is oriented 059/18°, and intersection lineations plunge 14° toward 003. The angle between bedding and S_2 is ~45°, and bedding dips more steeply than S_2 , suggesting that bedding is overturned. Further southeast, at locality 10 (Fig. 11, coordinates: 46.0585°N, 113.4004°W), slaty S_2 is nearly perpendicular to bedding at an angle of ~83°, coincident with the hinge of the Rock Creek anticline (Figs. 4 and 11). Intersection lineations

are horizontal and trend toward 205. East of the hinge, S_2 fabrics dip to the NW. At locality 11 (Fig. 11, coordinates: 46.0608°N, 113.3899°W), S_2 is oriented 210/80°, and the angle between bedding and S_2 is ~66°. Intersection lineations plunge 009° toward 017.

In the center of Dexter Basin, at locality 12 (Fig. 11, coordinates: 46.0481°N, 113.4053°W) on the western limb of the Rock Creek anticline, a pair of W-verging F_2 Z folds is well exposed in interbedded slates and quartzites of the Mesoproterozoic Mount Shields Formation (Fig. 12A). Ripple marks on their overturned limbs indicate both folds are anticlines. In contrast to similar F_1 folds in the Mesoproterozoic Piegan Group, folds in the Mount Shields Formation have a chevron-like geometry, likely due to rheological contrasts between the two lithologies and the folds' positions at lower metamorphic grades. On average, axial planar S_2 foliation is oriented 025/55°, and hinge lines plunge 06° toward 201, subparallel to hinge lines measured

in F_1 parasitic folds of the Fishtrap recumbent anticline (Fig. 12B). Axial planar fabrics are subparallel to the S_2 foliation observed along the western limb of Rock Creek anticline (Figs. 4 and 12B).

In the northern study area, steeply dipping S_2 foliation with an average orientation of 030/75° was observed in strata of the Mesoproterozoic Piegan Group in the hanging wall of the Georgetown thrust (Fig. 4). Angles between bedding and S_2 range between 50° and 70°, and bedding- S_2 intersection lineations plunge gently to the NE and SW. Strata here make up the eastern limb of a much broader F_2 fold, and the western limb is located just beyond the study area's western boundary. S_2 fabrics were not abundantly observed in the Paleozoic section throughout the study area, although a shallowly SE-dipping S_2 foliation was observed in slates of the Cambrian Silver Hill Formation of the southeastern study area in the core of a minor F_2 syncline (Fig. 4).

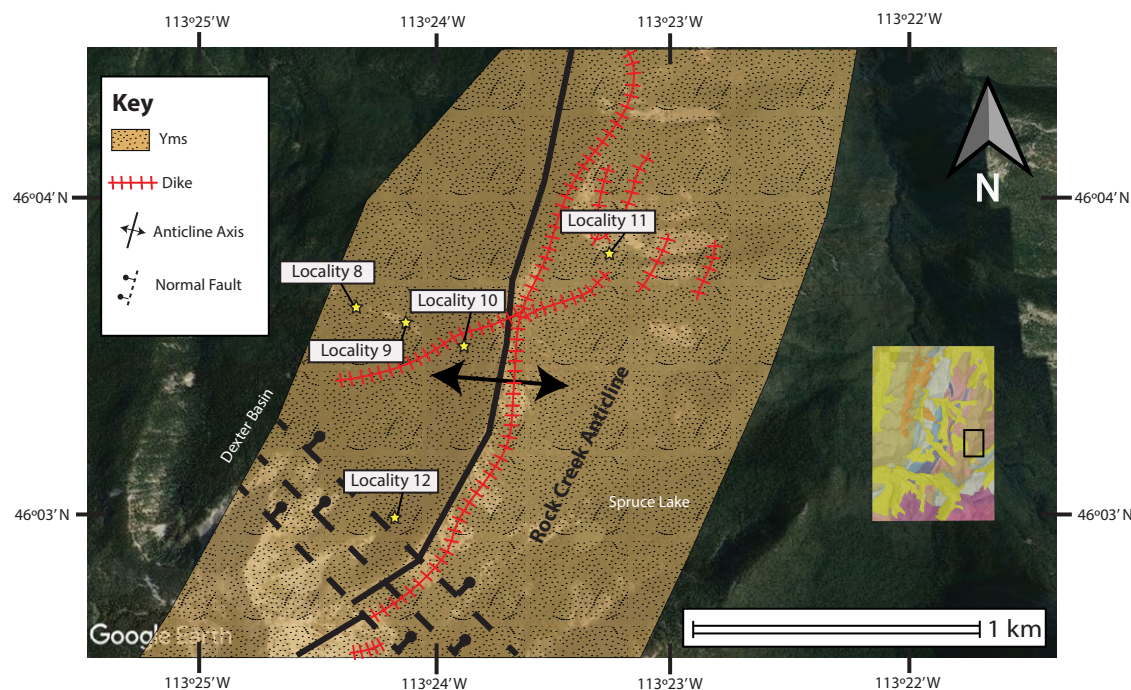


Figure 11. Strip map of the Dexter Basin and surrounding area showing S_2 localities discussed in text. See Figures 3 and 4 for unit abbreviations. Imagery sourced from Google Earth. Used with permission.

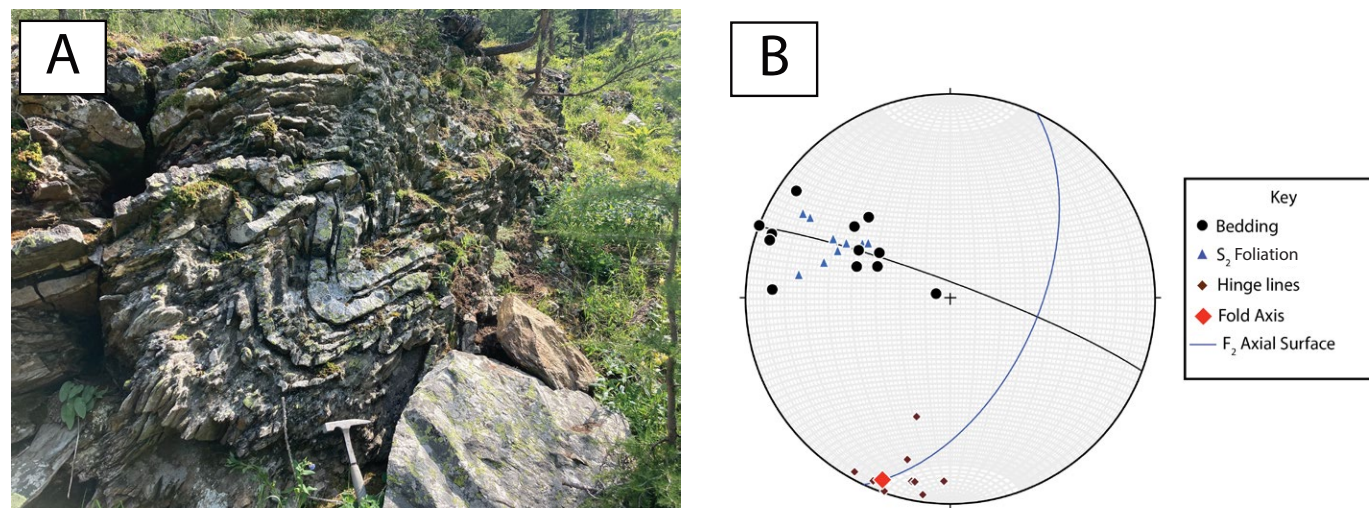


Figure 12. (A) W-verging F_2 fold in the Mesoproterozoic Mount Shields Formation on the western limb of the Rock Creek anticline. Photo facing WNW. (B) Pi diagram showing data from two F_2 folds in the Dexter Basin (Fig. 4). Fold axis plunges 06° toward 201° . Measured hinge lines are roughly concordant to the fold axis. Axial surface is oriented $025/55^\circ$.

5. DISCUSSION

5.1 Structural Synthesis

5.1.1 Geometry and Kinematics of F_1 and F_2 Folding

To illustrate the structural style and kinematics of F_1 and F_2 folding, an E-W-oriented cross section was constructed approximately perpendicular to the strike of major structural features in the study area (section A-A'; Figs. 4 and 13). Upright Mesoproterozoic Belt Supergroup through Paleozoic strata exposed in the study area are situated on the upper limb of the F_1 Fishtrap recumbent anticline (Fig. 13), which formed following burial by the overlying Sapphire allochthon along the Late Cretaceous Georgetown thrust. The west vergence of both F_1 and F_2 folding in the west-central Anaconda Range is anomalous in the predominantly E-vergent Cordilleran retroarc fold-and-thrust belt. At the deepest structural levels exposed in the study area, parasitic folds with shallowly SW-plunging hinge lines

(Fig. 8A) in the hinge of the F_1 Fishtrap recumbent anticline are clearly NW-vergent. At slightly higher structural levels to the north, along the crest of the Anaconda Range in the southeastern study area (Fig. 4), both measured and calculated bedding- S_1 intersection lineations plunge moderately to the WNW (Fig. 6B), roughly parallel to crenulation lineations measured in phyllites of the Mesoproterozoic Mount Shields Formation (Fig. 6E). While S_1 fabrics are, for the most part, not developed in this unit, we interpret these crenulations as related to the development of NW-dipping S_1 fabrics in mechanically incompetent Mount Shields phyllites. Further, F_1 rootless isoclines in the Mesoproterozoic Piegan Group verge to the NNW, as opposed to NW as in the Fishtrap recumbent anticline hinge. Collectively, these observations suggest that the orientation of the Fishtrap recumbent anticline fold axis changes from SW trending in the southernmost study area to WNW trending to the north, resulting in a slight vergence shift likely related to changes in the map pattern (Fig. 4). In the Fishtrap recumbent anticline hinge, stratigraphic contacts

are oriented roughly NNE-SSW, parallel to F_1 fold axes, while to the north along the crest of the Anaconda Range, they are oriented NE-SW (Fig. 4).

We were unable to locate the hinge of the Fishtrap recumbent anticline in the study area besides where it is exposed near Warren Peak (Figs. 4 and 7), likely due to its position at deeper structural levels than those exposed in most of the study area. Previous workers have mapped the Fishtrap recumbent anticline hinge directly south of Warren Peak to McGlaughlin Peak and Rainbow Lake (Fig. 3), where another notable hinge exposure exists, and into the Fishtrap Creek drainage where it disappears beneath Quaternary sediments (Fig. 3; Flood, 1974; Wiswall, 1976; Wallace et al., 1992). Subsequent work to the southeast on West Goat Peak and Long Peak (Fig. 3) has revealed S_1 transposition fabrics refolded by F_2 folds in overturned strata of the Mesoproterozoic Prichard Formation and Mesoproterozoic Ravalli Group on the lower limb of the Fishtrap recumbent anticline (C. Elliott and J. Lonn, personal commun., 2022). At these localities, the axial surface of the Fishtrap recumbent anticline

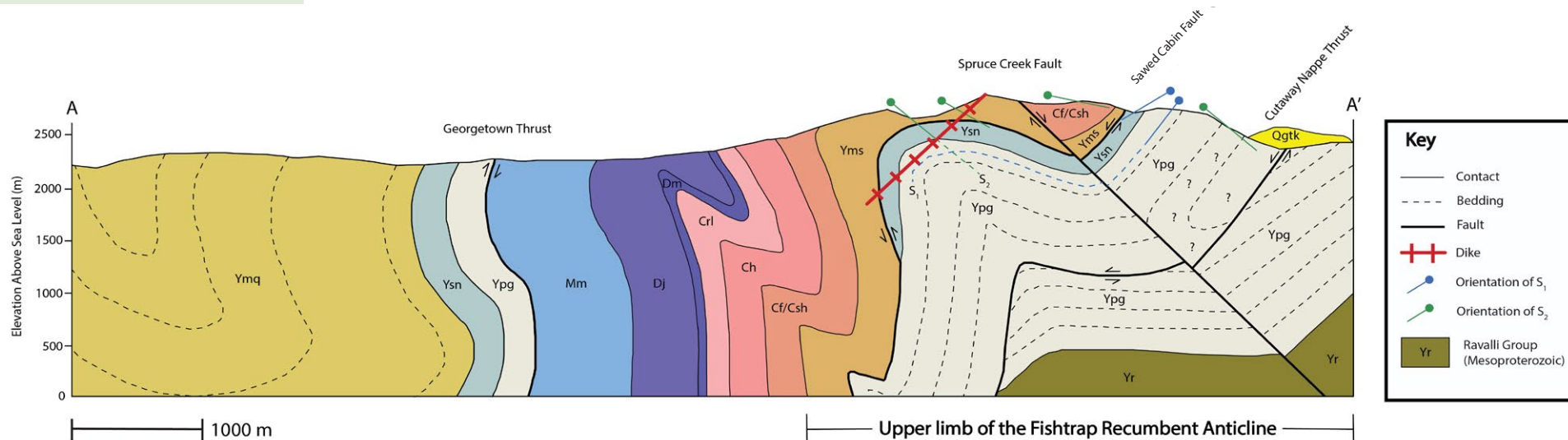


Figure 13. Cross section along line A-A' in Figure 4, showing the upper limb of the F_1 Fishtrap recumbent anticline. F_2 upright folds control regional structure at this scale. The entire structure is not depicted on this section due to its scale, but Piegan and Ravalli strata in the Rock Creek anticline likely core it at depth. Question-marked area in the Piegan Group above the Cutaway nappe thrust represents the geometry of the F_1 Cutaway recumbent fold. No vertical exaggeration. See Figures 3 and 4 for unit abbreviations.

is subhorizontal to shallowly E-dipping (C. Elliott and J. Lonn, personal commun., 2022). Taking all of this into account, the Fishtrap recumbent anticline is clearly a regional-scale structure involving the entire Belt Supergroup exposed in the Anaconda Range.

The W-vergent F_2 folding is largely coaxial with F_1 . F_2 upright folds modify F_1 folds, S_1 transposition fabrics, and the Georgetown thrust (Figs. 3 and 13). We interpret the F_2 Rock Creek anticline as an asymmetric W-vergent fold based on parasitic folds in the Mesoproterozoic Mount Shields Formation (Fig. 12A). While we use the terms F_1 and F_2 to distinguish between recumbent and upright folding in the study area, their common west-vergence and coaxiality suggest that both types of folding were the result of the same stress field and represent a continuum of deformation rather than two discrete deformation events. Given the Rock Creek anticline's increased amplitude toward lower structural levels and the regional scale of the Fishtrap recumbent anticline (Fig. 3), we envision

that F_2 folds developed as parasitic folds along the Fishtrap recumbent anticline's upper limb (Figs. 13 and 14). Overall, we suggest that the entire study area experienced an initial episode of typical E-vergent, foreland-directed kinematics along the Georgetown thrust followed by an episode of W-vergent, hinterland-directed kinematics, which was accompanied by structural thickening and associated regional metamorphism.

Previous workers in the region attempted to reconcile W-vergent folding with E-vergent tectonics by (1) explaining the Fishtrap recumbent anticline as a predominantly E-vergent structure displaying W-vergent kinematics due to its ductile rheology and (2) linking F_2 W-vergent folding to a series of minor, listric thrust faults, which they referred to as imbricate thrusts (section B-B', Lidke and Wallace, 1992; section C-C', Wallace et al., 1992). Wallace et al. (1992) linked the Fishtrap recumbent anticline to E-directed movement up a blind, late-formed, W-dipping ramp below a series of stacked thrust sheets. Due to the high ductility of Mesoproterozoic

Belt Supergroup strata in the area, they speculated that rocks below the ramp lost their ability to transmit stress to rocks above the ramp, which was accommodated by W-vergent ductile shortening and the development of the Fishtrap recumbent anticline (section C-C', Wallace et al., 1992). We disagree with this interpretation and posit that the thrust sheets observed by these workers do not exist, and their interpretations produce overly complicated, younger-over-older thrust relations. Further, their model is based on stratigraphic mis-correlation of the Mesoproterozoic Ravalli Group, which they mapped as the Mesoproterozoic Mount Shields Formation, in thrust-contact below the older Mesoproterozoic Piegan Group. Subsequent mapping has revealed their Mount Shields Formation to be the Mesoproterozoic Ravalli Group in normal stratigraphic position below the Piegan Group, although the contact between the two is strained and characterized by bedding-parallel shear zones (Lonn et al., 2003; Lonn and McDonald, 2004). In their interpretation of F_2 upright folding, Lidke and

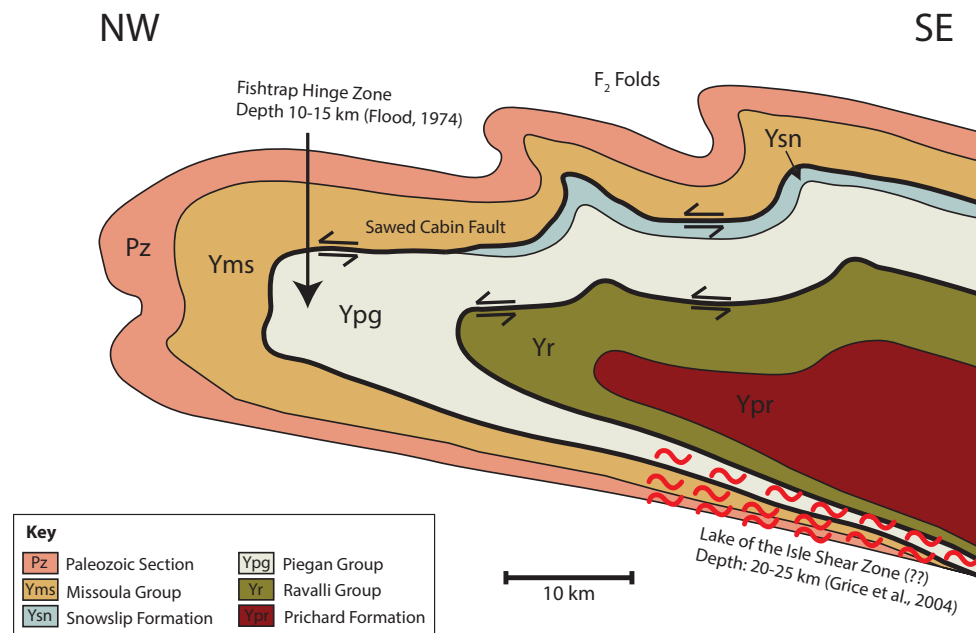


Figure 14. Conceptual diagram illustrating relationships between major structures discussed in text. We conceive of the F_1 Fishtrap recumbent anticline as a kilometer-scale structure cored by the Mesoproterozoic Prichard Formation and involving the entire Mesoproterozoic Belt Supergroup exposed in the Anaconda metamorphic core complex footwall. Map-scale bedding-parallel faults and shear zones originally interpreted as out-of-sequence thrusts by Lidke and Wallace (1992) and detachments by Lonon et al. (2003) are reinterpreted as larger-scale expressions of axial planar S_1 fabrics. These features likely accommodated ductile flow and extension of the mechanically incompetent Mesoproterozoic Piegan Group along the limbs of the Fishtrap recumbent anticline. F_2 folds are coaxial with the Fishtrap recumbent anticline and may represent parasitic folds superimposed on its upper limb. We further interpret the Lake of the Isle shear zone as the “blind” thrust at the base of the Fishtrap recumbent anticline due to extreme attenuation observed by Grice et al. (2004) and its position at the deepest structural level in the Anaconda metamorphic core complex footwall. Horizontal scale is approximate and derived from the modern distance between the Fishtrap recumbent anticline hinge and the Lake of the Isle shear zone. Not drawn to scale.

Wallace (1992) and Wallace et al. (1992) suggested that W-vergent folds in the study area formed along series of E-directed, listric imbricate thrusts (Fig. 7; Lidke and Wallace, 1992). Originally E-vergent folds were rotated counterclockwise along these imbricate thrusts and overturned, displaying apparently W-vergent kinematics. We did not observe these structures in the map area, although they do exist and are characterized by poorly exposed zones of breccia and gouge. We disagree with this interpretation, however, because shear-sense indicators and mesoscale F_2 folds in the study area show

clear evidence of W-directed kinematics that do not appear to have been altered by subsequent deformation that would have produced an apparent vergence direction.

5.1.2 Relationships among the Fishtrap Recumbent Anticline, Bedding-Parallel Faults, and Tectonic Attenuation

S_1 transposition fabrics axial planar to the Fishtrap recumbent anticline in the Mesoproterozoic

Piegan Group and Snowslip Formation are sub-parallel to the bedding-parallel Sawed Cabin fault and Cutaway nappe thrust. Because of this, we interpret bedding-parallel faults and shear zones in the Anaconda Range as larger-scale expressions of S_1 transposition fabrics. Tectonic attenuation of the Mesoproterozoic Belt Supergroup section in the study area is localized in carbonate-bearing lithologies of the Mesoproterozoic Piegan Group and basal Missoula Group, including the Mesoproterozoic Snowslip and Shepard Formations, which have been mostly or completely omitted by the Sawed Cabin fault. This is likely due to the unique rheology of carbonate rocks, which are able to accumulate large amounts of strain and deform plastically at low pressure-temperature conditions (Bestmann et al., 2000). While metamorphic grade in the study area did not exceed lower to middle amphibolite facies, calcite exhibits crystal-plastic behavior at $\sim 180^\circ\text{C}$ (Burkhard, 1990), explaining the pervasive nature of ductile deformation in carbonate-bearing lithologies. Strain accumulation in carbonate-bearing strata of the Piegan Group and basal Missoula Group was likely enhanced by their position between quartzites of the overlying Mesoproterozoic Mount Shields Formation and underlying Mesoproterozoic Ravalli Group. Interestingly, bedding-parallel faults and shear zones in the Anaconda Range are localized at rheological interfaces between mechanically incompetent carbonate-rich and more competent quartzofeldspathic strata of the Belt Supergroup. South of the study area, the contact between the Piegan and Ravalli Group is a prominent shear zone similar to the Sawed Cabin fault (Fig. 3; Lonon and McDonald, 2004). Furthermore, south of Warren Peak, the Snowslip Formation is completely omitted by the Sawed Cabin fault, and we depict this relationship on our A-A' section at depth (Fig. 13). Combined with demonstrated axial planar relationships between S_1 transposition fabrics and F_1 folding, these observations strongly suggest that extension on the upper limb of the Fishtrap recumbent anticline both attenuated and completely sheared out incompetent strata of the Belt Supergroup, and that bedding-parallel faults like the Sawed Cabin fault formed during development of the Fishtrap

recumbent anticline (Fig. 14). Because of this association, as well as W-vergent kinematic indicators in strata adjacent to the fault, we interpret the Sawed Cabin fault as a sinistral, top-to-the-W structure on our A-A' section (Fig. 13).

Both the Sawed Cabin fault and the strained contact between the Mesoproterozoic Piegan Group and Ravalli Group may be analogous to stretching faults proposed by Means (1989), which are hypothesized to occur in the limbs of tight folds where bedding transposition has occurred, among other structural settings. Mechanically, stretching faults are characterized by active slip along the fault surface accompanied by lengthening of wall-rock blocks in the slip direction. NW-directed kinematic indicators in the Mesoproterozoic Piegan Group demonstrate bedding-parallel extension in the direction of sinistral slip along the Sawed Cabin fault. Strata of the overlying Mount Shields Formation, however, likely shortened or remained relatively rigid during slip along the Sawed Cabin fault, perhaps qualifying this structure as a mixed or half-stretching fault (Means, 1989). The strained contact between the Piegan and Ravalli Groups may represent a similar case. Regardless of how these structures are classified, they clearly accommodated ductile flow of mechanically incompetent carbonate-bearing Mesoproterozoic Belt Supergroup strata in the upper limb of the Fishtrap recumbent anticline. We further posit that our interpretation of bedding-parallel faults and shear zones more succinctly satisfies the Occam's razor principle and reduces complexity more so than previous interpretations (e.g., Lidke and Wallace, 1992; Lonn et al., 2003), basing itself on simple fabric relationships, rheological observations, and self-similarity of structures at all scales.

Due to precarious terrain at its type locality, our interpretation of the Cutaway nappe thrust and associated Cutaway recumbent fold is limited at best. Due to the Cutaway nappe thrust's rough parallelism with the S_1 fabric and apparently folded bedding observed in the Cutaway recumbent fold, we infer that, at the very least, these structures were related to development of the Fishtrap recumbent anticline. Previous mapping demonstrated that the Cutaway nappe thrust is folded by an F_2

fold just east of the study area (Lidke and Wallace, 1992), and our mapping suggests that it is folded by the Rock Creek anticline in the southern field area (Fig. 4). Clearly, these structures predate F_2 folding. Further, at the outcrop scale, F_1 rootless isoclines exhibit small shear zones on their attenuated overturned limbs (Fig. 6C). Given the self-similarity of structures at all scales in the study area, we feel it reasonable to interpret the geometry of the Cutaway nappe thrust and Cutaway recumbent fold as a drag fold similar to the rootless isoclines observed in outcrop. Regardless, while the Cutaway nappe thrust is clearly a real feature, the existence of the Cutaway recumbent fold is questionable due to lack of data. It is quite possible that bedding discordance above and below the Cutaway nappe thrust may be better explained as a hanging-wall ramp/footwall flat relationship, and that this thrust represents a smaller feature perhaps related to the Georgetown thrust.

Stratal attenuation along the limbs of large, similar-style recumbent folds is not uncommon in the footwalls of Cordilleran metamorphic core complexes. In the footwall of the Ruby Mountains–East Humboldt metamorphic core complex of eastern Nevada, the S-verging Winchell Lake nappe attenuated Neoproterozoic–Mississippian sedimentary strata from an original thickness of ~8 km to only a few hundred meters (McGrew et al., 2000; Colgan et al., 2010; Henry et al., 2011; Long and Kohn, 2020). Further, the E-verging O'Neill Peak recumbent syncline in the footwall of the northern Snake Range metamorphic core complex of eastern Nevada attenuated Eocambrian strata along its limbs (Wrobel et al., 2021). Clearly, regional-scale recumbent folds that attenuate section and exhibit both typical and anomalous vergence are key structural elements of the Cordilleran hinterland region.

5.1.3 Relationship between the Fishtrap Recumbent Anticline and the Lake of the Isle Shear Zone

While far more detailed mapping is needed to truly discern the relationship between the Fishtrap recumbent anticline and other significant

structures in the Anaconda Range, our reinterpretation of bedding-parallel faults in terms of F_1 folding has implications outside of the study area. Bedding-parallel faults and shear zones between the basal Mesoproterozoic Missoula Group and Mount Shields Formation as well as the Mesoproterozoic Piegan and Ravalli Groups have been mapped northeast of the study area (Fig. 3; Lidke and Wallace, 1992; Wallace et al., 1992; Lonn et al., 2003), suggesting that the Fishtrap recumbent anticline extends to the east, although the hinge of the fold has never been documented in the eastern Anaconda Range. The overall map pattern in this region, consisting of a NE-SW-oriented homocline involving the Mesoproterozoic Prichard Formation, Ravalli Group, Piegan Group, and Missoula Group (Fig. 3), however, may reflect the overall geometry of the Fishtrap recumbent anticline, making it a kilometer-scale, perhaps crustal-scale, structure. The strained Piegan-Ravalli Group contact extends into uppermost-amphibolite-facies rocks of the Lake of the Isle shear zone, where it is truncated by the Late Cretaceous Storm Lake Stock, obscuring relations with severely attenuated migmatitic rocks to the east. The contact is subparallel to the metamorphic foliation related to the Lake of the Isle shear zone (Grice et al., 2004), suggesting a linkage between the Fishtrap recumbent anticline and the Lake of the Isle shear zone. Interestingly, Grice et al. (2004) interpreted the Lake of the Isle shear zone as a fault that cuts up section to the west. From E to W, progressively younger Mesoproterozoic Belt Supergroup units in the shear zone are juxtaposed against the Middle Cambrian section, indicating that offset between Belt Supergroup and Middle Cambrian units decreases to the west (Appendix F of Grice, 2006). Combining this interpretation with the severe amount of attenuation, uppermost-amphibolite-facies metamorphic conditions, and migmatization at the structurally deepest levels of exposure in the Anaconda metamorphic core complex footwall, we interpret the Lake of the Isle shear zone as a "blind" thrust at the base of the Fishtrap recumbent anticline, analogous to the classic Alpine-style nappes observed in Europe (Fig. 14). If the Lake of the Isle shear zone really is a fault that cuts up section to the west, then it is roughly

compatible with the W-vergent kinematics of the Fishtrap recumbent anticline.

5.2 Chronology of Deformation

Previous geochronologic work suggested that most deformation in the study area took place before the onset of extension in the Anaconda metamorphic core complex ca. 53 Ma (Foster et al., 2010; Neal et al., 2023). New relationships elucidated in this study combined with previous geochronologic studies in the region provide a rough chronology of deformation in the Anaconda metamorphic core complex footwall. Development of the Late Cretaceous Georgetown thrust is constrained by magnetic fabric data, as well as 75 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ and 70 Ma U-Pb ages from the Philipsburg Batholith (Naibert et al., 2010; Gray et al., 2022), which intrudes the Georgetown thrust in the Flint Creek Range (Fig. 3). While the batholith was likely emplaced along the thrust plane in the core of a fault-bend fold, magnetic fabrics strongly suggest that no internal deformation related to the Georgetown thrust occurred in the Philipsburg Batholith (Naibert et al., 2010). Taking this into account, thin-skinned thrusting along the Georgetown thrust ceased as early as 75 Ma; however, paleomagnetic data from the batholith do record significant clockwise rotation of the Sapphire allochthon and east-adjacent Lombard thrust sheet (Fig. 2; Naibert et al., 2010; Gray et al., 2022). While the thrust itself was clearly emplaced prior to emplacement of the Philipsburg Batholith, individual thrust sheets were still active at 70 Ma and may have been active as early as ca. 94 Ma and as late as ca. 64 Ma (Gray et al., 2022).

In the eastern Anaconda Range, the strained contact between the Mesoproterozoic Piegan Group and Ravalli Group is crosscut by the 74.6 Ma Storm Lake Stock (Grice et al., 2004; Kalakay et al., 2014), suggesting that the Fishtrap recumbent anticline and structures related to it formed before emplacement of the stock. Given that the Georgetown thrust must have formed as early as 75 Ma and that the Philipsburg Batholith is unaffected by subsequent folding, we posit that the development

of F_1 and F_2 folding began ≥ 75 Ma and largely ceased by 74.6 Ma. Further, if the Lake of the Isle shear zone really is the “blind” thrust at the base of the Fishtrap recumbent anticline, then existing time constraints for the shear zone suggest that this part of the structure was active between ca. 75 Ma and 74.6 Ma, based on dates from a foliated sill and the crosscutting Storm Lake Stock (Grice et al., 2004). Weakly developed solid-state fabrics sub-parallel to S_1 observed in a 51.87 Ma granodiorite stock (Neal et al., 2023) suggest minor reactivation of the Fishtrap recumbent anticline hinge during the onset of Anaconda metamorphic core complex extension, although this deformation is only locally developed. Solid-state fabrics are roughly perpendicular to the NE-SW-oriented Anaconda detachment, suggesting minor contraction perpendicular to extension.

5.3 Tectonic Implications

The anomalous W-vergent deformation described in this study was synchronous with incursion of the Cordilleran magmatic arc into the Helena salient. East of the Anaconda metamorphic core complex, the ramp-top emplacement of the ca. 76 Ma (Lund et al., 2002), ~12–18-km-thick Boulder Batholith (Vejmelek and Smithson, 1995; Burton et al., 1998; Berger et al., 2011; Lageson et al., 2020) and other Late Cretaceous intrusive suites combined with the synchronous development of upper-crustal thrust sheets and basement-cored “Laramide” uplifts to create a structural-magmatic culmination within the Helena salient, dilating the upper crust by as much as 15–20 km (Lageson et al., 2001). This resulted in the development of a high-elevation, tectono-magmatic hinterland plateau region (“Montanapiano” of Lageson et al., 2020) analogous and likely connected to the “Nevadapiano” of DeCelles (2004). The subsequent development of the Anaconda and Bitterroot core complexes is further testament to enhanced crustal thicknesses in this region, and paleoaltimetry work from NW Montana suggests the Cordilleran orogenic front may have been underlain by ~55-km-thick crust prior to Eocene gravitational collapse

(Fan et al., 2017). The Anaconda metamorphic core complex footwall, therefore, provides a window into a unique region of the Cordilleran hinterland that intersected with the retroarc fold-and-thrust belt and magmatic arc. Development of the Fishtrap recumbent anticline both spatially and temporally coincided with the emplacement of Late Cretaceous batholiths and their associated volcanic carapaces, as well as the development of upper-crustal thrust sheets and deep-seated, basement-cored uplifts in the Helena salient.

W-vergent tectonic regimes are atypical throughout the North American Cordillera; however, notable exceptions exist. In the Selkirk Mountains of British Columbia, a prominent doubly vergent structure known as the Selkirk fan features SW-vergent, hinterland-directed folds that transition to NE-vergent, foreland-directed folds (Gibson et al., 2008). This zone of structural divergence initially formed during Middle to Late Jurassic obduction of the Quesnellia arc and closure of the Slide Mountain Ocean basin, resulting in the development of kilometer-scale, SW-vergent fold nappes similar in character to the Fishtrap recumbent anticline on the western flank (“prowedge”) of the fan and NE-vergent structures on the eastern flank (“retrowedge”; Gibson et al., 2008). While we posit that the footwall of the Anaconda metamorphic core complex is underlain by the kilometer-scale, W-verging Fishtrap recumbent anticline, an E-vergent thrust nappe referred to as the Mill Creek Nappe (Fig. 3) exists in high-grade, uppermost-amphibolite-facies rocks of the eastern footwall. While its relationship to the Fishtrap recumbent anticline has never been investigated, it is compelling to envision the Fishtrap recumbent anticline and Mill Creek nappe as parts of a larger structural fan similar to that observed in the Selkirk Mountains. Double vergence in this segment of the Canadian Cordillera has been explained in terms of the relative convergence of subducting oceanic lithosphere and overlying continental lithosphere (Willett et al., 1993). In the interpretation of Gibson et al. (2008), the apex of the Selkirk fan is situated above a singularity representing the point where oceanic or marginal basin lithosphere was subducted beneath continental lithosphere. Given

its position ~200 km inboard of the accretionary boundary, approximately demarcated by the Sr 0.706 isopleth and the Western Idaho suture zone (Fig. 2), it is compelling to envision the Fishtrap recumbent anticline and Mill Creek nappe as the result of a similar process. Inboard migration of the Cordilleran magmatic arc into the Helena salient is further evidence to suggest that a similar singularity may have been positioned beneath the Montana Cordillera during Late Cretaceous time, and that relative convergence of the subducting Farallon plate and overlying North American plate may have created a doubly vergent structural fan represented by the Fishtrap recumbent anticline and Mill Creek nappe.

While the structural fan model is compelling, it is complicated by the Anaconda Range's position at the intersection of the Cordilleran hinterland, magmatic arc, and retroarc fold-and-thrust belt. The Selkirk fan is a distinct element of the Cordilleran hinterland that represents a zone of transition between deformation along the accretionary boundary to the west and the fold-and-thrust belt to the east. West-vergent folds in the Anaconda metamorphic core complex footwall, however, refold the Late Cretaceous Georgetown thrust, disrupting structures of the fold-and-thrust belt. Therefore, the Fishtrap recumbent anticline may not represent a zone of structural transition as observed in the Selkirk Mountains, and instead it likely represents a disruption of the foreland-propagating Helena salient. Interestingly, recent work in the northern U.S. Cordillera has elucidated a considerable rotational component of deformation in the Helena salient related to terrane accretion along the western North American margin, which was both synchronous with and postdated emplacement of the Georgetown thrust (Gray et al., 2022). Accretion, tectonic wedging, and clockwise rotation of the Blue Mountains Province (Vallier et al., 1977; Silberling et al., 1987) of northeast Oregon, western Idaho, and southeastern Washington occurred synchronous with 94–64 Ma thrusting and clockwise rotation of thrust plates in the Helena salient (Gray et al., 2019, 2022). Rotation from the accretionary margin to the retroarc fold-and-thrust belt was facilitated by sinistral transpression along the

Lewis and Clark Line (Fig. 2; Sears and Hendrix, 2004; Rascoe and Gray, 2020). Sedimentary and volcanic strata of the Sapphire allochthon record ~30° of clockwise rotation during this time period (Eldredge and Van der Voo, 1988; Elston et al., 2002), and the ca. 75–70 Ma Philipsburg Batholith records ≤50° of clockwise rotation (Naibert et al., 2010; Gray et al., 2022), suggesting considerable rotation of the Sapphire allochthon and east-adjacent Lombard thrust sheet following development of the Georgetown thrust. Clearly, structural development of the Helena salient consisted of a considerable rotational component both during and following development of major Late Cretaceous thrust faults, and development of the Fishtrap recumbent anticline was roughly synchronous with crustal-scale rotational tectonics.

It stands to reason that a rotating crustal block composed of sedimentary rock of varying mechanical properties and subject to a complicated, three-dimensional stress field would deform internally to accommodate continued rotation. Further, rotational shear could very well produce divergent, top-to-the-NW kinematics observed in the study area and the Fishtrap recumbent anticline broadly. To this end, we propose that the Fishtrap recumbent anticline and associated F_2 folds developed as a result of rotational shear during large-scale rotation of the Sapphire allochthon and underlying Lombard thrust sheet. Brittle rotation in the upper crust was accommodated by ductile, kilometer-scale folding at deeper structural levels. This deformation was clearly enhanced by the rheology of the Mesoproterozoic Belt Supergroup, specifically the mechanically incompetent carbonates of the Mesoproterozoic Piegan Group, which could flow plastically and accumulate large amounts of strain. We prefer this model over others because it (1) considers the major role that rotational tectonics played in the structural development of the Helena salient following development of the foreland-directed Georgetown thrust and (2) does not require a buttress or wedge to create opposite kinematics. While it has been proposed that the Blue Mountains Province was underthrust and wedged beneath the western North American margin during its accretion (Lund et al., 2008;

Gray et al., 2022), and while large nappe folds have been related to terrane accretion in the Selkirk Mountains (Gibson et al., 2008), the study area is ~200 km inboard of the accretionary boundary and likely did not experience the direct effects of crustal wedging or terrane obduction. Rather, stress from oblique accretion of the Blue Mountains Province was transmitted inboard by regional structures such as the Lewis and Clark Line (Fig. 2). Further, sinistral transpression of the Sapphire allochthon and Lombard thrust sheet along this structure during Late Cretaceous time resulted in upward extrusion of rock to produce the flower structure mapped north of the study area near Garrison, Montana (Sears and Hendrix, 2004). Despite the Fishtrap recumbent anticline's position ~75 km south of the trace of the Lewis and Clark Line, it is compelling to envision the fold as the result of a similar process. We posit that rotational shear in response to crustal-scale rotation of the Helena salient is a simpler way to explain kilometer-scale, oppositely vergent folding in the Cordilleran retroarc fold-and-thrust belt.

6. CONCLUSION

New geologic mapping in the Anaconda metamorphic core complex footwall strongly suggests that the F_1 Fishtrap recumbent anticline attenuated strata of the Mesoproterozoic Belt Supergroup via upper limb extension. S_1 transposition fabrics in Mesoproterozoic Piegan Group and basal Missoula Group strata that attenuate parts of the section are roughly axial planar to the F_1 recumbent folds. Map-scale bedding-parallel faults and shear zones that both omit (Sawed Cabin fault) and thicken (Cutaway nappe thrust) section are subparallel to S_1 fabrics and are reinterpreted as larger-scale expressions of S_1 fabric development. Upright F_2 folds with axial planar S_2 foliation refold S_1 fabrics at outcrop scale. The new structural relationships elucidated in this study suggest that the Fishtrap recumbent anticline is a kilometer-scale, Alpine-style nappe that underlies much of the Anaconda metamorphic core complex footwall, and that the Lake of the Isle shear zone is the “blind” thrust at its base. These new

structural relationships paired with previous geochronologic constraints suggest that the Fishtrap recumbent anticline formed at ≥ 75 Ma and that folding had largely ceased by 74.6 Ma. We posit that kilometer-scale recumbent folding in this region was the result of rotational tectonics and sinistral transpression along the Lewis and Clark Line driven by terrane accretion along the western North American margin. The Anaconda metamorphic core complex footwall is an enigmatic, understudied region of the U.S. Cordillera, and future workers should continue to document outcrop-scale fabric relationships throughout the Anaconda and Flint Creek Ranges to better determine the geometry of the Fishtrap recumbent anticline and test the structural and tectonic interpretations we have proposed in this contribution.

ACKNOWLEDGMENTS

We would like to thank our colleagues Colleen Elliot and Katie McDonald at the Montana Bureau of Mines and Geology for their support of this project. Special thanks go to Mia Wafer, Tia Goebel, and Samantha Dittrich for their assistance in the field and laboratory. This manuscript was greatly improved by suggestions from Devon Orme, Mary Hubbard, David Foster, Andrew Zuza, and an anonymous reviewer. This research was supported by the U.S. Geological Survey EDMAP program, the Tobacco Root Geological Society, and a Geological Society of America graduate student research grant to B. Neal.

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