GEOLOGIC MAP OF THE KELLY LAKE 7.5' QUADRANGLE SOUTHWESTERN MONTANA

by

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Introduction

The Montana Bureau of Mines and Geology selected the Kelly Lake 7.5' quadrangle for mapping because its excellent alpine exposures in a key locality offer the opportunity to solve some regional stratigraphic and structural problems through 1:24,000-scale mapping. The quadrangle, in the central Anaconda Range of southwestern Montana (figure 1), lies within the hinterland of the Cretaceous Sevier thrust belt. The regionally significant Georgetown thrust (Emmons and Calkins, 1913) bisects the quadrangle into two domains having vastly different stratigraphy. Like the hinterlands of other orogenic belts worldwide, this region experienced a period of significant post-orogenic extension that is represented by the Eocene west-adjacent Bitterroot and east-adjacent Anaconda metamorphic core complexes. Rocks of the Kelly Lake quadrangle lie within the footwall of the recently recognized Anaconda detachment zone (O'Neill and others, 2002, 2004; Kalakay and Lonn, 2002; Lonn and others, 2003; Kalakay and others, 2003), but their complex geology has been previously explained through purely compressional tectonism (Wiswall, 1976; Wallace and others, 1992).

The northeastern quarter of the Kelly Lake quadrangle was mapped in detail by Wiswall (1976) and the entire quadrangle was included on both a 1:250,000-scale map (Ruppel and others, 1993) and a 1:50,000-scale map (Wallace and others, 1992). However, these efforts failed to recognize the effects of Late Cretaceous and early Tertiary extensional tectonism now known to be significant in this region.

Stratigraphy

Sedimentary and metasedimentary rocks of the Kelly Lake quadrangle belong to the Middle Proterozoic Belt Supergroup and the Cambrian rocks unconformably overlying them. The units and their age relationships are described in figure 2 and the Description of Map Units section of this report.

It has long been known that the Missoula Group is more than 10,000 feet thick on the hanging wall of the Georgetown thrust, but only 200 to 1,700 feet thick on the footwall (Emmons and Calkins, 1913; Poulter, 1956; Csejtey, 1962; Heise, 1983), and this relationship is also valid for the Kelly Lake quadrangle. The thinness of the footwall section has generally been attributed to pre-Middle Cambrian erosion and an angular unconformity (Emmons and Calkins, 1913). Lidke and Wallace (1992) and Wallace and others (1992) were the first to suggest that the thin section is, instead, the result of tectonism, and mapped a system of younger-over-older thrusts to explain the omitted section. Lonn and others (2003) noted that on the adjacent Philipsburg 30'x60' quadrangle, the footwall's lower Belt through lower Paleozoic metasedimentary package has been affected by zones of near-bedding-parallel ductile strain that have tectonically thinned the entire section. However, they attributed this strain to extension rather than contraction. The concept of tectonic attenuation extends into the Kelly Lake quadrangle, where the Missoula Group in the Georgetown footwall ranges from 300 to 1,800 feet thick, while the hanging wall section is at least 11,000 feet thick. In addition, structural thinning has affected the Cambrian units, possibly the Ravalli Group, and particularly the middle Belt carbonate that is less than 300 feet thick in places. Note that this study recognizes Ravalli Group (lower Belt Supergroup) rocks in the Kelly Lake quadrangle.

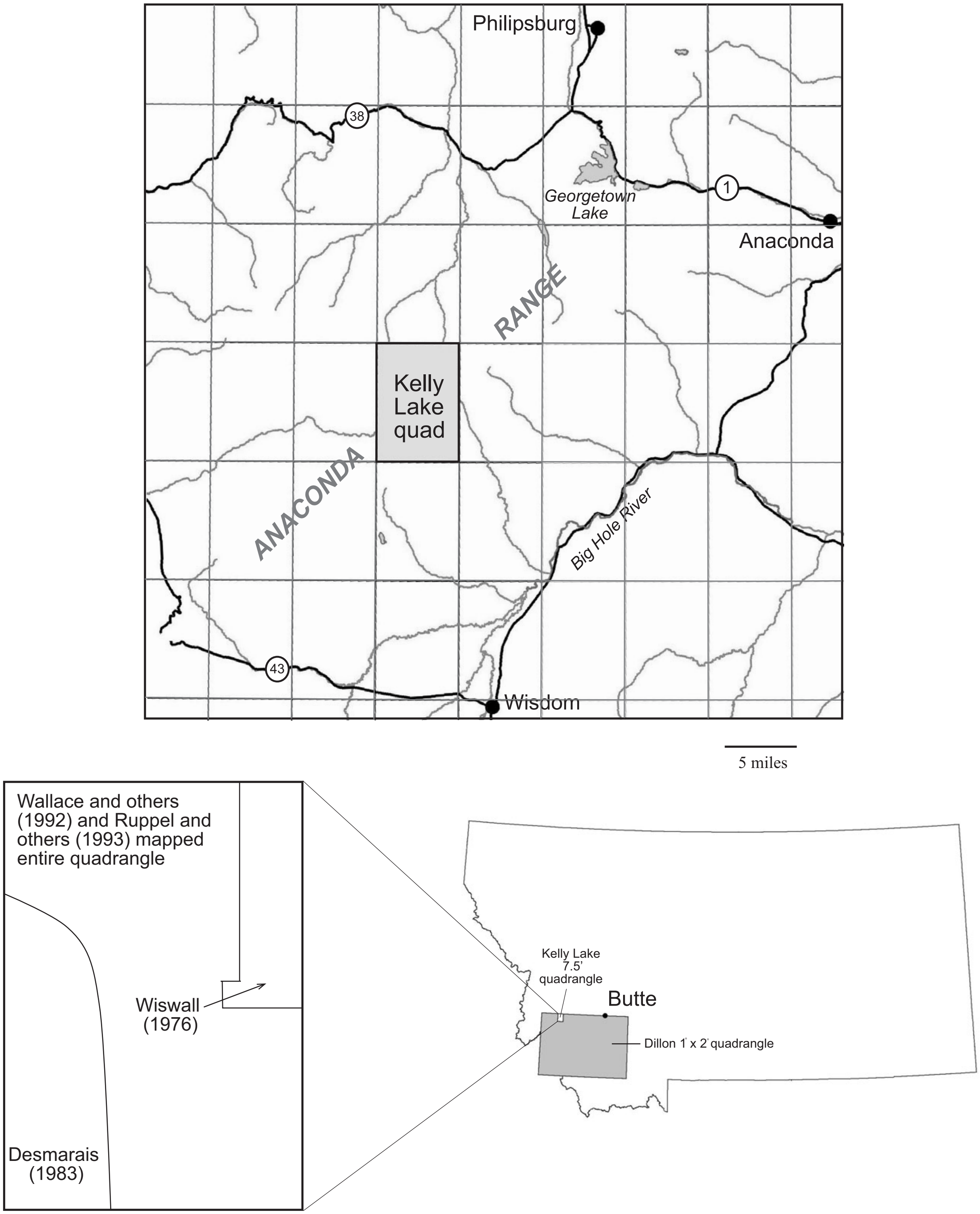


Figure 1. Location of Kelly Lake 7.5' quadrangle and index map of previous geologic mapping.

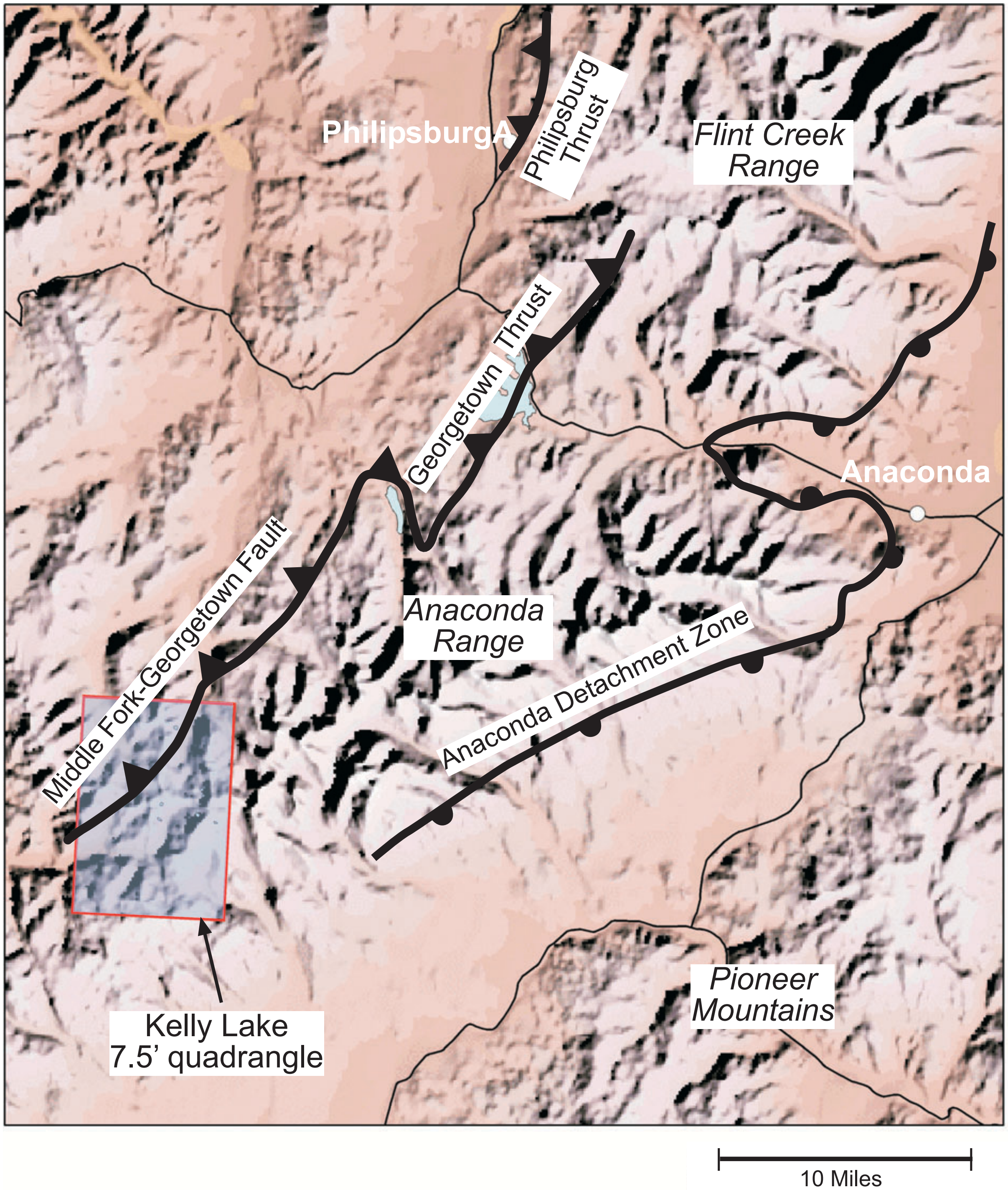


Figure 2. Map showing location of major regional structural features in the Flint Creek and Anaconda Ranges.

Structure

The new map of the Kelly Lake quadrangle illustrates the structural complexity of the entire region. Cretaceous Sevier-style compression deformed the thick (>30,000 feet) sequence of Proterozoic through Cretaceous sedimentary rocks to create the nearly flat, regionally extensive Georgetown thrust (Emmons and Calkins, 1913) that placed middle Belt carbonate rocks over upper Paleozoic and Mesozoic rocks for a minimum stratigraphic offset of 24,000 feet (Lidke and Wallace, 1992). Although original thrust geometries are not preserved in the Kelly Lake quadrangle, the northeast-striking Middle Fork-Georgetown fault zone (new name proposed) that bisects the quadrangle does separate the Georgetown thrust's hanging wall and footwall. The thickness contrast in the Missoula Group section between hanging wall (>11,000 feet) and footwall (300-1,800 feet) has been discussed in the stratigraphy section. There also appears to be a contrast in the degree of deformation and metamorphism.

Georgetown Thrust Hanging Wall

The Georgetown thrust hanging wall, although less structurally complex than the footwall, contains a major low-angle normal fault, the Shadow Lake detachment. This bedding-parallel fault places Mount Shields Member 2 over middle Belt carbonate, omitting at least 3,500 feet of the Proterozoic section. The fault has been deformed by open, upright, northeast-trending folds, and the resulting sinuous fault trace continues for more than 15 miles northwest of the Kelly Lake quadrangle. The Shadow Lake detachment has been intruded by the 73 Ma (Wallace and others, 1989) Sapphire batholith; so the fault is likely to be the result of Late Cretaceous extension.

Georgetown Thrust Footwall

Rocks in the footwall of the Georgetown thrust have been more complexly deformed and appear to be of higher metamorphic grade. The footwall contains the ductilely strained, tectonically attenuated stratigraphy discussed in the stratigraphy section. The stratigraphy has been thinned in thick, nearly bedding-parallel zones of ductile shear that display no obvious stratigraphic discontinuities, and by distinct, bedding-parallel faults that clearly omit stratigraphy. The northeastern quarter of the map area provides spectacular examples of these types of deformation. The folded, bedding-parallel Sawed Cabin detachment, interpreted as a low-angle normal fault that places younger Missoula Group (upper Belt Supergroup) abruptly over older middle Belt carbonate, grades northward into a broad ductile shear zone with a severely flattened and stretched gradational contact containing no obvious stratigraphic discontinuities. In the ductile shear zone, high-strain zones alternate with unstrained or less-strained zones. The high-strain zones typically display a nearly bedding- or layering-parallel mylonitic foliation, boudinaged beds, flattened and stretched grains, and rootless isoclines. The Ravalli Group-middle Belt carbonate contact near Sawed Cabin and Ripple Lakes is similar to the middle Belt carbonate-Missoula Group contact: in some places it is an abrupt bedding-parallel fault contact; in others it appears to be a strained gradational contact. The effect of the two different structural styles is the same: an attenuated stratigraphic section of variable thickness. Note the thickness changes in formations on the cross section (Plate 1); they suggest that the units have been boudinaged on a grand scale. This deformational event is expressed on Wallace and others' (1992) and Lidke and Wallace's (1992) maps as the East Fork thrust system, a zone of bedding-parallel younger-over-older thrust faults. However, the attenuation is better explained by extension than by contraction. The age of this event is constrained by the intrusion of Late Cretaceous plutons (Wallace and others, 1992; Lidke and Wallace, 1992), so again, as in the Georgetown thrust hanging wall, a Late Cretaceous extensional event appears to be represented. Metamorphism of the Georgetown thrust footwall rocks probably occurred synkinematically (Flood, 1974; Wiswall, 1976).

Several more deformational events followed. At Kelly Lake, the Sawed Cabin detachment fault has been repeated by the Kelly Lake thrust, implying synchronous or alternating extension and contraction. At least two subsequent fold generations are present as demonstrated by refolded fold axes and folds that verge both east and west. The multiple fold events complexly deform the detachment faults and associated schistosity; the deformation is magnificently displayed in the cirques of Sawed Cabin and Kelly Lakes. The most prominent of the fold generations is associated with a strong, steeply west-dipping axial plane cleavage. The complex fold patterns are present throughout the Anaconda and Flint Creek Ranges and, while traditionally attributed to compressive tectonism, Kalakay and others (2003) and Lonn and others (2003) have suggested that some folding may be genetically related to the exhumation of the Anaconda core complex's footwall during early Tertiary crustal extension.

North- to northeast-striking, high-angle, brittle faults cut the thrusts, detachments, and folds, and comprise the fault zone previously mapped as the Cretaceous Georgetown thrust (Wallace and others, 1992). Although the zone does juxtapose the hanging wall and footwall of the thrust, the original thrust geometries are not preserved. The zone probably developed in the early Tertiary and, because it appears to juxtapose structurally lower rocks on the east (Georgetown footwall) against structurally higher rocks on the west (Georgetown hanging wall), it may represent a down-to-the-west normal fault or a strike-slip fault. Renaming this fault zone the **Middle Fork-Georgetown fault zone** is proposed here, in order to distinguish it from the original Cretaceous, folded, bedding-parallel Georgetown thrust preserved south of Georgetown Lake (Emmons and Calkins, 1913).

Igneous Rocks

Because igneous rocks were not the focus of this study, igneous geology on the Kelly Lake quadrangle has been taken mostly from Desmarais (1983) and Wallace and others (1992). Foliated granodiorite (Kgdf) exposed in the southwestern part of the quadrangle with an inferred age of 78 Ma (Desmarais, 1983) is the oldest plutonic rock in the study area. The foliation is parallel to its contacts and to foliation within the metasedimentary country rock. Desmarais (1983) documented rapid cooling of this pluton from 78-70 Ma that he interpreted to represent rapid uplift of 8-13 km. It is possible that the Late Cretaceous extensional event discussed in the structure section may have been responsible for exhuming this pluton.

Large 50-55 Ma (Wallace and others, 1992) plutons (Tgd and Tgde) also intruded the map area at shallow depths (Desmarais, 1983). Within the Georgetown footwall, numerous dikes intrude all plutons and the sedimentary units, most often along a north- to north-northeast-striking schistosity related to one of the fold events. These dikes cross-cut the detachment faults, the bedding-parallel schistosity, and the Tertiary(?) high-angle faults. Dikes are rare within the Georgetown hanging wall.

Regional Tectonic Implications

The Shadow Lake and Sawed Cabin detachments, and the tectonically attenuated section all appear to be the product of extensional tectonism. Lonn and others (2003) noted that these styles of deformation are widespread in the north-adjacent Philipsburg 30'x60' quadrangle, and they also attributed the deformation to extension. The minimum age of this extensional event is constrained by the intrusion of Late Cretaceous plutons (Hyndman and others, 1983; Wallace and others, 1986, 1989, 1992) in the Anaconda and Flint Creek ranges. Other evidence for Cretaceous extension in southwestern Montana includes:

1) As discussed above, the thermal history of the Cretaceous granodiorite pluton on the west side of the Kelly Lake quadrangle indicates rapid uplift from 78-70 Ma (Desmarais, 1983).
2) In the southern Flint Creek Range, movement on the Hidden Lake and East normal faults occurred in the Late Cretaceous and may have been responsible for the unroofing of the Philipsburg batholith (Buckley, 1990).
3) Also in the Flint Creek Range, shallow emplacement (Hyndman and others, 1988; Buckley, 1990) of the 64 Ma (Wallace and others, 1986) Mount Powell batholith into kyanite-bearing Late Cretaceous metamorphic rocks suggests major Late Cretaceous exhumation.
4) Late Cretaceous stretching lineations in the southern Sapphire Range have the same bearing as Eocene lineations related to movement on the Bitterroot and Anaconda detachments, and could be attributed to an earlier period of extension (Foster, 2000).

However, foreland thrusting at this latitude is known to have continued into the Paleocene (Harlan and others, 1988), suggesting that these Late Cretaceous extensional features were generated by extensional collapse of the hinterland of the Sevier orogenic belt synchronous with regional crustal shortening (Kalakay and others, 2004; Lonn and Mc Donald, 2004). Hodges and Walker's (1992) summary of evidence for significant Cretaceous extension in the North American cordillera also supports this concept, as do numerous studies in the Andes and Himalaya confirming the occurrence of active extension in a convergent setting (Dalmayrac and Molnar, 1981; Burchfiel and Royden, 1985; McNulty and Farber, 2002).

The complex fold geometries of the Kelly Lake quadrangle also extend across the Anaconda and Flint Creek Mountains and have been difficult to explain. On the eastern flanks of these ranges, at least some of the folding seems to be genetically related to the Eocene Anaconda metamorphic core complex, and therefore Kalakay and others (2003) and Lonn and others (2003) have proposed that the folds may have resulted from extensional processes.

Finally, the characteristics of the Middle Fork-Georgetown fault zone, including poorly preserved thrust geometries, steeply dipping fault planes, and indications of normal or strike-slip sense of movement, extend along most of the previously mapped trace of the Georgetown and Philipsburg thrusts (Lonn and others, 2003). The previously mapped Georgetown-Philipsburg thrust system is therefore a later Tertiary high-angle fault system that separates the hanging wall and footwall of the original Cretaceous Georgetown thrust. The original folded, bedding-parallel thrust has been preserved only on the east side of the zone near Georgetown Lake and on a few isolated fault blocks scattered along the zone.

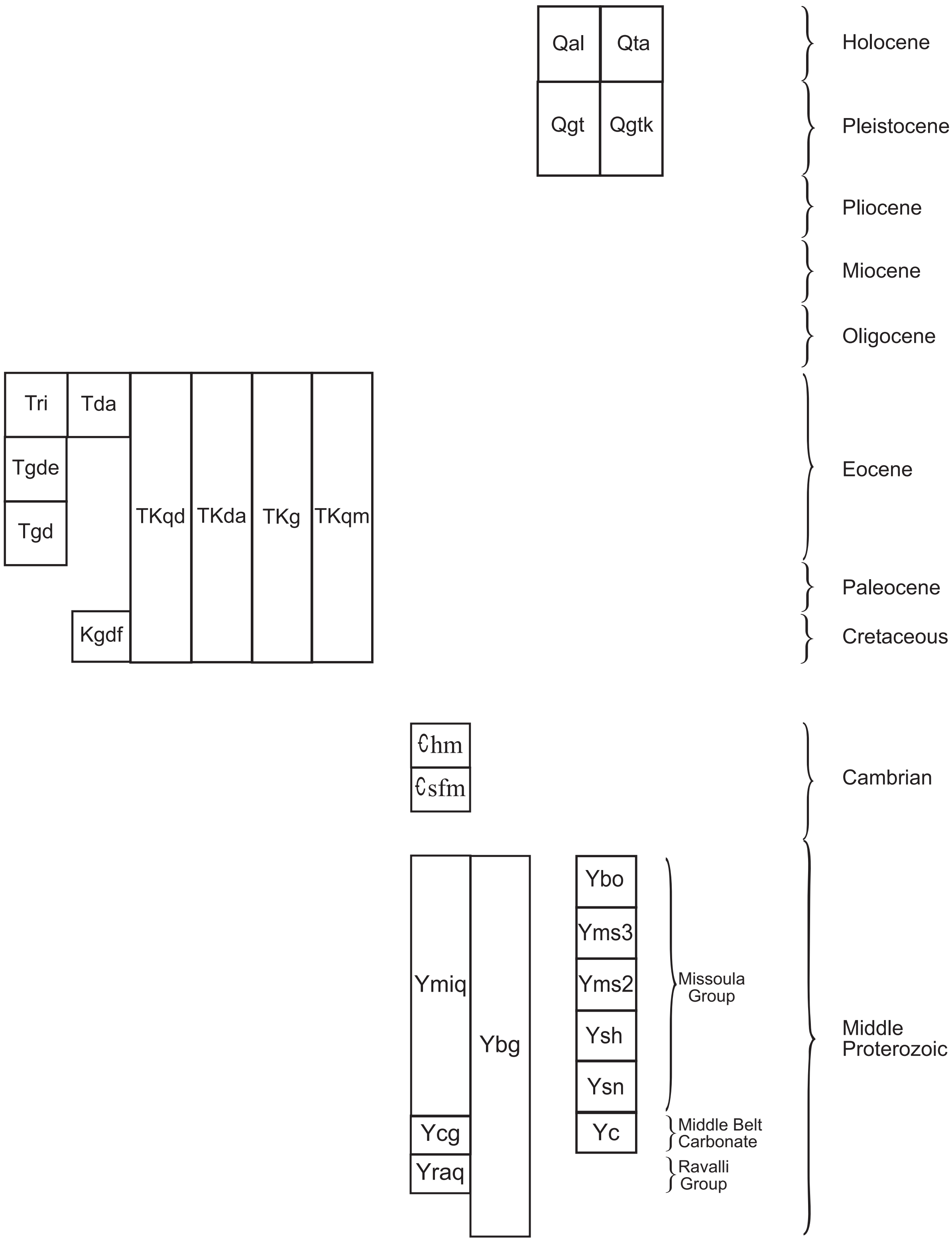


Figure 3. Age correlation of map units.

Description of Map Units

Qal	ALLUVIAL DEPOSITS OF ACTIVE CHANNELS AND PRESENT FLOOD PLAINS (HOLOCENE) Well-rounded, well-sorted, bouldery gravel and sand with some thin beds of clayey silt. Probably less than 100 feet thick.
Qta	TALUS DEPOSITS (HOLOCENE) Accumulations of angular boulders on and beneath steep slopes. Thickness 5-30 feet.
Qgt	GLACIAL TILL (PLEISTOCENE) Unsorted, mostly unstratified clay, silt, sand, and gravel with subrounded boulders as much as 10 feet in diameter. Till is mostly found in thin ground moraine deposits overlying bedrock but also occurs in some thicker end and lateral moraine deposits. Thickness as much as 100 feet.
Qgtk	GLACIAL TILL AND KAME DEPOSITS, UNDIVIDED (PLEISTOCENE) Glacial till consists of unsorted, mostly unstratified clay, silt, sand, and gravel with subrounded boulders up to 10 feet in diameter. Kame deposits are moderately to well-sorted, well-stratified, sub-rounded to rounded sand, pebbles, and boulders deposited by streams flowing within and on glaciers. Both types of deposits commonly have a hummocky surface, but kame deposits tend to contain more rounded and better sorted clasts, and are well drained, while till is characterized by unsorted subangular clasts and poor drainage creating extensive swampy areas. Thickness 20-100 feet.
Tri	INTRUSIVE RHYOLITE (EOCENE) Buff to light-gray, porphyritic rhyolite in dikes and pods. Contains 20-40% phenocrysts of potassium feldspar, plagioclase, quartz, and lesser biotite in an aphanitic groundmass. Intrudes plutons dated as middle Eocene. After Wallace and others (1992).
Tda	DACITE, INTRUSIVE (EOCENE) Light- to medium-gray dacite and granodiorite porphyry. Contains phenocrysts of plagioclase, quartz, biotite, potassium feldspar, and rarely hornblende (Wallace and others, 1992). A K/Ar date of 51-50 Ma was obtained by Desmarais (1983).
Tgde	GRANODIORITE OF ELK PARK (EOCENE) Medium- to fine-grained, slightly porphyritic, hypidiomorphic granular, biotite granodiorite. Consists of 40% plagioclase, 28% quartz, 19% potassium feldspar, and 9% brown biotite. Microcataclastic texture common. Intrudes the granodiorite of Pintler Creek (Tgd). One K/Ar date yielded a 53 Ma age. After Wallace and others (1992).
Tgd	GRANODIORITE OF PINTLER CREEK (EOCENE)

Fine- to coarse-grained, porphyritic to equigranular, hypidiomorphic granular, muscovite-biotite granodiorite. Microcataclastic texture is common near the contacts that are usually discordant. Contains 42% plagioclase, 29% quartz, 21% potassium feldspar, 3% biotite, and 3% muscovite. K/Ar dates ranged from 55 to 50 Ma. After Wallace and others (1992).

TKg GRANITE PORPHYRY AND APLITE (UPPER CRETACEOUS OR LOWER TERTIARY)
Sills, dikes, and pods of light-gray porphyritic granite and aplite. Composed of plagioclase, potassium feldspar, quartz, and biotite. After Wallace and others, 1992).

TKda DACITE (UPPER CRETACEOUS OR LOWER TERTIARY)
Light- to medium-gray dacite and granodiorite porphyry. Contains phenocrysts of plagioclase, quartz, biotite, potassium feldspar, and rarely hornblende (Wallace and others, 1992).

TKqd QUARTZ DIORITE AND ANDESITE (UPPER CRETACEOUS OR LOWER TERTIARY)
Gray, slightly porphyritic dikes, sills, and pods of quartz diorite and andesite that contain phenocrysts of plagioclase and hornblende. After Wallace and others (1992).

TKgm GRANITE, MUSCOVITE-BEARING (UPPER CRETACEOUS OR LOWER TERTIARY)
Coarse-grained muscovite leucogranite in pods, dikes, and sills that are restricted to the quartzite of the metamorphosed Ravalli Group (Yraq).

Kgdf GRANODIORITE, FOLIATED (UPPER CRETACEOUS)
Medium-grained, equigranular to slightly porphyritic, foliated hornblende-biotite granodiorite, with some hornblende-biotite tonalite. Consists of 47% plagioclase, 25% quartz, 4% potassium feldspar, 13% brown biotite, and 7% hornblende. Foliation is defined by parallel biotite flakes and by alternating hornblende-biotite-rich and biotite-rich bands. After Wallace and others (1992) and equivalent to their Granodiorite of Jennings Camp Creek (Kjc). Foliation is usually parallel both to the contact with the country rock and to foliation within the country rock. Desmarais (1983) inferred a 78 Ma crystallization age for this pluton, and inferred rapid uplift of it shortly afterwards.

Єhm MARBLE OF THE METAMORPHOSED HASMARK FORMATION (CAMBRIAN)
Upper 300 feet consists of light-gray, finely laminated dolomitic marble. Oolites and pisolites are sometimes visible. The lower 700 feet consists of massive, bluish-gray dolomite that commonly displays mottled weathering. Most of this unit is strongly foliated with original bedding not preserved. After Lidke and Wallace (1992).

Єsfm QUARTZITE OF THE METAMORPHOSED SILVER HILL AND

FLATHEAD FORMATIONS (CAMBRIAN)
Fine- to coarse-grained, well-sorted quartzite that contains well-rounded grains of 98-100% quartz, with minor phyllite, marble, and calc-silicate gneiss with wavy laminae in the upper part of the unit. Although Lidke and Wallace (1992) reported a thickness of 150-250 feet, in the Kelly Lake quadrangle it has been structurally thinned to less than 100 feet.

MISSOULA GROUP

Ymiq QUARTZITE OF THE METAMORPHOSED MISSOULA GROUP, UNDIVIDED (MIDDLE PROTEROZOIC)
Light gray, fine- to coarse-grained, poorly sorted, feldspathic metaquartzite containing floating pebbles and granules. Feldspar content averages 20-25% with potassium feldspar dominant over plagioclase. Commonly strongly foliated, with grains flattened in a plane roughly parallel to bedding. Strained zones or layers alternate with unstrained layers. Unstrained zones contain flat laminations and large trough and planar cross beds. Lower contact with underlying middle Belt carbonate (Ycg) is either a ductile, bedding-subparallel fault (the Sawed Cabin detachment) or a stretched and flattened gradational contact. Upper contact with Cambrian metasediments is a strongly foliated ductilely strained zone. In fact, the entire Ymiq section is thought to represent a ductilely strained and tectonically attenuated section (Lonn and others, 2003) that developed during an episode of Late Cretaceous extension (Lonn and McDonald, 2004; Kalakay and others, 2004). Varies from 300 to 1800 feet thick.

Ybo BONNER FORMATION (MIDDLE PROTEROZOIC)
Pink, medium- to coarse-grained feldspathic quartzite containing small floating pebbles and granules and abundant large black to green mud chips. Chalky white feldspar grains are obvious in hand sample, with feldspar comprising 17-22% of the rock. Although indistinguishable in the field from Mount Shields Member 2, samples stained for potassium feldspar show that potassium feldspar is usually predominant over plagioclase. Lewis (1998) and Lonn and others (2003) found a similar composition in Bonner Formation to the north. Beds of quartzite more than 5 feet thick and large trough cross beds are also characteristic. Thickness of the exposed section on the Kelly Lake quadrangle is 1600 feet, with a total thickness of 2000 feet reported to the north (Wallace and others, 1989).

Yms_3 MOUNT SHIELDS FORMATION, MEMBER 3, INFORMAL (MIDDLE PROTEROZOIC)
Poorly exposed, purple to red, quartzite, siltite, and argillite couples and couplets containing abundant mud chips and cracks. Some thin sand beds contain granule-sized grains. Also contains a few intervals of quartzite in beds as much as 5 feet thick with trough and planar cross beds. Approximately 1,800 feet thick.

Yms_2 MOUNT SHIELDS FORMATION, MEMBER 2, INFORMAL (MIDDLE

PROTEROZOIC)
Pink to light gray, fine- to coarse-grained, poorly sorted, cross-bedded, feldspathic quartzite with sparse floating pebbles and abundant green mud chips. Chalky white feldspar grains are obvious in hand sample and comprise 15-24% of the rock. Slabbed and stained samples show the plagioclase content is greater than or equal to potassium feldspar in contrast to Bonner Formation (Lewis, 1998; Lonn and others, 2003). Approximately 1,800 feet is exposed; the lower contact is a fault.

Ysh SHEPARD FORMATION (MIDDLE PROTEROZOIC)
Microlaminae and couplets of dark-green siltite and light-green argillite that are dolomitic and have a characteristic orange-brown weathering rind. Includes some beds 3 to 6 inches thick of coarse, white quartzite with granules and small angular pebbles and some distinctive dolomitic intraclast conglomerate beds. About 550 feet is exposed; the upper contact is a fault.

Ysn SNOWSLIP FORMATION (MIDDLE PROTEROZOIC)
Upper part is a thick sequence at least 3,000 feet thick of fine- to medium-grained, poorly sorted feldspathic quartzite in beds 1-5 feet thick. Floating pebbles are common. Contains abundant flat laminations and climbing ripples, and uncommon trough cross beds. Feldspar content averages 15-25%, with plagioclase predominant over potassium feldspar. Difficult to distinguish from Bonner or Mount Shields Formations. The lower part is thin-bedded quartzite-argillite couplets. Some of the thin sand beds contain granule-sized lithic fragments and rounded, frosted quartz grains. Some thin beds are comprised of 100% quartz. Unit typically develops a distinctive hematite stain on weathered surfaces. One mile west-northwest of Kelly Lake this lower part of the unit has been metamorphosed to a phyllite containing porphyroblasts of andalusite and cordierite. Thickness of the lower part is unknown, but it appears to be 850 feet on Lidke and Wallace's (1992) map.

<u>MIDDLE BELT CARBONATE</u>

Yc MIDDLE BELT CARBONATE (MIDDLE PROTEROZOIC)
Includes the Wallace and Helena Formations. The upper part is characterized by tan-weathering, dolomitic siltite and quartzite capped by black argillite in pinch-and-swell couplets and couples. The quartzite and siltite commonly have scoured bases or bases with load casts. The lower part consists of cycles, from 3 to 30 feet thick and usually incomplete, of a basal white quartzite or intraclast unit, overlain by even and lenticular couplets of green siltite and argillite without mud cracks, and capped by dolomitic beds. However, these cycles are difficult to recognize in the typical small outcrop. The unit is more easily recognized by wavy but parallel, silver-green couplets of darker-green siltite and lighter-green argillite, by white quartzite, by beds of tan- or gray-weathering dolomite or limestone from 1 to 3 feet thick, and by weathered-out pods of carbonate in the green siltite. Molar-tooth structures and non-polygonal "crinkle" cracks are common throughout the section. The bottom of this

unit is not exposed in the Kelly Lake quadrangle, and severe deformation makes thickness estimates problematic, but Lidke and Wallace (1992) estimated 4,000 feet nearby, while Wallace and others (1992) estimated 6,000 feet.

Ycg CALC-SILICATE GNEISS OF THE METAMORPHOSED MIDDLE BELT CARBONATE (MIDDLE PROTEROZOIC)

Interlayered greenish, diopside-rich calc-silicate rock, fine-grained quartzite, marble, and minor schist. Metamorphic equivalent of the Helena and Wallace Formations. While some layers still exhibit original sedimentary structures, others have developed a strong layering-parallel schistosity. This shear foliation and the associated bedding-parallel faults are responsible for thinning this unit to as little as 300 feet in places. Original thickness was probably 4,000-6,000 feet (Lidke and Wallace, 1992; Wallace and others, 1992).

RAVALLI GROUP

Yraq QUARTZITE OF THE METAMORPHOSED RAVALLI GROUP (MIDDLE PROTEROZOIC)

Gray, fine- to medium-grained, strongly foliated quartzite in beds 6 inches to 5 feet thick separated by thin phyllite or biotite-muscovite schist layers. Original sedimentary structures are sometimes preserved, and include abundant flat laminations, trough cross-beds, and contorted bedding created by soft-sediment deformation. Slabbed and stained samples show a potassium feldspar content much greater than that of plagioclase, similar to the ratio reported for Ravalli Group rocks in the southern Sapphire Range (Lonn and others, 2003). The upper contact with metamorphosed middle Belt carbonate (Ycg) is often a ductile, bedding-parallel fault, but south of Sawed Cabin Lake and near Ripple Lake the original gradational contact, although strained, is preserved, showing that these rocks lie depositionally beneath Ycg and are indeed Ravalli Group (Revett Formation?) rocks. Previously these rocks were mapped as Mount Shields Formation (Wallace and others, 1992; Ruppel and others, 1993). Severe deformation precludes thickness estimates, but the unit appears to more than 4,000 feet thick on the adjacent Warren Peak quadrangle just to the east.

Ybg GNEISS AND SCHIST OF THE METAMORPHOSED BELT SUPERGROUP (MIDDLE PROTEROZOIC)

Quartz-feldspar-biotite gneiss and minor biotite-muscovite schist. Thick medium- to coarse-grained, light-colored layers of quartz, feldspar, and biotite alternate with thinner darker layers that contain biotite, muscovite, and sillimanite (Wallace and others, 1992). The leucocratic layers appear to be metamorphosed Belt quartzite, but we were unable to identify the equivalent formation. However, on the east side of Star Creek, Yraq is in gradational contact with Ybg.

MAP SYMBOLS


Contact: dashed where approximately located; dotted where concealed


Fault: unknown sense of movement; dotted where concealed

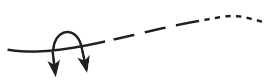

Normal fault: dotted where concealed; bar and ball on downthrown side

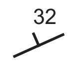

Reverse or thrust fault: teeth on upthrown block; dotted where concealed


Low-angle normal fault, ticks on hanging wall: dashed where fault merges into a broad zone of ductile shear; dotted where concealed


Anticline: showing trace of axial plane and plunge direction where known; dotted where concealed

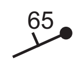

Syncline: showing trace of axial plane and plunge direction where known; dotted where concealed


Overturned anticline: showing trace of axial plane and direction of dip of bedding; dashed where approximately located, dotted where concealed



Strike and dip of bedding

Strike and dip of overturned bedding



Strike and dip of bedding where stratigraphic tops were confirmed using primary sedimentary structures


Horizontal bedding


Vertical bedding

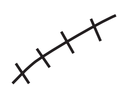

Vertical foliation

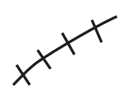
Foliation

Foliation parallel to layering, usually bedding

Cleavage

Small-scale fold axis


Dacite dike (Tda): shown in red on map


Dacite dike (TKda): shown in pink on map

References Cited

Buckley, S.N., 1990, Ductile extension in a Late Cretaceous fold and thrust belt, Granite County, west-central Montana: Missoula, University of Montana, M.S. thesis, 42 p., map scale 1:6,000.

Burchfiel, B.C., and Royden, L.H., 1985, North-south extension within the convergent Himalayan region: Geology, v. 13, p. 679-682.

Csejtey, Bela, 1962, Geology of the southeast flank of the Flint Creek Range, western Montana: Princeton, NJ, Princeton University, Ph.D. dissertation, 175 p., map scale 1:62,500.

Dalmayrac, Bernard, and Molnar, Peter, 1981, Parallel thrust and normal faulting in Peru and constraints on the state of stress: Earth and Planetary Science Letters, v. 55, p. 473-481.

Desmarais, N.R., 1983, Geology and geochronology of the Chief Joseph plutonic-metamorphic complex, Idaho-Montana: Seattle, University of Washington, Ph.D. dissertation, 150 p., map scale 1:50,000.

Emmons, W.C., and Calkins, F.C., 1913, Geology and ore deposits of the Philipsburg quadrangle, Montana: U.S. Geological Survey Professional Paper 78, 271 p.

Flood, R.E., 1974, Structural geology of the upper Fishtrap Creek area, central Anaconda Range, Deer Lodge County, Montana: Missoula, University of Montana, M.S. thesis, 71 p., map scale 1:62,500.

Foster, D.A., 2000, Tectonic evolution of the Eocene Bitterroot metamorphic core complex, Montana and Idaho, *in* Roberts, Sheila, and Winston, Don, eds., Geologic Field Trips, Western Montana and Adjacent Areas: Rocky Mountain Section of the Geological Society of America, University of Montana, p. 1-29.

Harlan, S.S., Geissman, J.W., Lageson, D.R., and Snee, L.W., 1988, Paleomagnetic and isotope dating of thrust-belt deformation along the eastern edge of the Helena salient, Crazy Mountains basin, Montana: Geological Society of America Bulletin, v. 100, p. 492-499.

Heise, B.A., 1983, Structural geology of the Mount Haggin area, Deer Lodge County, Montana: Missoula, University of Montana, M.S. thesis, 77 p., map scale 1:12,000.

Hodges, K.V., and Walker, J.D., 1992, Extension in the Cretaceous Sevier orogen, North American Cordillera: Geological Society of America Bulletin, v. 104, p. 560-569.

Hyndman, D.W., Silverman, A.J., Ehinger, R., and Benoit, W., 1983, The Philipsburg Batholith, western Montana: mineralogy, petrology, internal variation, and evolution: Montana Bureau of Mines and Geology Memoir M 49, 37 p.

Hyndman, D.W., Alt, David, and Sears, J.W., 1988, Post-Archean metamorphic and tectonic evolution of western Montana and northern Idaho, *in* Ernst, W.G., ed., Metamorphism and Crustal Evolution in the Western Conterminous U.S. (Rubey Volume VII): Englewood Cliffs, New Jersey, Prentice-Hall, p. 332-361.

Kalakay, T.J., and Lonn, J.D., 2002, Geometric and kinematic relationships between high temperature and low temperature faulting in the Anaconda detachment zone, southwest Montana: Geological Society of America Abstracts with Programs, v. 34, n. 6, p. 370.

Kalakay, T.J., Foster, D.A., and Thomas, R.C., 2003, Geometry and timing of deformation in the Anaconda extensional terrane, west-central Montana: Northwest Geology, v. 32, p. 133.

Kalakay, T.J., Foster, D.A., and Lonn, J.D., 2004, Timing of formation and hinterland collapse Sevier orogenic wedge: New evidence from the cordillera of western Montana: Geological Society of America Abstracts with Programs, v. 36, n. 4, p. 73.

Lewis, R.S., 1998, Stratigraphy and structure of the lower Missoula Group in the Butte 1^0 x 2^0 and Missoula West 30' x 60' quadrangles, Montana: Northwest Geology, v. 28, p. 1-14.

Lidke, D.J., and Wallace, C.A., 1992, Rocks and structure of the north-central part of the Anaconda Range, Deer Lodge and Granite Counties, Montana: U.S. Geological Survey Bulletin 1993, 31 p., map scale 1:24,000.

Lonn, J.D., McDonald, C., Lewis, R.S., Kalakay, T.J., O'Neill, J.M., Berg, R.B., and Hargrave, P., 2003, Preliminary geologic map of the Philipsburg 30' x 60' quadrangle, western Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 483, 29 p., scale 1:100,000.

Lonn, J.D., and McDonald, Catherine, 2004, Cretaceous(?) syncontractional extension in the Sevier orogen, southwestern Montana: Geological Society of America Abstracts with Programs, v. 36, n. 4, p. 36.

McNulty, Brendan, and Farber, Daniel, 2002, Active detachment faulting above the Peruvian flat slab: Geology, v. 30, p. 567-570.

O'Neill, J.M., Lonn, J.D., and Kalakay, T.J., 2002, Early Tertiary Anaconda metamorphic core complex, southwestern Montana: Geological Society of America Abstracts with Programs, v. 34, n. 4, p. A10.

O'Neill, J.M., Lonn, J.D., Lageson, D.R., and Kunk, M.J., 2004, Early Tertiary Anaconda metamorphic core complex, southwestern Montana: Canadian Journal of Earth Sciences, v. 41, p. 63-72.

Poulter, G.J., 1956, Geologic map of the Georgetown thrust area southwest of Philipsburg, Granite and Deer Lodge Counties, Montana: Montana Bureau of Mines and Geology Geologic Map GM 1, scale 1:48,000.

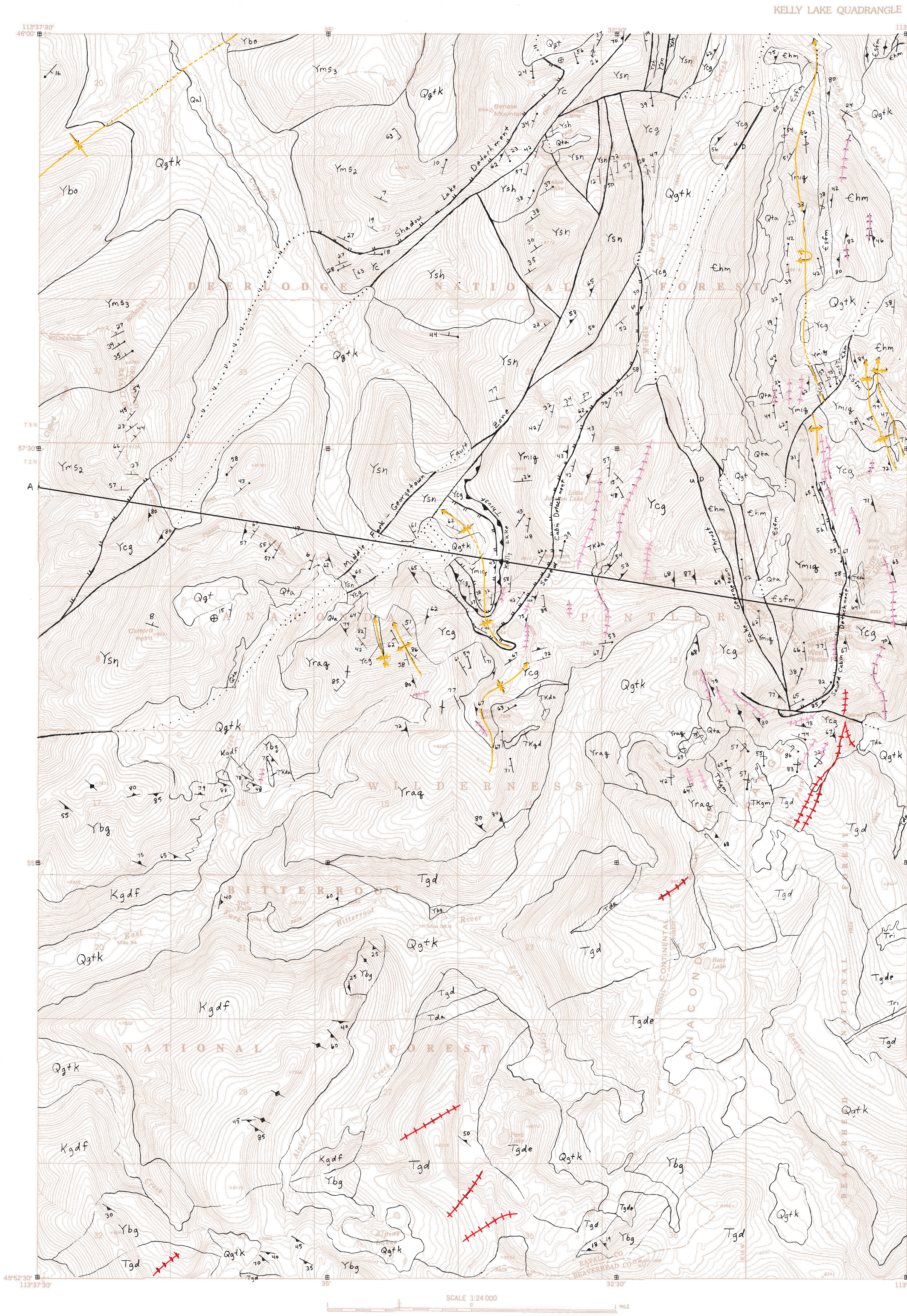
Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1^0 x 2^0 quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1803-H, scale 1:250,000.

Wallace, C.A., Schmidt, R.G., Lidke, D.J., Waters, M.R., Elliott, J.E., French, A.B., Whipple, J.W., Zarske, S.E., Blaskowski, M.J., Heise, B.A., Yeoman, R.A., O'Neill, J.M., Lopez, D.A., Robinson, G.D., and Klepper, M.R., 1986, Preliminary geologic map of the Butte 1^ox2^o quadrangle, Montana: U.S. Geological Survey Open-File Report 86-292, scale 1:250,000.

Wallace, C.A., Lidke, D.J., Waters, M.R., and Obradovich, J.D., 1989, Rocks and structure of the southern Sapphire Mountains, Granite and Ravalli Counties, western Montana: U.S. Geological Survey Bulletin 1824, 29 p., map scale 1:50,000.

Wallace, C.A., Lidke, D.J., Elliott, J.E., Desmarais, N.R., Obradovich, J.D., Lopez, D.A., Zorski, S.E., Heise, B.A., Blaskowski, M.J., and Loen, J. S., 1992, Geologic map of the Anaconda-Pintlar Wilderness and contiguous roadless areas, Granite, Deer Lodge, Beaverhead, and Ravalli Counties, western Montana: U.S. Geological Survey Miscellaneous Field Studies map MF-1633-C, 36 p., map scale 1:50,000.

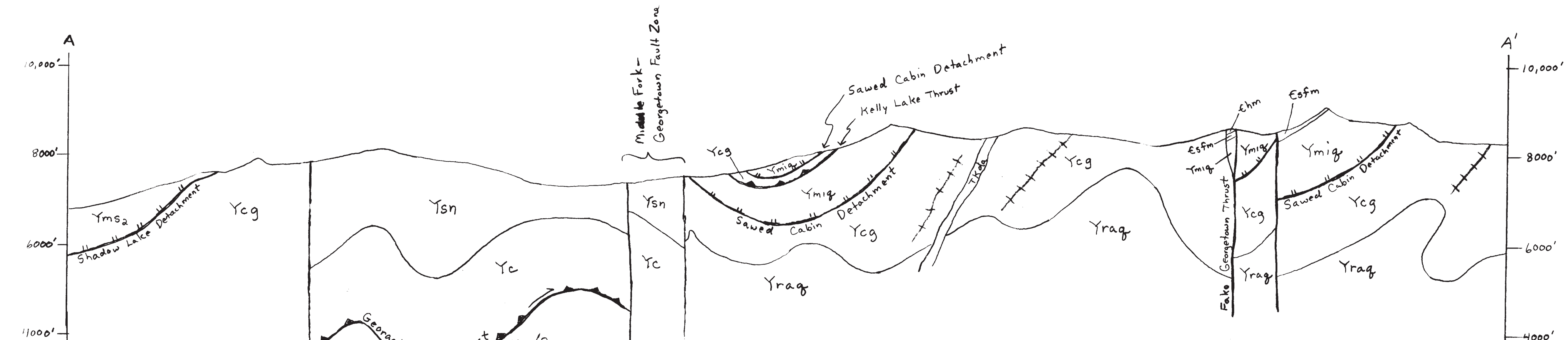
Wiswall, Gil, 1976, Structural styles of the southern boundary of the Sapphire tectonic block, Anaconda-Pintlar Wilderness Area, Montana: Missoula, University of Montana, M.S. thesis, 62 p., map scale 1:48,000.



Map Units and Symbols (see text for descriptions)

Qal	Alluvial deposits of active channels and modern flood plains (Holocene)
Qta	Talus deposits (Holocene)
Qgt	Glacial till (Pleistocene)
Qgtk	Glacial till and kame deposits, undivided (Pleistocene)
Tri	Rhyolite, intrusive (Eocene)
Tda	Dacite, intrusive (Eocene)
Tgde	Granodiorite of Elk Park (Eocene)
Tgd	Granodiorite of Pintler Creek (Eocene)
TKg	Granite porphyry and aplite (Upper Cretaceous or Lower Tertiary)
TKda	Dacite (Upper Cretaceous or Lower Tertiary)
TKqd	Quartz diorite and andesite (Upper Cretaceous or Lower Tertiary)
TKqm	Granite, muscovite-bearing (Upper Cretaceous or Lower Tertiary)
Kgdf	Granodiorite, foliated (Upper Cretaceous)
Ꞓhm	Marble of the metamorphosed Hasmark Formation (Cambrian)
Ꞓsfm	Quartzite of the metamorphosed Silver Hill and Flathead Formations (Cambrian)
Ymiq	Quartzite of the metamorphosed Missoula Group (Middle Proterozoic)
Ybo	Bonner Formation (Middle Proterozoic)
Yms_3	Mount Shields Member 3, informal (Middle Proterozoic)
Yms_2	Mount Shields Member 2, informal (Middle Proterozoic)
Ysh	Shepard Formation (Middle Proterozoic)
Ysn	Snowslip Formation (Middle Proterozoic)
Yc	Middle Belt carbonate (Middle Proterozoic)
Ycg	Calc-silicate gneiss of the metamorphosed middle Belt carbonate (Middle Proterozoic)
Yraq	Quartzite of the metamorphosed Ravalli Group (Middle Proterozoic)
Ybg	Gneiss and schist of the metamorphosed Belt Supergroup (Middle Proterozoic)

- Contact: dashed where approximately located; dotted where concealed
- Fault: unknown sense of movement; dotted where concealed
- Normal fault: dotted where concealed; bar and ball on downthrown side
- Reverse or thrust fault: teeth on upthrown block; dotted where concealed
- Low-angle normal fault, ticks on hanging wall: dashed where fault merges into a broad zone of ductile shear; dotted where concealed
- Anticline: showing trace of axial plane and plunge direction where known; dotted where concealed
- Syncline: showing trace of axial plane and plunge direction where known; dotted where concealed
- Overturned anticline: showing trace of axial plane and direction of dip of bedding; dashed where approximately located, dotted where concealed
- 32 Strike and dip of bedding
- 75 Strike and dip of overturned bedding
- 65 Strike and dip of bedding where stratigraphic tops were confirmed using primary sedimentary structures
- Horizontal bedding
- Vertical bedding
- Vertical foliation
- 75 Foliation
- 25 Foliation parallel to layering, usually bedding
- 70 Cleavage
- 20 Small-scale fold axis
- Dacite dike (Tda): shown in red on map
- Dacite dike (TKda): shown in pink on map



No vertical exaggeration
Datum: mean sea level
Quaternary deposits not shown

MBMG Open File 500

Geologic Map of the Kelly Lake 7.5' Quadrangle Southwestern Montana

Jeffrey D. Lonn and Catherine McDonald

2004

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