PRELIMINARY GEOLOGIC MAP OF THE MONTANA PART OF THE MISSOULA WEST 30' X 60' QUADRANGLE

Compiled and Mapped by Reed S. Lewis

1998

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Introduction

The purpose of this compilation is to provide digital geologic map coverage for the Missoula West 30' x 60' quadrangle. Existing geologic mapping was compiled at 1:24,000 scale and supplemented with 10 weeks of field work in 1997. The field work was concentrated in the northern part of the area, north and northwest of Lolo Creek. The compiled maps were scanned and then attributed using an ARC/INFO format. Areas of preexisting mapping are shown in figures 1-3, and references are listed at the end of the text. Work by Hall (1968) in the northeast part of the area was used extensively, as were unpublished geologic maps of Chester Wallace and David Lidke of the U.S. Geological Survey. Without this previous work, the present project could not have been completed. However, numerous changes were made to both sets of maps, and the author is responsible for the final interpretation shown herein.

Structure

The area with the least amount of structural complexity is in the north-central part of the map along the west side of Petty Mountain and Telephone Butte. A significant section of the Belt Supergroup is exposed here, from the Wallace Formation up to the upper part of the Mount Shields Formation. Good exposures are present, and this is the best area for stratigraphic studies. Thrust faults and later normal faults have disrupted the stratigraphic sequence both to the west and east of this area, but in a general sense one goes down section westward, as well as southward. The best exposures of the lower member of the Wallace Formation are on Crater Mountain west of Fish Creek. Rocks high in the stratigraphic section are generally poorly exposed but best seen along Deep Creek and Albert Creek. Metamorphic grade increases rapidly south of Lolo Creek, and sillimanite is present from Lolo Peak south (Wehrenberg 1971).

Four styles of faulting are present in the northern part of the area. Northwest-striking thrust faults of probable Cretaceous age are the oldest structures recognized. Examples include the Tarkio and Albert Creek thrusts (sections A-A' and B-B'). These faults place older rocks over younger rocks and portions of these structures are steep enough to be considered reverse faults. Normal faults are present behind and parallel to several of the thrusts, bringing young rocks of the hanging wall down again. These normal faults may merge at depth with the thrust faults, as shown in cross sections A-A' and B-B'. They probably formed as a response to relaxation after thrusting and are most likely latest Cretaceous or Tertiary in age. Two of the largest normal faults in the area are the Ninemile fault, north of Missoula, and the Boyd Mountain fault, which enters the map area near the northeast end of section A-A'. Both have a northwest strike, and a considerable component of down-to-the-southwest listric normal movement (Winston 1986; Sears 1988). Although the Boyd Mountain and Ninemile faults may also merge at depth with thrust faults, they are not as closely located to thrusts as those normal faults discussed above. Yin and Oertel (1995) have suggested that the Ninemile fault may have also had an earlier history involving thrust motion.

A second type of normal fault is represented by a single low-angle, nearly horizontal structure, with younger rocks on the upper plate. Interpreted here as a detachment, it is exposed in the western part of the area in several isolated exposures on the higher peaks (Kid Lake fault, section A-A'). This fault was previously interpreted as a thrust fault (Wallace and Lidke 1990; Lewis et al. 1992a), but the younger-over-older relations indicate normal movement, as do extensional quartz-filled gash veins in the hanging wall (Winston 1990). Kinematic indicators along the fault indicate movement of the upper plate from east to west (Knight 1997), opposite the vergence of thrust faults in the area. Age of this structure is uncertain, but most likely early Tertiary. A final group of normal faults are steep, with northerly or northeasterly strikes. The northeast set in and near the Lolo Hot Springs batholith (Nold 1968, 1974) is similar to other northeast-trending extensional faults with parallel dike swarms in the region and was probably active in Eocene time. The more northerly structures may be somewhat younger, possibly Miocene or Pliocene.

East-west faulting along and just south of Lolo Creek is complex and poorly understood. Langton (1935) originally mapped a south-side-up thrust in this area, as did Wehrenberg (1971). Later work by Rowe (1984) indicated normal movement along the Lolo Creek fault, with the south side up. This latest interpretation is shown on the present map. Regardless of the dip, south-side-up faulting is likely given the rapid southward increase in metamorphic grade in this area.

The Bitterroot mylonite (unit Tm on the map) is a major deep-seated shear zone that dips gently to the east at the Bitterroot front, and is domed to the west over the crest of Bitterroot Range (section C-C'). Kinematic indicators show top-to-the-east motion (Hyndman et al. 1975; Chase 1977; Hyndman and Myers 1988). Movement along this zone is thought to have occurred between 46 and 48 Ma during formation of a metamorphic core complex (Hodges and Applegate 1993), although it may have had Late Cretaceous dip-slip movement as well (Hyndman 1980). Alternatively, it may have been a west-dipping thrust zone that was reactivated as a result of Tertiary extension and tilted eastward. The mylonite zone has been eroded from the crest of the Bitterroot Range, but at least portions of it have been mapped to the west in Idaho (Lewis et al. 1992b). There it was termed the Spruce Creek mylonite zone, which dips westward. Kinematic indicators at Spruce Creek show top-to-the-east motion, but the westward dip indicates post-movement doming of the mylonite zone, a feature recognized by several workers in the area (Wehrenberg 1971; Hyndman,1980; Chase et al. 1983). The mylonite zone is cut by north-northeast-striking normal faults along the front of the Bitterroot range, and the mylonite on the east side of these structures dips westward (section C-C'). These range-front faults are Basin-and-Range style and are probably the youngest normal faults in the area; some appear to offset Quaternary glacial deposits to the south of the area (Barkman, 1984) and may be active.

Folding in the northern part of the area is typically along northwest-trending axes. The carbonate-bearing Wallace Formation was particularly susceptible to folding. This folding probably coincided with formation of the thrust faults during Cretaceous time. The area of high-grade metamorphic rocks south of Lolo Creek is structurally complex and has undergone multiple fold events (Wehrenberg 1971; Chase 1973, 1977). Folding was followed by formation of the Bitterroot mylonite zone, and then by doming. This doming, as well as the faulting along the range front, has exposed the deep structural levels we now see in the Bitterroot range.

Notes on Mechanical Properties of Units

Skip Hegman, geological engineer on the Missoula District of the Lolo National Forest, has provided the following information regarding the road-building characteristics and erosive nature of several of the rock units in the map area. The best material for road surfaces is argillite and siltite of the McNamara, Mount Shields, and Snowslip formations. Red argillite is preferable to less durable green argillite. Contact-metamorphosed rocks of the Wallace Formation are also suitable for road material. In flat areas or along faults the Bonner Quartzite weathers to a clay-rich soil due to weathering of potassium feldspar grains. The Shepard Formation weathers readily, forms dusty roads, and can be a source of silt into streams. On south-facing slopes the middle member of the Wallace Formation is resistant and requires ripping during road construction. On north-facing exposures or along faults this unit weathers readily to orange, clay-rich soils and requires graveling along road surfaces. The middle member of the Wallace is a significant sediment producer in the area. The Hasmark Formation forms clay-rich soils, but where unweathered, it requires blasting during road construction. The Tertiary granite unit is highly erosive, and Forest Service roads with grades over 5 % in granitic rock have to be graveled. The TKgd unit (granodioritic rocks) weathers to large boulders that hamper road construction.

Description of Lithologic Units

Qal ALLUVIUM OF MODERN CHANNELS AND FLOOD PLAINS (QUATERNARY)
Well-rounded gravel and sand with lesser amounts of silt and clay.

Qao OLDER ALLUVIUM, UNDIVIDED (QUATERNARY)
Includes alluvial terrace deposits, braided stream deposits, alluvial fan deposits, and glacial outwash deposits.

Qat ALLUVIUM OF ALLUVIAL TERRACE DEPOSIT (QUATERNARY)
Well-rounded cobbles, gravel, and sand in deposits with flat-topped surfaces that are 10-30 ft (3-9 m) above the present flood plain.

Qls LANDSLIDE DEPOSIT (QUATERNARY)

Unconsolidated material, typically clay-rich, that has moved down slope. Common northwest of Missoula in Tgc unit, particularly where it is overlain by more permeable Taf unit (Harris 1997).

Qgl GLACIAL LAKE DEPOSIT (QUATERNARY)
Varved, light-brown clay and silt of Glacial Lake Missoula.

Qgt GLACIAL TILL (QUATERNARY)
Poorly sorted deposits of boulders and finer material in high mountain valleys.

Tsf FLUVIAL SEDIMENTARY DEPOSIT (MIOCENE THROUGH PLIOCENE)
Unconsolidated material consisting of weathered cobbles and finer-grained sediment. Cobbles in the upper Petty Creek area are Belt Supergroup, primarily quartzite, suggesting either a local source or a northerly source. Exposure immediately north of Missoula is described as conglomerate by Harris (1997).

Taf ALLUVIAL FAN DEPOSIT (MIOCENE THROUGH PLIOCENE)
Locally derived, poorly sorted, angular to rounded boulders, cobbles, gravel, sand, and silt. Probably equivalent to the Sixmile Formation of southwest Montana (Sears 1997).

Tgc GRAVEL AND CLAY (EOCENE THROUGH MIOCENE)
Channel and flood plain deposits of the ancestral Bitterroot and Clark Fork rivers. Includes well-sorted and well-rounded cobbles, gravel, sand, silt, clay, and volcanic ash deposits. Clasts are not locally derived. Marked angular unconformity at top of unit near Missoula is overlain by Taf unit. To the south in the Bitterroot Valley the underlying Tgc beds are not as steeply dipping and this contact is a disconformity. Coarser intervals are permeable, but clay-rich zones are not. Probably equivalent to the Renova Formation of southwest Montana (Jim Sears, pers. comm., 1997).

Tr RHYOLITE DIKE (EOCENE)
Buff to light gray with variable amounts of smoky quartz and potassium feldspar phenocrysts. Entirely glassy (gray vitrophyre) in exposures north of Montana Creek. Large dike west of the Lolo Hot Springs batholith is locally syenitic in composition and, like many of the dikes, follows preexisting faults (Simpson, 1985; Lewis 1992a).

Ttr RHYOLITE TUFF (EOCENE)
Pink to buff crystal-rich tuff containing approximately 30% phenocrysts of smoky quartz and sanadine in an aphanitic matrix.

Td DACITE DIKE (EOCENE)
Gray, porphyritic rocks with plagioclase, biotite, and hornblende phenocrysts in

an aphanitic matrix.

Tvf FELSIC VOLCANIC ROCKS (EOCENE)
Gray, porphyritic, volcanic tuffs or lava flows northwest of the Lolo Hot Springs batholith (Simpson 1985). Unit includes poorly exposed rhyolite flows(?) or dikes(?) southwest of Florence.

Tg GRANITE (EOCENE)
Light-gray to pale-pink, nonfoliated biotite monzogranite. Largest mass is the Lolo Hot Springs batholith, which is mostly medium grained but which contains some fine-grained zones, particularly near the margins (Leischner 1959; Simpson 1985). Alkali feldspar is strongly perthitic, and miarolitic cavities contain smoky quartz and alkali feldspar crystals. Smaller body in extreme southwest part of map is poorly mapped but is distinguished from the Idaho batholith by $K_2O>Na_2O$, <400 ppm Sr, and well-developed perthite. It has been mapped only in the Ranger Peak area on the Idaho side of the state line (Lewis et al. 1992b) and is projected into Montana on the basis of geochemical analyses (samples IG32A, IG33A, and IG37A) of Shuster and Bickford (1985).

Tm MYLONITIC ROCKS (EOCENE)
Well-foliated and well-lineated mylonite along the front of the Bitterroot Range. Rocks have a granitic protolith south of Bass Creek and a metasedimentary protolith to the north. Movement is down-to-the-east based on shear-sense indicators (Hyndman et al. 1975; Hyndman and Myers 1988).

TKgd GRANODIORITIC ROCKS (EOCENE AND CRETACEOUS)
Primarily medium-grained, nonfoliated biotite granodiorite but also includes fine-grained biotite granodiorite, hornblende-biotite granodiorite, tonalite, and quartz diorite, some of which is foliated. These rocks, previously mapped as the Skookum Butte stock (Nold 1968, 1974), almost certainly represent more than one period of intrusion. Granodiorite in the west in the Sally Basin area is characterized by euhedral biotite crystals, interstitial potassium feldspar and quartz, and a relatively narrow zone of contact metamorphism. These features suggest shallow emplacement levels and a probable Eocene age. More nearly equigranular rocks at Skookum Butte are similar in appearance to Cretaceous granodiorite of the Idaho batholith. Rocks in the central part of the unit weather to large boulders that, although they resemble glacial deposits, are probably in situ.

TKgb DIORITE AND GABBRO (TERTIARY OR CRETACEOUS)
Fine-grained diorite and gabbro consisting of plagioclase, hornblende, and pyroxene. Typically occurs as thin dikes and sills, but also present as larger masses.

Kgd BIOTITE GRANODIORITE (CRETACEOUS)

Foliated and nonfoliated fine- to medium-grained (muscovite-) biotite granodiorite. Includes rocks mapped as granitic sheets by Wehrenberg (1971). Largest mass in the southern part of the area is part of the Idaho batholith, and there it contains zones with megacrystic potassium feldspar (Chase 1973; Shuster and Bickford 1985). The batholith in general is characterized by $Na_2O>K_2O$, except where megacrystic, in which case K_2O exceeds Na_2O. The age of the batholith in this area is uncertain, in part due to inheritance of Precambrian zircon and the possible disturbance of the U-Pb system during Eocene mylonitic deformation (see discussions in Bickford et al. 1981; Shuster and Bickford 1985; and Foster and Fanning 1997). Three U-Pb zircon ages of 69 to 75 Ma (Shuster and Bickford 1985; Toth and Stacey 1992) from along the Lochsa River west of the map area are probably the best age estimate for the Kgd unit. Samples near and in the mylonite zone give Eocene U-Pb zircon ages (Chase et al. 1983; Foster and Fanning 1997).

Kto TONALITE (CRETACEOUS)

Foliated, medium-grained, biotite- and hornblende-biotite tonalite and granodiorite. Sphene fission track ages of 81 and 85 Ma from similar rocks just west of the map area (Ferguson 1975) provide the best age estimates for this unit.

Crl RED LION FORMATION (CAMBRIAN)

Described by Hall (1969) as interbedded silty dolomite, dolomitic siltstone, and green shale (Dry Creek Shale Member) overlain by interlaminated limestone and siltstone (Sage Member). The Sage Member is nodular and composed of distinctive gray micritic mottles that weather recessively within a groundmass of darker, more resistant silt and dolomite (Winston 1998). Thickness 300-373 ft (92-114 m).

Ch HASMARK FORMATION (CAMBRIAN)

Hall (1969) describes unit as cliff-forming, medium- to coarsely-crystalline, gray dolomite. Contains lenses, stringers, and irregular patches of chert. Thickness 1,860-2,000 ft (570-610 m).

Csh SILVER HILL FORMATION (CAMBRIAN)

Hall (1969) reports a limestone member, consisting of gray, orange-mottled limestone, local brown calcareous siltstone, and green shale, and a shale and glauconitic sandstone member consisting of interbedded green shale and greenish-gray glauconitic sandstone. Thickness 465 ft (142 m).

Cf FLATHEAD QUARTZITE (CAMBRIAN)

Vitreous quartzite. Not mapped by Hall (1969), who showed all quartzite below the Silver Hill as Pilcher Quartzite. Projected into area based on mapping to the north by Wells (1974), who estimated the thickness to be 40-100 ft (12-31 m).

According to Winston (1998) the Flathead in the Missoula area is only 10-20 ft (3-6 m) thick and composed of green, glauconitic quartzose sandstone with tracks and trails.

Yan ANORTHOSITE (PROTEROZOIC?)
Massive to foliated, light-gray, medium-grained anorthosite. Berg (1965) speculated that the anorthosite bodies were residual from a melting event rather than intrusive in origin, in which case a Cretaceous age would be more likely than Proterozoic.

BELT SUPERGROUP

Ypi PILCHER QUARTZITE (MIDDLE PROTEROZOIC)
Coarse- to medium-grained, reddish or buff quartzite containing thin beds of sandy argillite as well as detrital muscovite. Characterized by trough cross-beds with distinctive alternating purple and light gray cross laminae (Winston 1998). Thickness uncertain, but 350-400 ft (110-120 m). Probably remains below the unconformity with the overlying Flathead Quartzite.

Ygr GARNET RANGE FORMATION (MIDDLE PROTEROZOIC)
Tan-weathering, grayish-green micaceous quartzite and impure argillite. Thickness was probably on the order of 3,000 ft (920 m) in the area based on estimates from adjoining areas (Hall 1969), but a complete section is no longer present.

Ym MCNAMARA FORMATION (MIDDLE PROTEROZOIC)
Red and green interbedded argillite and siltite, and buff quartzite. Contains distinctive green and red chert beds and clasts. Mudcracked, rippled and even silt and fine sand to clay couplets are common; less common are horizontally laminated sand beds (Winston 1998). Thickness in the map area is uncertain but probably on the order of 2,000-3,000 ft (610-915 m).

Ybo BONNER QUARTZITE (MIDDLE PROTEROZOIC)
Pink or buff, medium- and coarse-grained feldspathic quartzite. Matrix-supported granules and pebbles present locally. Abundant trough cross-beds. Contains 15 to 25% potassium feldspar, but only trace amounts of plagioclase. Thickness in the map area is uncertain, but probably on the order of 1,000-2,000 ft (300-610 m).

Yms MOUNT SHIELDS FORMATION, UNDIVIDED (MIDDLE PROTEROZOIC)
Quartzite and subordinate argillite and siltite in lower part of section. Upper part is predominantly argillite and siltite. Typical reddish color is bleached out to light gray in the Fish Creek drainage, probably as a result of metamorphism and (or) hydrothermal alteration. Exposures do not permit subdividing the unit in this

area.

Yms$_3$ MOUNT SHIELDS FORMATION, MEMBER 3 (MIDDLE PROTEROZOIC)
Reddish argillite and siltite with lesser amounts of green siltite and argillite and thin-bedded quartzite. Thin dolomitic zone in uppermost part of section. Contains salt casts that are otherwise rare in the Belt Supergroup. Thickness is uncertain but probably on the order of 2,000-2,500 ft (610-760 m).

Yms$_2$ MOUNT SHIELDS FORMATION, MEMBER 2 (MIDDLE PROTEROZOIC)
Reddish very fine- to medium-grained quartzite and lesser amounts of argillite and siltite. Thin layers of dolomitic rock present locally. Abundant planar laminations and ripple cross laminations. Upper 200 ft (61 m) of section are the coarsest, and can be difficult to distinguish from the Bonner Quartzite. Sampling in the northern part of the area indicates subequal amounts of plagioclase and potassium feldspar (25-35% total) in contrast to the plagioclase-poor Bonner Quartzite. Hall (1969) measured a section of member 2 on Petty Mountain, which at the time was thought to be Bonner Quartzite. A total thickness of 900 ft (275 m) was determined. Mount Shields member 1 was not recognized in the Missoula West quadrangle, but is present to the east in the northern part of the Butte 1 x 2 degree quadrangle (Slover and Winston 1986).

Ysh SHEPARD FORMATION (MIDDLE PROTEROZOIC)
Green microlaminated argillite, and thin lenticular beds of green dolomitic siltite and fine-grained quartzite. Dolomitic beds have characteristic orange-brown weathering rinds. Uppermost part is a distinctive pinkish-red, thinly bedded dolomitic quartzite and siltite. Abundant load casts and ripple marks. Poorly exposed and easily missed when mapping. Unit has formed calc-silicate rocks next to the Lolo Hot Springs batholith and contains scapolite in the Kid Lake area. Included in the uppermost part of the Miller Peak Formation by previous mappers in the Missoula area (Nelson and Dobell 1961). Section of the Miller Peak Formation measured by Hall (1969) on Petty Mountain included approximately 850 ft (260 m) of the Shepard Formation, but this part of section was poorly exposed. Unit appears thicker west of Petty Creek.

Ysn SNOWSLIP FORMATION (MIDDLE PROTEROZOIC)
Green and red argillite and siltite in the lower and middle parts of the section. Uppermost 200 ft (61 m) of section is reddish quartzite that is difficult to distinguish from member 2 of the Mount Shields Formation. Abundant straight-sided mud cracks in lower part of section. Hall (1969) measured a section on Petty Mountain that was assigned at that time to the lower part of the Miller Peak Formation. The Snowslip in that section is 2,975 ft (910 m) thick.

Yw WALLACE FORMATION, UNDIVIDED (MIDDLE PROTEROZOIC)
Primarily carbonate-bearing rocks of the middle member of the Wallace

Formation but may include green siltite and argillite of the lower member along the lower part of Lolo Creek.

Ywcs CALC-SILICATE ROCKS OF THE WALLACE FORMATION (MIDDLE PROTEROZOIC)
Green, diopside- and hornblende-rich rocks that are interlayered with thin quartzitic beds forming a calc-silicate gneiss (Nold 1968). Unit results from metamorphism of the middle member of the Wallace Formation (Ywm). More resistant to weathering than Ywm.

Ywm WALLACE FORMATION, MIDDLE MEMBER (MIDDLE PROTEROZOIC)
Dolomitic and calcareous siltite and quartzite, and black argillite. Minor amounts of green siltite and argillite. Quartzite beds show evidence of scour, along with hummocky cross stratification. Some quartzite is carbonate free. Tan-weathering dolomitic siltite with black argillite caps ("black and tan" rock type) is common. Unit is scapolite-bearing in the extreme western part of the area. Presence of black argillite and abundant calcite distinguishes these rocks from the Shepard Formation. Vertical fractures in quartzite are common, as are "birdsfoot" cracks on argillite surfaces. Orange-weathering dolomite-rich sedimentary breccia is present within the middle member. Clasts are predominantly white quartzite and range in size from less than a centimeter to several meters. Thickness of middle member highly uncertain, but probably on the order of 2,500-4,500 ft (760-1,370 m). No upper member of the Wallace Formation was mapped in this area, unlike in the Coeur d'Alene Mining District to the west. The upper member there is probably a lateral equivalent to the Snowslip and Shepard formations mapped in this study.

Ywl WALLACE FORMATION, LOWER MEMBER (MIDDLE PROTEROZOIC)
Green siltite and light green argillite predominate, typically with carbonate pods, but includes dolomitic siltite and quartzite. Bedding typically cyclical, with thin carbonate beds at the top of each cycle. Lower and middle parts are thinly bedded and the least quartzitic, and are probably lateral equivalents of the Empire Formation mapped just north of the area by Wells (1974). Thickness highly uncertain, but probably on the order of 3,000-5,000 ft (900-1500 m).

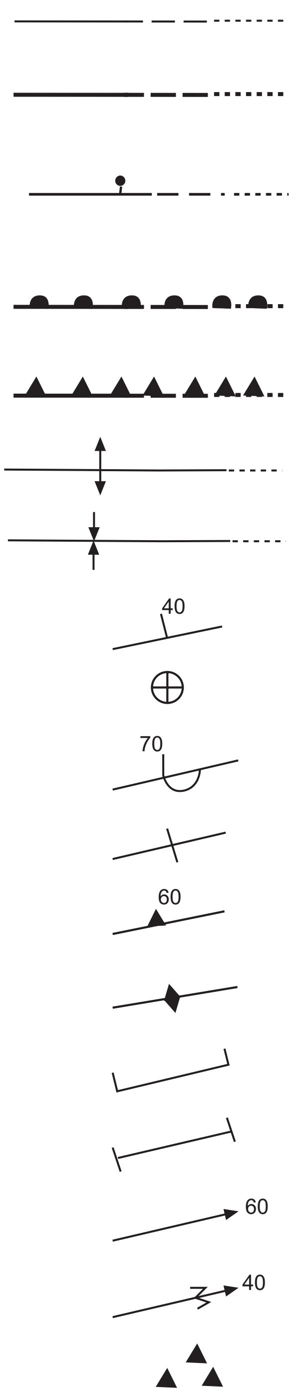
Yq QUARTZITE OF THE BELT SUPERGROUP (MIDDLE PROTEROZOIC)
Highly recrystallized quartzite and lesser amounts of phyllite and schist. These rocks are along strike with rocks of the Mount Shields Formation and were considered metamorphosed equivalents of the Mount Shields by C. Wallace and Lidke (1991). Previous workers assigned them to the Ravalli Group (Wehrenberg 1971; Winston 1991). Because these rocks are at structurally low levels, they are probably Ravalli Group equivalent.

Yqfg QUARTZOFELDSPATHIC GNEISS OF THE BELT SUPERGROUP (MIDDLE

PROTEROZOIC)
Gray-weathering, well-layered, quartz-rich feldspathic gneiss. Unit contains areas of unmapped granitic sills and dikes. Quartz content averages 51% and biotite 13% in the southwest part of the area (Chase 1973), where the rock clearly had a sedimentary protolith. Williams (1976) reports a lower quartz content (average 32%) for the Bass Lake area, and there the unit may include unmapped granitic rock. Includes the gray-weathering gneiss units of Anderson (1959) and Wehrenberg (1971). Chase (1977) correlates these rocks with the Ravalli Group of the Belt Supergroup, but previous assignments to the Prichard Formation (Anderson 1959; Wehrenberg 1971; Chase 1973) are more likely given the overall lack of quartzite in the unit.

Ysgn SCHIST AND GNEISS OF THE BELT SUPERGROUP (MIDDLE PROTEROZOIC)
Brown-weathering biotite- and muscovite-biotite schist, biotite-sillimanite gneiss, muscovite-biotite quartzite, and minor calc-silicate rocks. Quartz content averages 38%, biotite 24%, and sillimanite 12% in the southern part of the area (Anderson 1959; Chase 1973). Typically has feldspar augen, and contains an abundance of unmapped granitic sills and dikes, as well as minor amounts of garnet amphibolite (metamorphosed mafic sills). Increasing amounts of gneiss and igneous material southward. Calc-silicate rocks are present along Kootenai Creek one mile west of the range front. Includes rocks mapped as the brown-weathering gneiss of Wehrenberg (1971), pelitic schist of Williams (1976), and sillimanite gneiss of Anderson (1959) and Berg (1965). Previous workers have correlated these rocks to the Prichard Formation of the Belt Supergroup, at present considered the most likely protolith.

Map Symbols



Contact, dashed where inferred, dotted where concealed

Fault, dashed where inferred, dotted where concealed

Normal fault, dashed where inferred, dotted where concealed; ball and bar on downthrown side

Detachment fault, dashed where inferred, dotted where concealed; teeth on upper plate

Thrust fault, dashed where inferred, dotted where concealed; teeth on upper plate

Anticline, dotted where concealed

Syncline, dotted where concealed

Strike and dip of bedding

Horizontal bedding

Strike and dip of overturned bedding

Strike of vertical bedding

Strike and dip of foliation

Strike of vertical foliation

Strike and dip of cleavage

Strike of vertical cleavage

Bearing and plunge of lineation

Bearing and plunge of small fold axis

Sedimentary breccia

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References of Previously Mapped Areas
(see Figures 1-3)

1. Anderson, R.E., 1959, Geology of lower Bass Creek Canyon, Bitterroot Range, Montana: Missoula, University of Montana, M.S. thesis, 70 p., scale 1:20,000.

2. Berg, R.B., 1965, Petrology of anorthosite bodies, Bitterroot Range, Ravalli County, Montana: Missoula, University of Montana, Ph.D. thesis, 158 p.

3. Chase, R.B., 1973, Petrology of the northeastern border zone of the Idaho batholith, Bitterroot Range, Montana: Montana Bureau of Mines and Geology Memoir 43, 28 p., scale 1:49,000 (approximate).

4. Chase, R.B., 1977, Structural evolution of the Bitterroot dome and zone of cataclasis *in* Chase, R.B. and Hyndman, D.W., eds., Mylonite detachment zone, eastern flank of Idaho batholith: Geological Society of America, Rocky Mountain Section, 30th Annual Meeting, Field Guide 1, p. 1-24, scale 1:200,000 (approximate).

5. Groff, S.L., 1954, Petrography of the Kootenai Creek area, Bitterroot Range, Montana: Missoula, University of Montana, M.A. thesis, 80 p.

6. Hall, F.W., 1969, Bedrock geology, north half of Missoula 30' quadrangle, Montana: Missoula, University of Montana, Ph.D. thesis, 253 p., scale 1:48,000.

7. Harris, W.J., 1997, Defining benefit and hazard: distribution of upper and lower Tertiary units on the northeast flank of the Missoula Valley, Montana: Missoula, University of Montana, M.S. thesis, 117 p., scale 1:24,000.

8. Jerome, N.H., 1968, Geology between Miller and Eightmile Creeks, northern Sapphire Range, western Montana: Missoula, University of Montana, M.S. thesis, 49 p.,

scale 1:31,680.

9. Langton, C.M., 1935, Geology of the northeastern part of the Idaho batholith and adjacent region in Montana: Journal of Geology, v. no. 43, p. 27-60, scale 1:425,000 (approximate).

10. Leischner, L.M., 1959, Border zone petrology of the Idaho batholith in vicinity of Lolo Hot Springs, Montana: Missoula, University of Montana, M.A. thesis, 76 p. scale 1:24,000.

11. Lewis, R.S., Burmester, R.F., McFaddan, M.D., Eversmeyer, B.A., Wallace, C.A., and Bennett, E.H., 1992a, Geologic map of the upper North Fork of the Clearwater area, northern Idaho: Idaho Geological Survey Geologic Map Series, scale 1:100,000.

12. Lewis, R.S., Burmester, R.F., Reynolds, R.W., Bennett, E.A., Meyers, P.E., and Reid, R.R., 1992b, Geologic map of the Lochsa River area, northern Idaho: Idaho Geological Survey Geologic Map Series, scale 1:100,000.

13. Lonn, J., and Sears, J.W., in press, Preliminary geologic map of the Bitterroot Valley: Montana Bureau of Mines and Geology Open-File Report 362, scale 1:48,000.

14. McMurtrey, R.G., Konizeski, R.L., and Brietkrietz, Alex, 1965, Geology and groundwater resources of the Missoula Basin, Montana: Montana Bureau of Mines and Geology Bulletin 47, 35 p., scale 1:85,000 (approximate).

15. Nold, J.L., 1968., Geology of the northeastern border zone of the Idaho batholith, Montana and Idaho: Missoula, University of Montana, Ph.D. thesis, 159 p., scale 1:60,000 (approximate).

16. Ross, C.P., 1963, The Belt series in Montana: U.S. Geological Survey Professional Paper 346, 122 p., map compiled by Betty Skipp, scale 1:250,000.

17. Sears, J.W., Unpublished geologic mapping in the Missoula area, Montana, scale 1:24,000 (personal communication, 1997).

18. Seyfert, C.K., Unpublished geological mapping in the Lolo Creek area, Montana, scale 1:24,000 (personal communication, 1990).

19. Simpson, S.J., 1985, Structure and petrology of the Rhodes Peak cauldron, Montana and Idaho: Missoula, University of Montana, M.S. thesis, 105 p., scale 1:24,000.

20. Toth, M.I., 1983, Reconnaissance geologic map of the Selway-Bitterroot Wilderness, Idaho County, Idaho, and Missoula and Ravalli counties, Montana: U.S.

Geological Survey Miscellaneous Field Study Map MF-1495-B, scale 1:125,000.

21. Wallace, C.A., and Lidke, D.J., Unpublished geological mapping in the Admiral Peak area, Montana and Idaho, scale 1:24,000 (personal communication, 1990).

22. Wallace, C.A., and Lidke, D.J., Unpublished geological mapping in the northeast part of the Missoula West 1:100,000 scale quadrangle, Montana, scale 1:24,000 (personal communication to Dick Berg, Montana Bureau of Mines and Geology, and Norm Smyrs, U.S. Forest Service, 1995).

23. Wehrenberg, J.P., 1971, Geology of the Lolo Peak area, northern Bitterroot Range, Montana: Northwest Geology, v. 1, p. 25-32, scale 1:82,600 (approximate).

24. Williams, R.D., 1976, Structural and metamorphic geology of the Bass Lake area, northern Bitterroot Range, Ravalli County, Montana: Missoula, University of Montana, M.S. thesis, 53 p., scale 1:85,000 (approximate).

25. Winston, D., and Lonn, J.D., 1988, Structural geology and Belt stratigraphy of the Tarkio area, Montana, in Weidman, R.M., and Van der Poel, C., eds, Guidebook of the Greater Missoula Area: Tobacco Root Geological Society 13th Annual Field Conference, Road Log No. 1., p. 1-34.

Additional References

Barkman, Peter E., 1984, A reconnaissance investigation of active tectonism in the Bitterroot Valley, western Montana: Missoula, University of Montana, M.S. thesis, 85 p.

Bickford, M. E., Chase, R.B., Nelson, B.K., Shuster, R.D., and Arruda, E.C., 1981, U-Pb studies of zircon cores and overgrowths, and monazite: implications for age and petrogenesis of the northeastern Idaho batholith: Journal of Geology, v. 89, no. 4, p. 433-457.

Chase, R.B., Bickford, M. E., and Arruda, E.C., 1983, Tectonic implications of Tertiary intrusion and shearing within the Bitterroot Dome, northeastern Idaho batholith: Journal of Geology, v. 91, no. 4, p. 462-470.

Ferguson, J.A., 1975, Tectonic implications of some geochronometric data from the northeastern border zone of the Idaho batholith: Northwest Geology, v. 4, p. 53-58.

Foster, D.A., and Fanning, C.M., 1997, Geochronology of the northern Idaho batholith and the Bitterroot metamorphic core complex: Magmatism preceding and contemporaneous with extension: Geological Society of America Bulletin, v. 109, no. 4, p. 379-394.

Hodges, K. V., and Applegate, J. D., 1993, Age of Tertiary extension in the Bitterroot metamorphic core complex, Montana and Idaho: Geology, v. 21, p. 161-164.

Hyndman, D.W., 1980, Bitterroot dome-Sapphire tectonic block, an example of a plutonic-core gneiss-dome complex with its detached suprastructure: *in* Crittenden, M.D., Coney, P.J., and Davis, G.H., eds., Cordilleran Metamorphic Core Complexes: Geological Society of America Memoir 153, p. 427-443.

Knight, Jay, 1997, personal communication.

Hyndman, D.W., and Myers, S. A., 1988, The transition from amphibolite-facies mylonite to chloritic breccia and role of the mylonite in formation of Eocene epizonal plutons, Bitterroot dome, Montana: Geologische Rundschau, v. 77, no. 1, p. 211-226.

Hyndman, D.W., Talbot, J.L., and Chase, R.B., 1975, Boulder batholith: A result of explacement of a block detached from the Idaho batholith infrastructure?: Geology, v. 3., p. 401-404.

Nelson, W.H., and Dobell, J.P., 1961, Geology of the Bonner quadrangle, Montana: U.S. Geological Survey Bulletin 111-F, p. 189-235.

Nold, J.L., 1974, Geology of the northeastern border zone of the Idaho batholith, Montana and Idaho: Northwest Geology, v. 3, p. 47-52.

Rowe, D.W., 1984, Structural analysis of the Lolo Creek fault area, northern edge of the Bitterroot dome, west-central Montana: Missoula, University of Montana, undergraduate thesis, 45 p.

Sears, J.W., 1988, Changes in Late Cretaceous structural styles between Nine Mile and Drummond, Montana, in Weidman, R.M., and Van der Poel, C., eds, Guidebook of the Greater Missoula Area: Tobacco Root Geological Society 13th Annual Field Conference, Road Log No. 3., p. 42-54.

Sears, J.W., 1997, University of Missoula, personal communication.

Shuster, R.D., and Bickford, M.E., 1985, Chemical and isotopic evidence for the petrogenesis of the northeastern Idaho batholith: Journal of Geology, v. 93, no. 6, p. 727-742.

Slover, S.M., and Winston, Don, 1986, Fining-upward sequences in Mount Shields Formation members 1 and 2, central Belt Basin, Montana, in Roberts, S.M., ed., Belt Supergroup: A Guide to Proterozoic rocks of Western Montana and Adjacent Areas: Montana Bureau of Mines and Geology Special Publication 94, p. 169-181.

Toth, M.I., and Stacey, J.S., 1992, Constraints on the formation of the Bitterroot lobe of the Idaho batholith, Idaho and Montana, from U-Pb zircon geochronology and feldspar Pb isotopic data: U. S. Geological Survey Bulletin 2008, 14 p.

Wells, J.D., 1974, Geologic map of the Alberton quadrangle, Missoula, Sanders, and Mineral Counties, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1157, scale 1:62,500.

Winston, Don, 1986, Sedimentation and tectonics of the Middle Proterozoic Belt basin and their influence on Phanerozoic compression and extension in western Montana and northern Idaho, in Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountains: AAPG Memoir 41, p. 87-117.

Winston, Don, 1990, Missoula, University of Montana, personal communication.

Winston, Don, 1991, Missoula, University of Montana, personal communication.

Winston, Don, 1998, Missoula, University of Montana, personal communication.

Yin, An, and Oertel, Gerhard, 1995, Strain analysis of the Ninemile fault zone, western Montana: insights into multiply deformed regions: Tectonophysics, v. 247, p. 133-143.

Figures and Plates

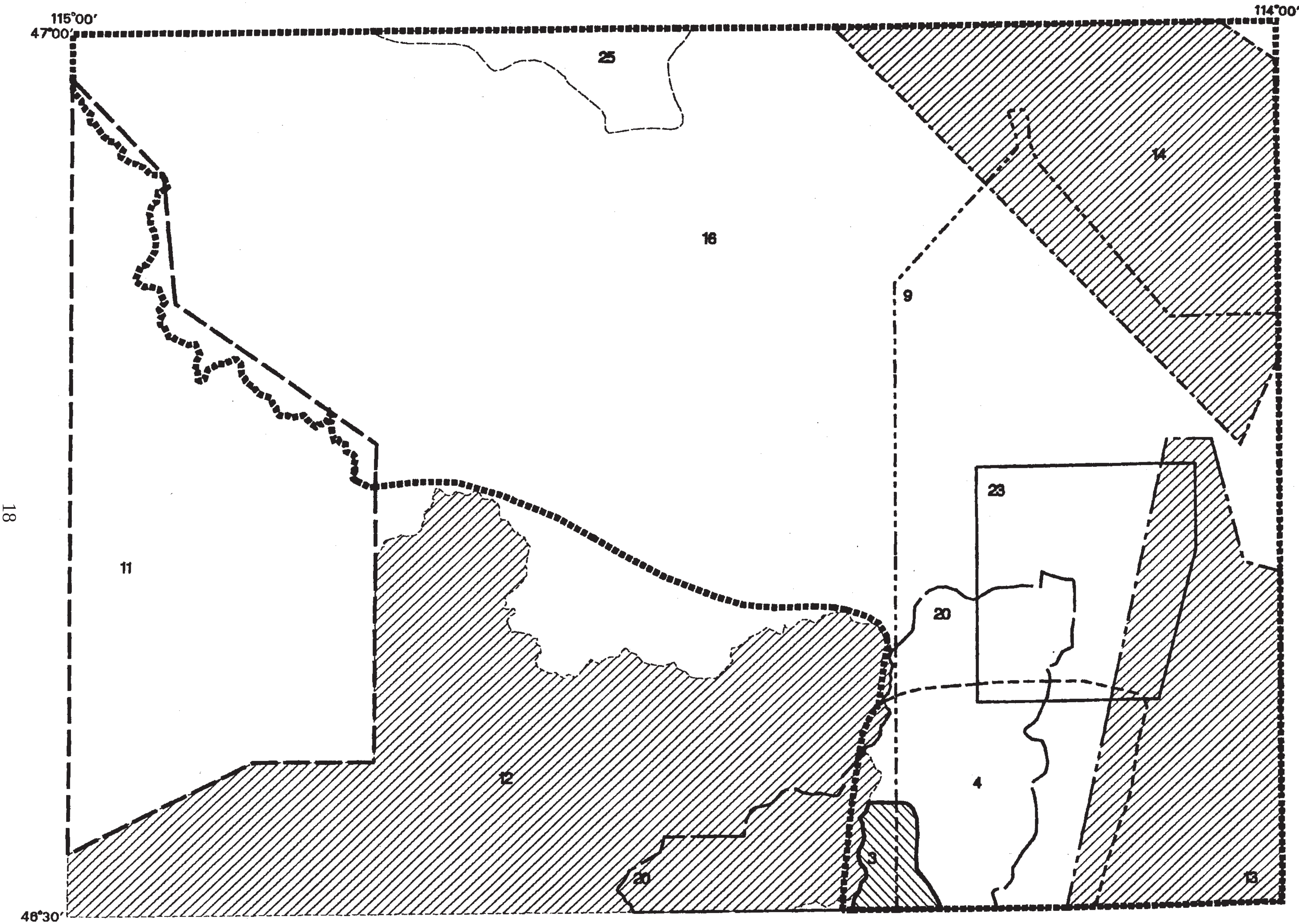

Figure 1. Areas of previously published mapping. See Reference section of text for references corresponding to numbered map areas.

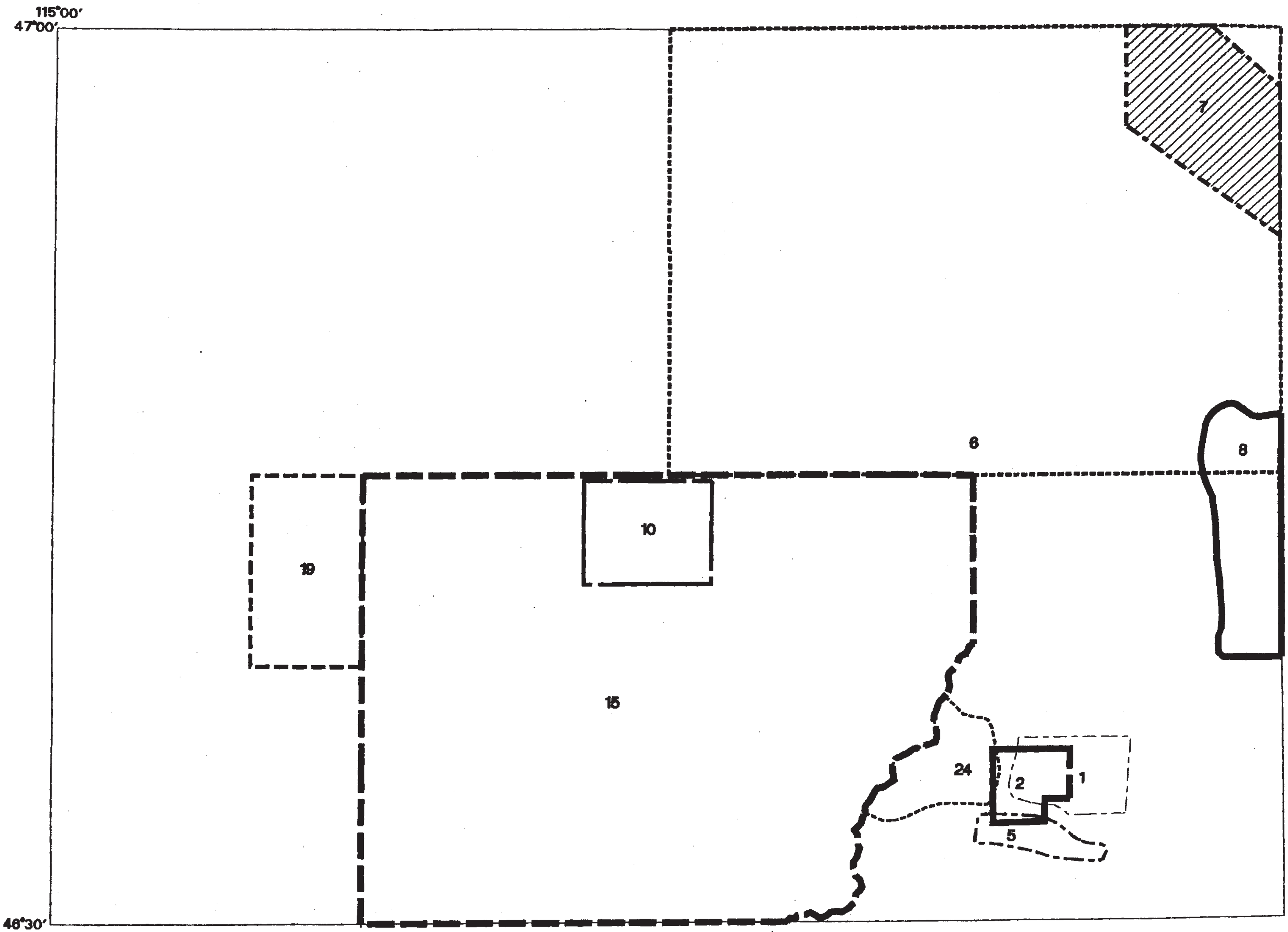

Figure 2. Areas of previously thesis mapping. See Reference
section of text for references corresponding to numbered map areas.

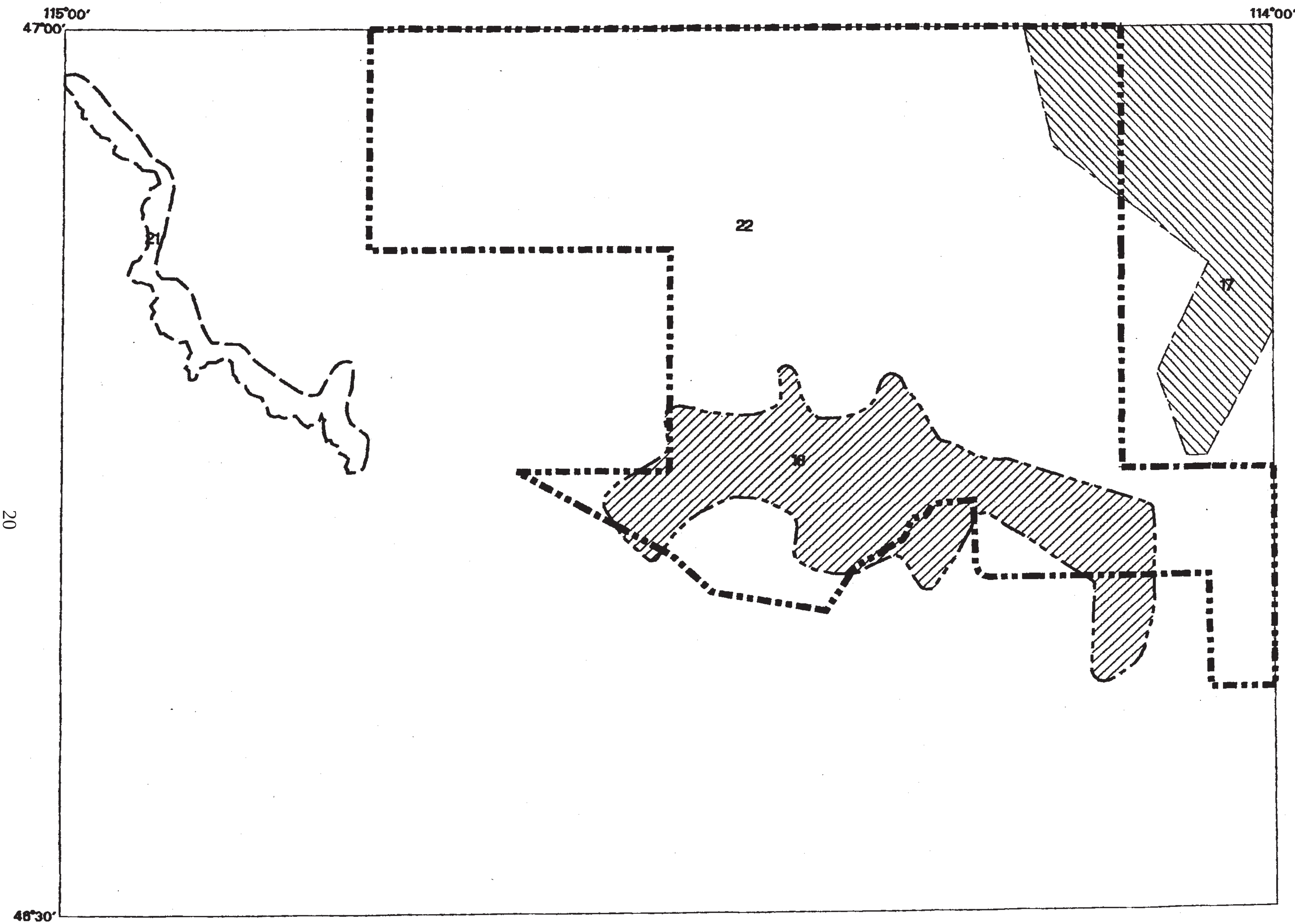

Figure 3. Areas of unpublished mapping. See Reference
section of text for references corresponding to numbered map areas.