TOBACCO ROOT GEOLOGICAL SOCIETY
13th ANNUAL FIELD CONFERENCE

GUIDEBOOK OF THE GREATER MISSOULA AREA

Compiled and edited by Robert M. Weidman
Assisted by Candis Van der Poel

1988

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Officers

Directors

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CONTENTS

ROAD LOGS:

ABSTRACTS:

ROAD LOG NO. 1
STRUCTURAL GEOLOGY AND BELT STRATIGRAPHY OF THE TARKIO AREA, MONTANA

Don Winston[1] and Jeff Lonn[1]

Initial point: Village Red Lion Inn parking lot
Distance: 102.2 miles
Highways: I-90, Fish Creek Road, old U.S. 10, various county roads
Field Stops:
No. 1 - I-90 Rest Area. Foot traverse.
No. 2 - I-90, Fish Creek Exit No.66.
No. 3 - Access road, Alberton Gorge.
No. 4 - Old railroad grade off county road to Quartz Creek Guard Station.
No. 5 - Old railroad grade, Micayune Gulch.

Introduction

Belt and Cambrian rocks are complexly folded and faulted in a segment of the western Montana fold and thrust belt (Winston, 1986d) that extends from the Jocko Mountains north of Missoula to the Coeur d'Alene district of Idaho. The Tarkio area, within this segment, contains both Belt rocks from the western part of the Belt basin and complex structures, which together bear on a variety of geologic hypotheses and problems of regional interest, making this excursion to the Tarkio especially important and timely. In particular, ripple-marked, mud-cracked argillite sequences of the Missoula Group in the Tarkio area illustrate the kinds of sedimentary structures upon which the lacustrine interpretation of the Belt (Winston, 1986b) is largely based. Folds and thrusts near Tarkio characterize the style of Mesozoic compression in the western thrust belt and are overprinted by Cenozoic high angle extensional faults. The Osborn fault, central to the concept of the "Lewis and Clark line" has been mapped from the Coeur d'Alene district into the Tarkio area, and Leach and others (1988) have proposed intense pre-Middle Cambrian folding along the Lewis and Clark line in the Coeur d'Alene district and near Superior, Montana, immediately northwest of Tarkio.

This field trip will provide participants an opportunity to see Belt mudflat sequences and judge for themselves whether they are lacustrine or marine. Participants will also see the Mesozoic folds and thrusts and Cenozoic normal faults and will be able to evaluate the structural analysis proposed by Lonn. They can also reflect on evidence for pre-Flathead folding and for the proposed Proterozoic age of the Lewis and Clark line in the Tarkio area. The lacustrine vs. marine interpretation of the Belt, a structural analysis of the Tarkio area, the question of pre-Flathead folding, and evidence for a Lewis and Clark line are discussed below.

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Sediment Types of the Great Belt Lake

The question of lacustrine vs. marine sedimentation in the Belt was first raised by Walcott (1910, 1916) and is still far from settled. History of the controversy was reviewed by Winston (1986b), and Grotzinger (1986) addressed the problem of distinguishing lacustrine from marine deposits in the middle Belt carbonate. Winston views the Belt basin to have been intracratonic, bordered by alluvial aprons that sloped down to an enclosed basin at times occupied by a large perennial lake, at other times occupied by ephemeral playas. The crux of the lacustrine and playa interpretation rests on sedimentologic analysis of the sandflat and mudflat deposits that bordered the lakes. Although thin bedded, ripple marked, mud cracked sequences immediately call to mind astronomic tide flats bordering an ocean, they also characterize playa flats in which processes of alternate flooding and desiccation are equally important. Playa deposits are simply not so well known to geologists in general.

The lacustrine interpretation presented here is based on the recognition and analyis of "sediment types", described by Winston (1986b). Geologists have long known that facies and facies sequences in the Belt are repeated at many levels and account for many of the problems of miscorrelation. Most of the Belt stratigraphy in the Tarkio area has been satsifactorily sorted out (Figure 1), and formations have been defined on grain size, composition and color (Winston, 1986A). Since color is in large part a post-depositional product, formations as presently defined are mixtures of sedimentologic, diagenetic, and in places metamorphic processes. In order to identify a purely sedimentologic framework, Winston (1986b) defined basic Belt sedimentary elements, or sedimentary "species", as "sediment types". Sediment types are based on repeated associations of grain size, original composition, and sedimentary structures. As such, they compare closely to lithofacies of some authors, but the term sediment type is used to emphasize their sedimentary unity. They comprise the basic sedimentary building blocks of the Belt and record the repeated expansion and contraction of long-lived suites of depositional environments that give rise to the repeated lithic sequences. Although sediment types are interpreted to record depositional environments, they are descriptively defined and identified. Winston (1986b) defined thirteen sediment types in the Ravalli Group, middle Belt carbonate and Missoula Group. More remain to be defined, but eight are chiefly represented in rocks of the Middle Belt carbonate and Missoula Group seen on this field trip. They are: the crossbedded sand, flat-laminated sand, the even couple, even couplet, lenticular couplet, microlamina, pinch-and-swell couple, and pinch-and-swell couplet sediment types (Figure 2). They are briefly described and interpreted here. For a more complete discussion of sediment types see Winston, l986b.

Crossbedded Sand Sediment Type

Description – Trough, planar and accretionary crossbedded coarse to fine sand, commonly forming the lower parts of sequences 50 cm to 3 m thick that fine upward through flat-laminated sand capped by silt or mud.

Interpretation - Channel deposits of braided streams that flowed in the lower regime, forming large scale bedforms recorded as trough and planar crossbeds.

Group	Formation	Member	Description
Middle and Upper Cambrian	Red Lion	Sage	Nodular limestone.
		Dry Creek	Green shale.
	Hasmark		Dolomite.
	Silver Hill		Shale and micritic limestone.
	Flathead		Fine- to medium-grained arenite.
Missoula Group	Garnet Range		Medium- to fine-grained arenite of quartz, feldspar and muscovite; hummocky cross stratification, dark olive green.
	McNamara		Fine-grained areinite and argillite of the even couple, even couplet, lenticular couplet and microlamina sediment types, purple and green.
	Bonner		Coarse- to fine-grained arenite of quartz, K spar, and chert, of the crossbedded sand, flat-laminated sand, and even couple sediment types, purple.
	Mount Shields	Member 4	Fine-grained argillite of the microlamina sediment type, green.
		Member 3	Fine-grained, arenite and argillite of the lenticular couplet, even couplet. even couple sediment types, ripples, mudcracks, mud chips, salt casts, red and green, calcareous on Lime Ridge plate.
		Member 2	Medium- to fine-grained arenite of quartz and feldspar, mostly of the flat-laminated sand sediment type, with less common intervals of the crossbedded sand and even couple sediment types, salmon red.
		Member 1	Fine-grained siltite and argillite of the even couple, even couplet and lenticular couplet sediment types, purple and green.
	Shepard	upper part	Fine-grained, calcareous and terrigenous argillite of the lenticular couplet and microlamina sediment types, dark gray, weathers tan.
		lower part	Fine-grained, very dark gray argillite that grades up to green and red argillite, capped by a bed of coarse quartzite; mostly of the microlamina and lenticular couplet sediment types, capped by a bed of the coarse sand and intraclast sediment type (Winston, 1986b), dark gray.
	Snowslip	Member 5	Medium- to fine-grained quartzite and argillite of the even couple and even couplet sediment types, mudcracked, purple.
		Member 4?	Green argillite of the lenticular couplet sediment type with hummocky couplets, green
		Members 1. 2, and 3?	Red and green argillite, even couple, even couplet and lenticular couplet sediment types, green and purple.
Middle Belt carbonate	Wallace		Gray and tan quartzite beds interstratified with black argillite, mostly of the pinch-and-swell couple, pinch-and-swell couplet , and microlamina sediment types, dark gray, calcareous beds weather tan.

Figure 1. Stratigraphic units of the Tarkio area.

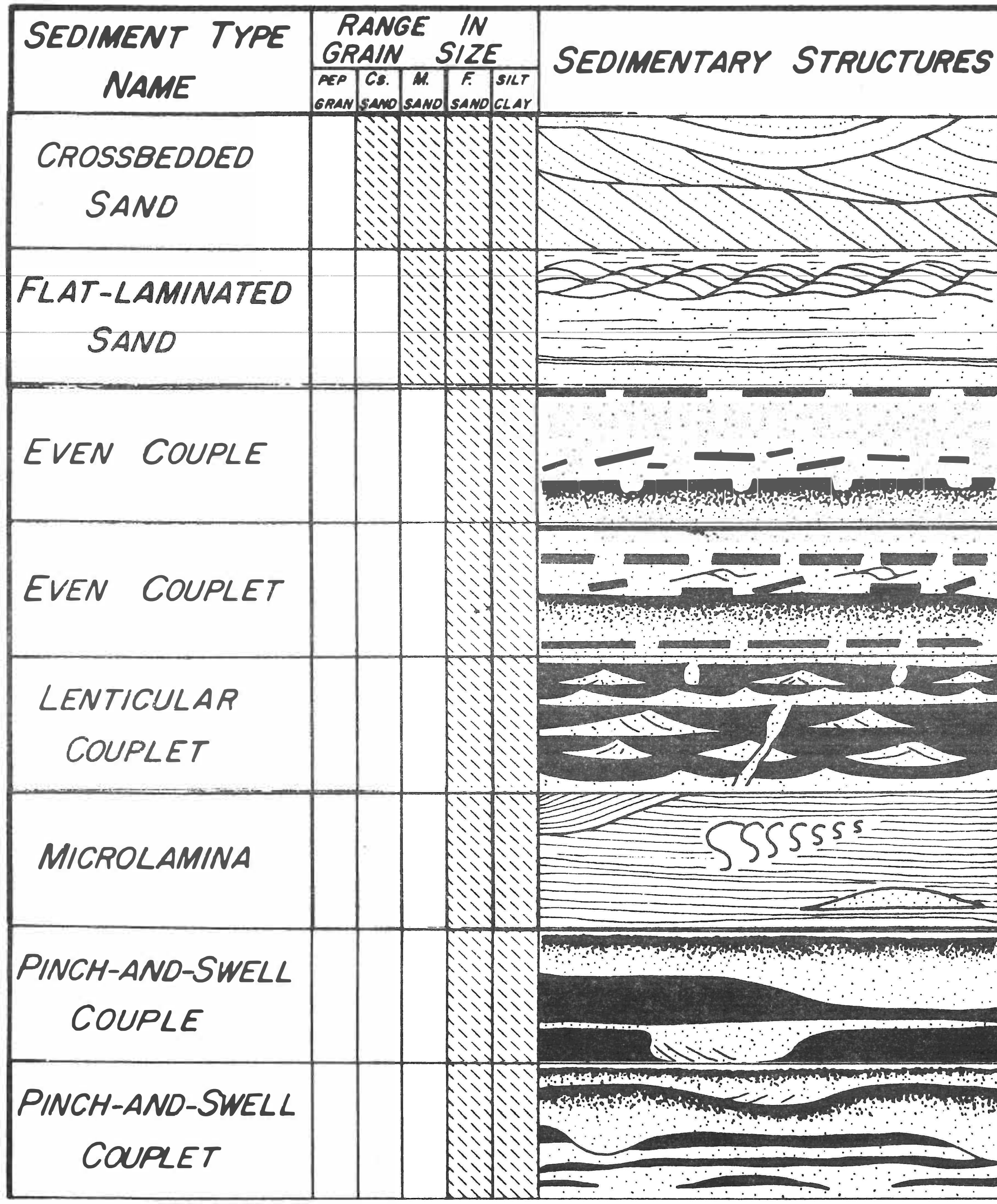

Figure 2. Belt sediment types of the Tarkio area.

Accretionary crossbeds were formed along the edges of shifting channels through which episodic floods flowed in the upper and lower regimes.

Flat-laminated Sand Sediment Type

Description - Tabular beds 10cm to 2 meters thick of fine- to medium-grained, feldspar, quartz sand that is mostly flat-laminated, but tends to pass to climbing ripples in the upper parts of some beds. The beds are capped by silt or mud beneath the sharp base of the overlying tabular sand bed.

Interpretation - Flat laminations record upper regime flow of sheetfloods across flat surfaces of the middle and lower, gently sloping parts of allvial aprons. Climbing ripples record decreasing flow velocity and shift to the lower flow regime; the mud caps record flow cessation. Stacks of tabular beds of the sediment type record repeated, episodic floods.

Even Couple Sediment Type

Description - Tabular beds 3 to 10 cm thick of mostly fine-grained, flat-laminated, feldspar and quartz sand, some of which contain mud chips and climbing ripples, and are capped by desiccated mud.

Interpretation - Like the flat-laminated sand sediment type, the flat laminations record upper regime sheetflood flow across sandflats at the toes of alluvial aprons. Mud caps record flow cessation.

Even Couplet

Description - Even layers 0.3 to 3 cm thick of graded silt or fine sand and silt to mud. Most silt layers are poorly to evenly laminated, but occasionally contain climbing ripples. Some couplets are cut by desiccation cracks and contain chips of transported mud polygons, others are uncracked.

Interpretation - Even mud cracked couplets were deposited by episodic floods across dried playa mudflats. Deposition from traction load was followed by mud settleout from suspension as the flooded playa lakes expanded across the mudflats. Uncracked couplets were deposited from episodic floods that entered the lake and deposited graded silt and clay layers from suspension.

Lenticular Couplet Sediment Type

Description - Thin beds 0.3 to 3 cm thick composed of a lower fine sand or silt layer with a flat base and straight-crested, rippled top, capped by mud. Some lenticular couplets are cut by desiccation cracks, others are not.

Interpretation - Sediments brought into the basin by floods remained submerged long enough for wind waves to rework the silt into ripples and resuspend the clay, which periodically settled out over the ripples.

Microlamina Sediment Type

Description - Thin, rather continuous layers from less than a millimeter to three millementers thick of silt laminae capped by clay or carbonate laminae. Some are carbonaceous and some are mud cracked. They commonly have small, tight, soft sediment folds and closely resemble lacustrine varves and oil shale.

Interpretation - Microlaminae record alternating silt and clay or carbonate mud deposition from suspension in protected, commonly shallow environments, beyond the reach of flood-induced sediments.

Pinch-and-Swell Couple Sediment Type

Description - Beds 3 to 10 cm thick of fine sand that grades up to dark mud. Bases of the sand layers are sharp and are loaded into black mud below, so that the sand layers thicken and thin across outcrops. The dark gray mud layers are commonly cut by contorted dikelets, and in some sequences the fine sand beds are calcareous.

Interpretation - Graded couplets were deposited by turbidite flows in the Great Belt Lake. As fine sand accumulated, it sank into the soft, carbonaceous mud below, forming the distinctive loads. Dikelets may have formed as water was expelled from the mud.

Pinch-and-Swell Couplet Sediment Type

Description - Beds 0.3 to 3 cm thick of fine sand or silt that grades up into

dark mud. Bases of the sand and silt layers are sharp and are loaded into black mud below. Dark mud layers are commonly cut by dikelets; some pinch-and-swell couplets are calcareous.

Interpretation - Graded pinch-and-swell couplets were deposisted by turbidity interflows and underflows in much the same way as the pinch-and-swell couples. Pinch-and-swell couplets are finer grained and thinner, reflecting more distal position in the Belt basin. Couples increase westward at the expense of couplets in the Wallace Formation, reflecting the source terrane of continent X to the west.

Sedimentologic Analysis

Stratigraphic analysis of the Ravalli and Missoula Groups demonstrates that packages characterized by the flat-laminated sand sediment type pass distally to those characterized by even couples, which in turn pass to even couplets, lenticular couplets and microlaminae (Winston, 1986b). Facies distributions of the flat-laminated sand to even couplet sediment types are interpreted to record episodic floods that flowed from alluvial aprons, across sandflats, mudflats and entered playa lakes as they expanded in response to the floods. The uncracked variety of the even couplet sediment type, lenticular couplet, microlamina, pinch-and-swell couple and pinch-and-swell couplet sediment types were deposited in standing lake water. The above interpretation closely resembles the facies tract of the Green River Formation described by Smoot (1963). The basinward fining and thinning, the aqueous expansion in response to flooding and close resemblance of microlaminae to oil shale are the most definitive evidence of internal lacustrine deposition. Absence of tidal channel deposits in the Belt clearly eliminates the astronomic tide flat interpretation.

Geologic Structure of the Tarkio Area

The other part of this field trip concerns the structural geology of the Tarkio area. It has been studied by Campbell (1960), Wells (1974), Harrison and others (1986) and Lonn (1984). Much of this section is from Lonn (1982). The Tarkio area lies within what Winston (1986d) has termed the western fold thrust belt (Plate 1). Although many geologists refer to the Montana fold and thrust belt, there are actually two of them: an eastern fold and thrust belt and a western fold and thrust belt.

The well known eastern thrust belt extends from the Canadian Front Range south through the Whitefish Range and Glacier Park, the Sawtooth and Lewis and Clark Range, the Big Belt and Little Belt mountains south to the Dillon block (northern part of the Archean Wyoming provence), where some thrusts steepen to Laramide style, and others wrap to the west and south around the Dillon Block through the frontal fold and thrust zone (Ruppel and others,1981).

The less well known western thrust belt extends north from the Grasshopper plate on the southwest (Ruppel and others, 1981) northward across the Perry line, through the Sapphire allochthon, where it swings west along the Garnet line (Winston, 1986d) and trends northwest through the Tarkio to the Jocko line (Winston, 1986d), where it swings sharply to the west and abuts the Spokane core complex. The Libby thrust system (Harrison and Cressman, 1985) may be a north-trending splay from the western thrust belt. Cretaceous folds and thrusts are cut by extensional, Tertiary faults, which in some places also appear to have reactivated parts of the thrust planes. Structural geology of both the Cretaceous folds and thrusts and the Tertiary listric normal faults in the Tarkio area important in understanding the western thrust belt. In particular, the Osburn fault, the principal structure of the "Lewis and Clark Line", passes southward to a thrust fault cutting Cambrian rocks.

Structural Elements of the Tarkio Area

The Tarkio area can be divided into five major domains or plates (Figure 3 and Plate 1), which differ from each other in structural style and the stratigraphic level of exposed sedimentary rocks. The domains, separated by major faults with large stratigraphic displacment and laterally persistent traces, are informally named here. From northeast to southwest they are 1) the Stark Mountain plate, 2) the Alberton plate, 3) the Lime Ridge plate, 4) the Tarkio plate, and 5) the Nemote Creek plate.

The northeasternmost domain, the Stark Mountain plate is bounded on the northeast by the Albert Creek thrust (Hall, 1968) and is composed of an east-dipping 8 km-thick pannel of Belt rocks ranging from the Revett on the

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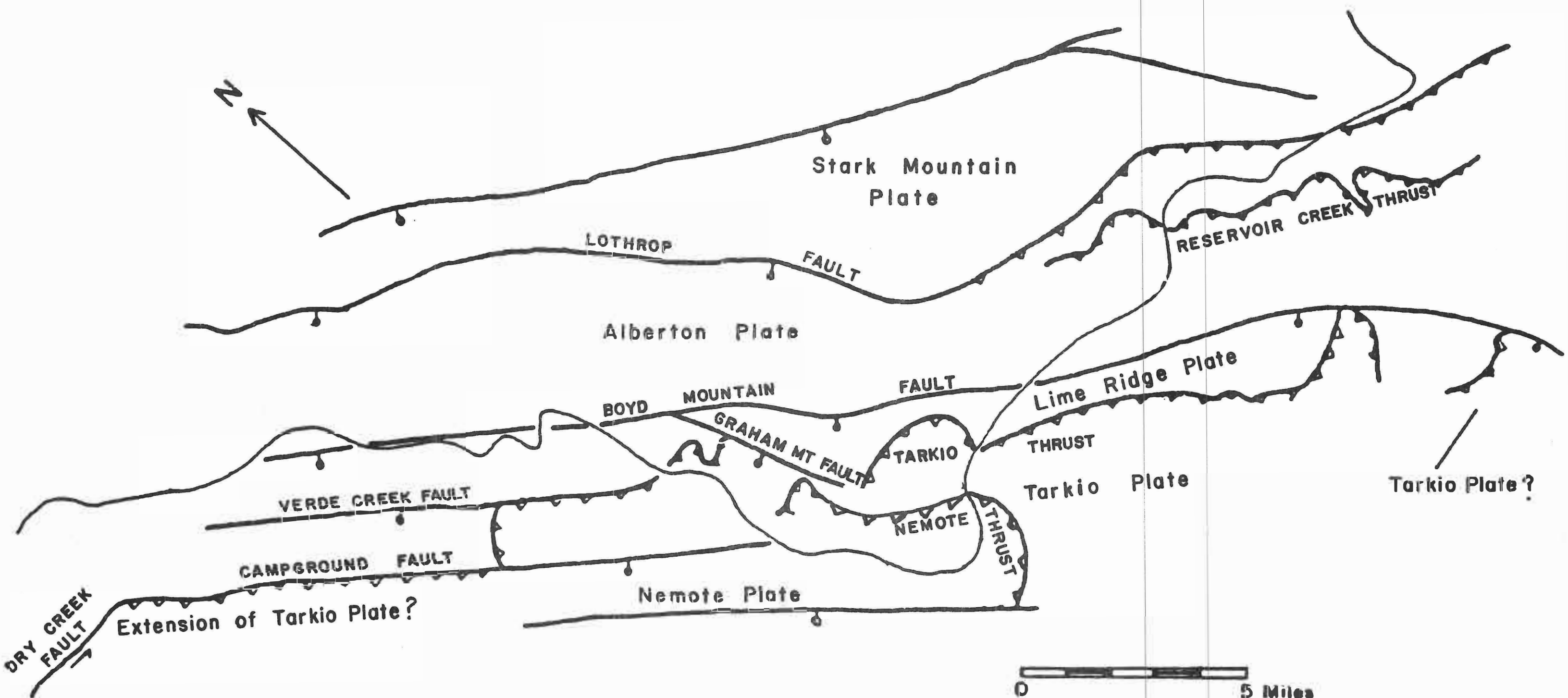

Figure 3. Generalized tectonic map of the Tarkio map area and surrounding area showing major plates and faults. Data outside Tarkio map area from Harrison and others, 1977; Hall, 1968.

northwest to Cambrian Flathead, Silver Hill, Hasmark and Red Lion formations on east of Alberton. The plate contains a small-scale reverse(?) fault within the Bonner and McNamara formations in the vicinity of Stark Mountain. Penetrative cleavage is developed in all units stratigraphiclly below the Mount Shields Formation.

Bounding the Stark Mountain plate on the west is a major northwest-trending normal fault that changes southward along strike to become a reverse fault near Alberton. Mapped on its northwestern end as an extension of the Osburn fault by Campbell (1960), and named the Lothrop thrust to the southeast by Hall (1968), it is here referred to as the Lothrop fault to avoid confusion with the Osburn fault of the Coeur d'Alene district. The northwest segment of the Lothrop fault with normal displacement may record reactivation of the Lothrop thrust by Tertiary extension. Based on right-lateral movement of the Osburn fault in the Coeur d'Alene district, Campbell (1960) and Harrison and others (1986) also plot strike slip displacement on the Lothrop fault. However, no field evidence for strike-slip movement on this or any other fault in the Tarkio area is evident.

Between the Lothrop fault and the Boyd Mountain fault to the southwest is the Alberton plate (Figure 3, Plate 1). Like the Stark Mountain plate, the Alberton plate also contains a very thick sequence of Belt rocks, in this case from the Revett Formation to the McNamara Formation, but penetrative cleavage extends up only into lower portions of the Wallace Formation. Rocks of the Alberton plate are deformed into broad, open folds, dominated by a doubly-plunging syncline, whose axis trends parallel to normal faults of the region. A thrust fault, the Reservoir Creek thrust (Hall, 1968) emerges from the west flank of this syncline in the southeastern part of the area, carrying the overturned Reservoir Creek anticline in the hanging wall. The Reservoir Creek thrust is probably a splay of the Lothrop thrust exposed to the east.

The Boyd Mountain fault separates the Alberton plate from the Lime Ridge plate (Figure. 3, Plate 1). It extends for at least 50 km (31 miles) from near Lolo Creek on the south (Hall, 1968) to the Osburn fault zone on the northwest. Normal, down-to-the-southwest movement is evident along its entire length. Apparent stratigrahic separation ranges from less than 100 meters to thousands of meters.

Units from the Mount Shields member 3 through the Hasmark comprise the Lime Ridge plate. Like the Alberton plate, the Lime Ridge plate has a southeasterly plunge in the northwest portion that flattens to the southeast. This plate contains one normal fault, the Graham Mountain fault, a splay of the Boyd Mountain fault, with stratigraphic offset of about 300 meters (1,000 ft.)

The Tarkio plate (Figure 3, Plate 1) has been thrust over the Lime Ridge plate along the Tarkio thrust. On its southern end, the Tarkio thrust places Wallace over Mount Shields member 3, but to the north it climbs abruptly and places Mount Shields member 2 over McNamara through a lateral ramp (Figure 3, Plate 1). This thrust is cut by the down-to-the-west, normal Graham Mountain fault, but its thrust trace is exposed to the northwest, where Mount Shields member 2 has been thrust over Hasmark. Farther north, the thrust joins the Verde Creek fault of Campbell (1960), which probably initiated as a reverse fault. The Tarkio plate as a flat plunge and is composed of Wallace and lower Missoula Group rocks.

The most westerly plate of the immediate area is the Nemote Creek plate. It consists of a small slice of Wallace brought over the Tarkio plate along the Nemote thrust. This thrust plate probably continues southwest of the Clark Fork River, where Wallace crops out (Plate 1), but the structure has not been fully mapped. Neither the rocks of the Nemote Creek plate nor those of the Tarkio plate are penetratively cleaved within the Tarkio map area or to the northwest (Laudon, 1978).

To summarize, the structural geometry of the Tarkio area is characterized by a series of elongate, northwest-trending plates, bounded by southwest-dipping thrusts and normal faults. The relationship among these plates is analyzed below.

Structural Analysis

Cross Sections - The structural interpretation is best illustrated by cross sections and fence diagrams (Figures 4 - 9), and the geologic map (Plate 1). The cross sections were constructed according to the principles developed by Dahlstrom (1969, 1970) and Price (1981) for thrusts in the Canadian Rockies and by Boyer and Elliot (1982) for thrusts systems in general. Generally, and in the Tarkio area, thrusts cut upsection in the direction of tectonic transport, propagate parallel to incompetent beds, cut deeply through competent ones, and do not decapitate anticlines and synclines.

The gentle plunge within the Tarkio area did not permit the use of down-plunge projection techniques (Stockwell, 1960) in the Tarkio area. However, the plunge exposes deeper structural and stratigraphic levels northwest of the Tarkio area (Campbell, 1960; Harrison and others, 1986) and provides qualitative conformation of the relationships between fault plates in the Tarkio area and the reveals the structural characteristics of the faults at depth.

The cross sections are balanced (Dahlstrom, 1969) to provide a valid structural framework. Within this framework, the cross sections were constructed to illustrate the least complicated interpretation, although other interpretations are considered below.

Because the Stark Mountain plate contains the most fully developed slaty cleavage, it is considered to be the structurally lowest plate. It was probably overridden by the Alberton plate along the Lothrop thrust. The long syncline in the Alberton plate immediately east of the Lothrop thrust probably indicates that the Alberton plate rode up a ramp in the Lothrop thrust throughout the Tarkio area. As pointed out above, extensional movement along the northern segment of the Lothrop fault has reactivated it into a listric normal fault. Listric rotation requires the Lothrop fault to flatten at depth, probably within the Wallace Formation. Gliding within the Wallace is supported in the tightly overturned anticline within the southern part of the Alberton plate which contains Wallace in its core.

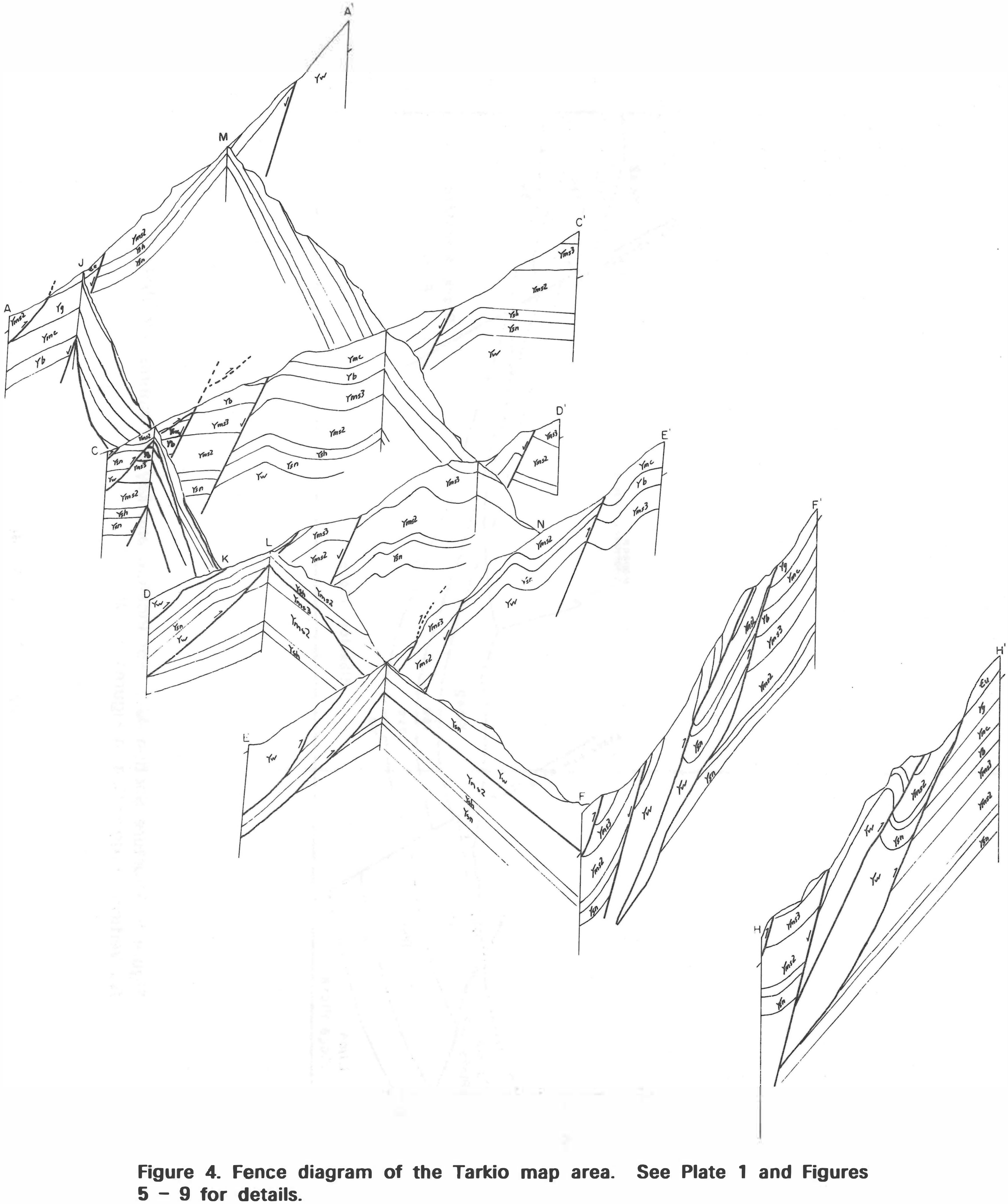

Figure 4. Fence diagram of the Tarkio map area. See Plate 1 and Figures 5 – 9 for details.

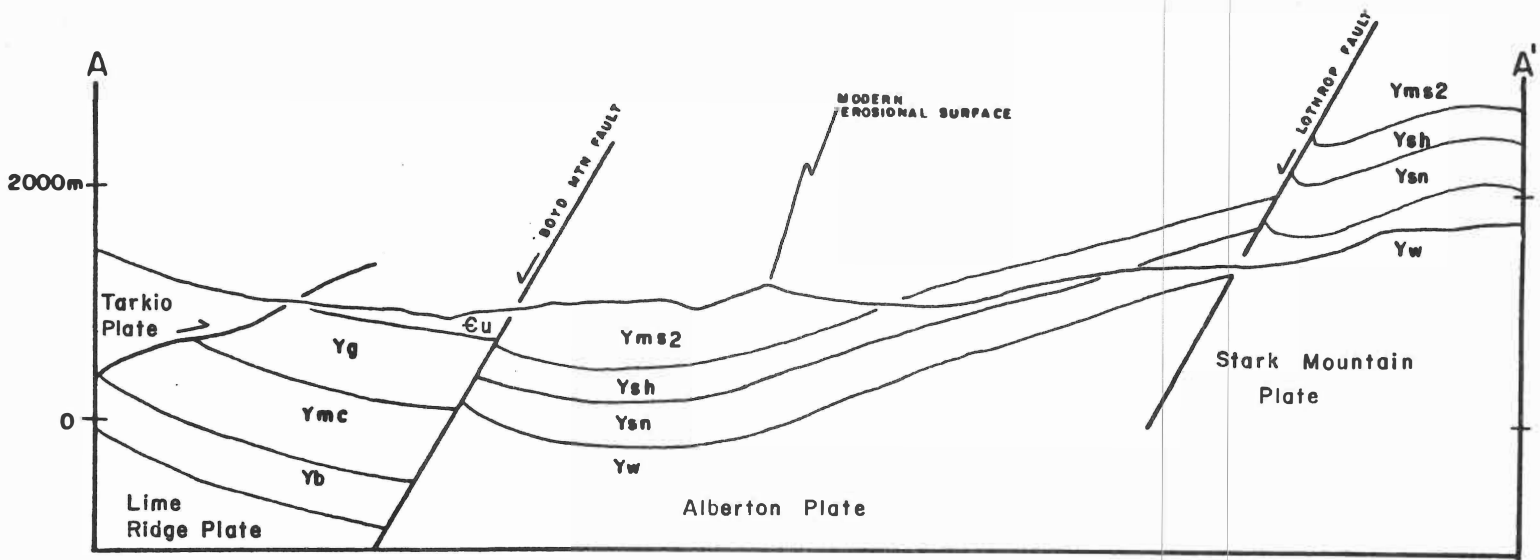

Figure 5. Structure Section AA'. For location and key to symbols see Plate 1. No vertical exaggeration in Figures 5 – 9.

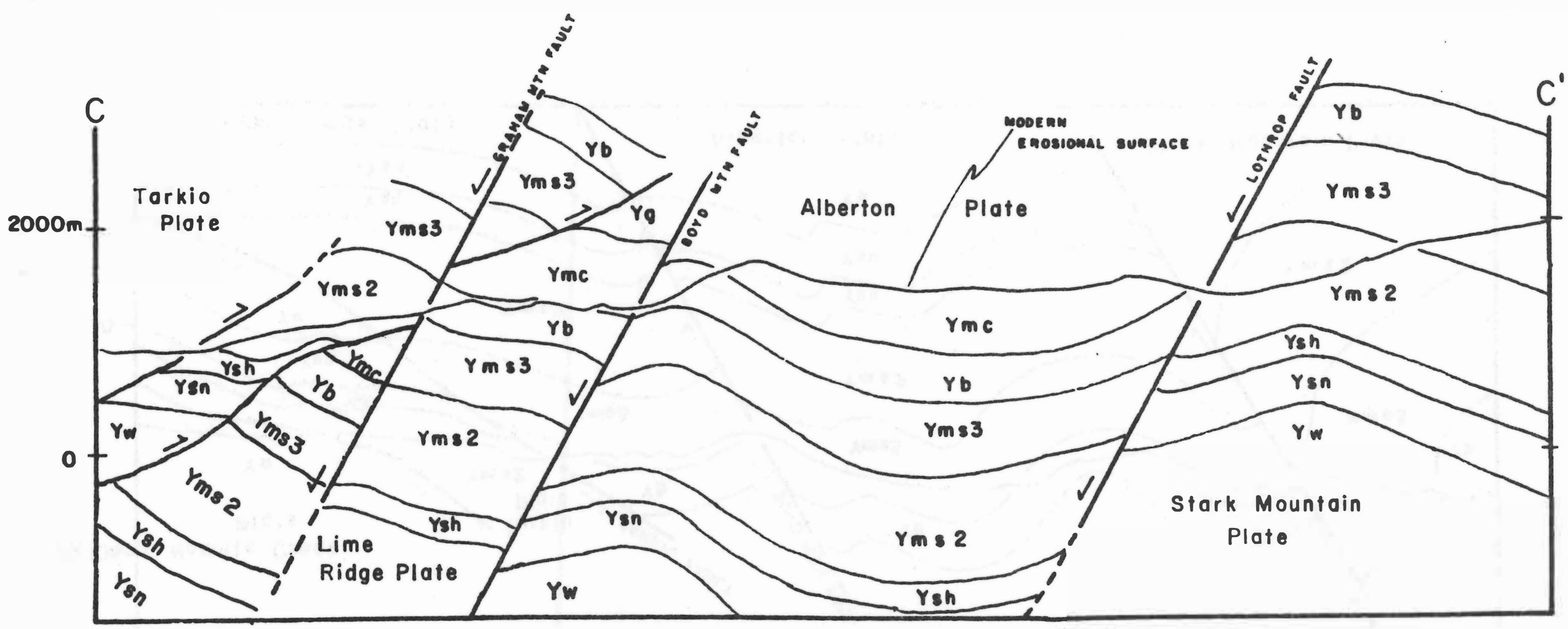

Figure 6. Structure Section CC′.

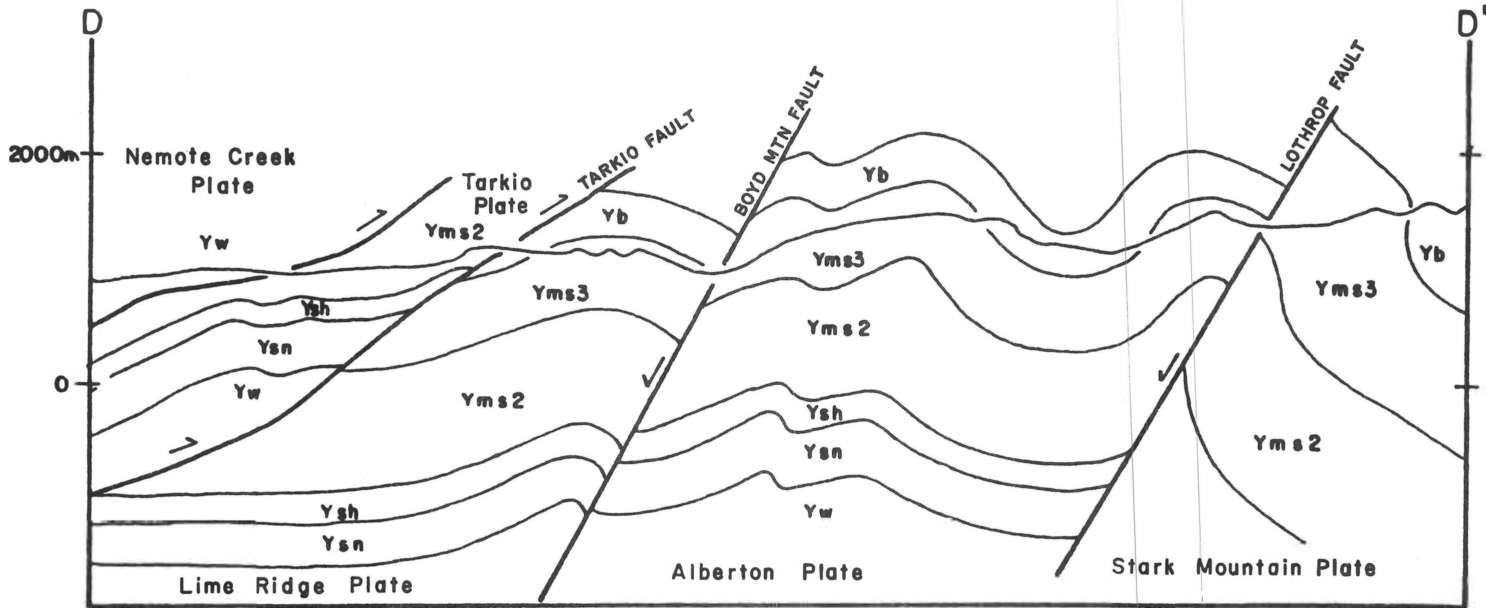

Figure 7. Structure Section DD′.

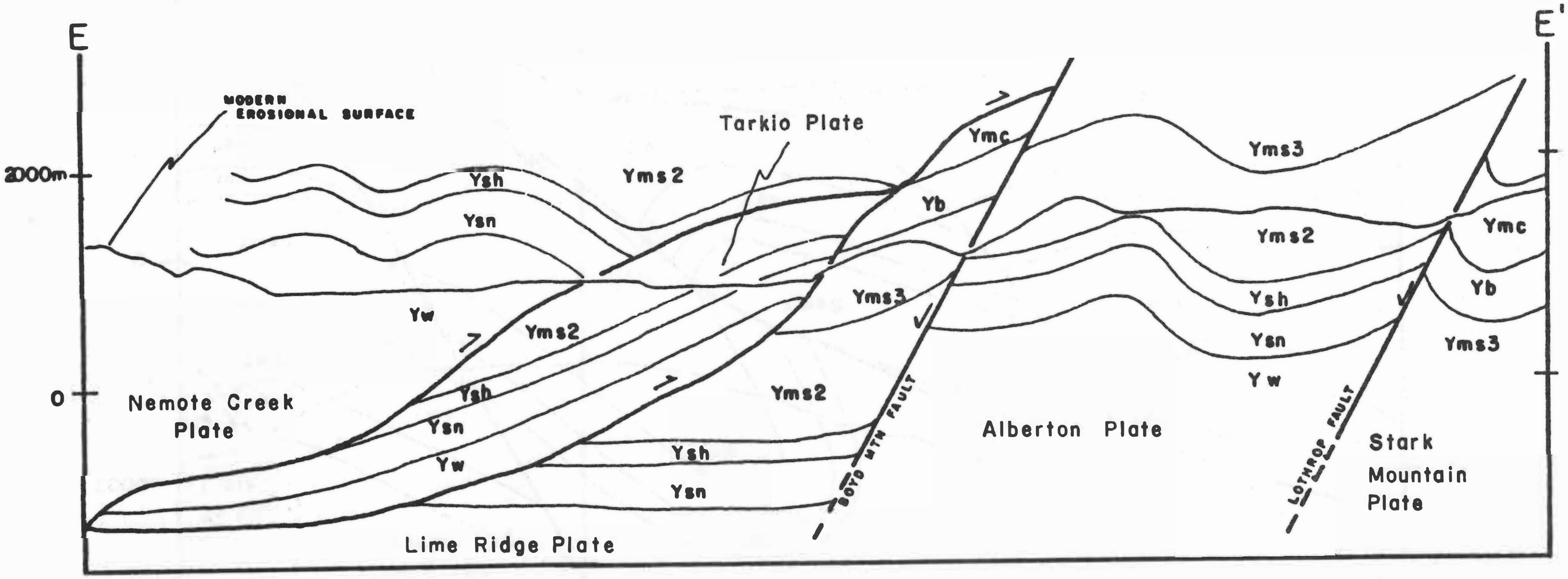

Figure 8. Structure Section EE'.

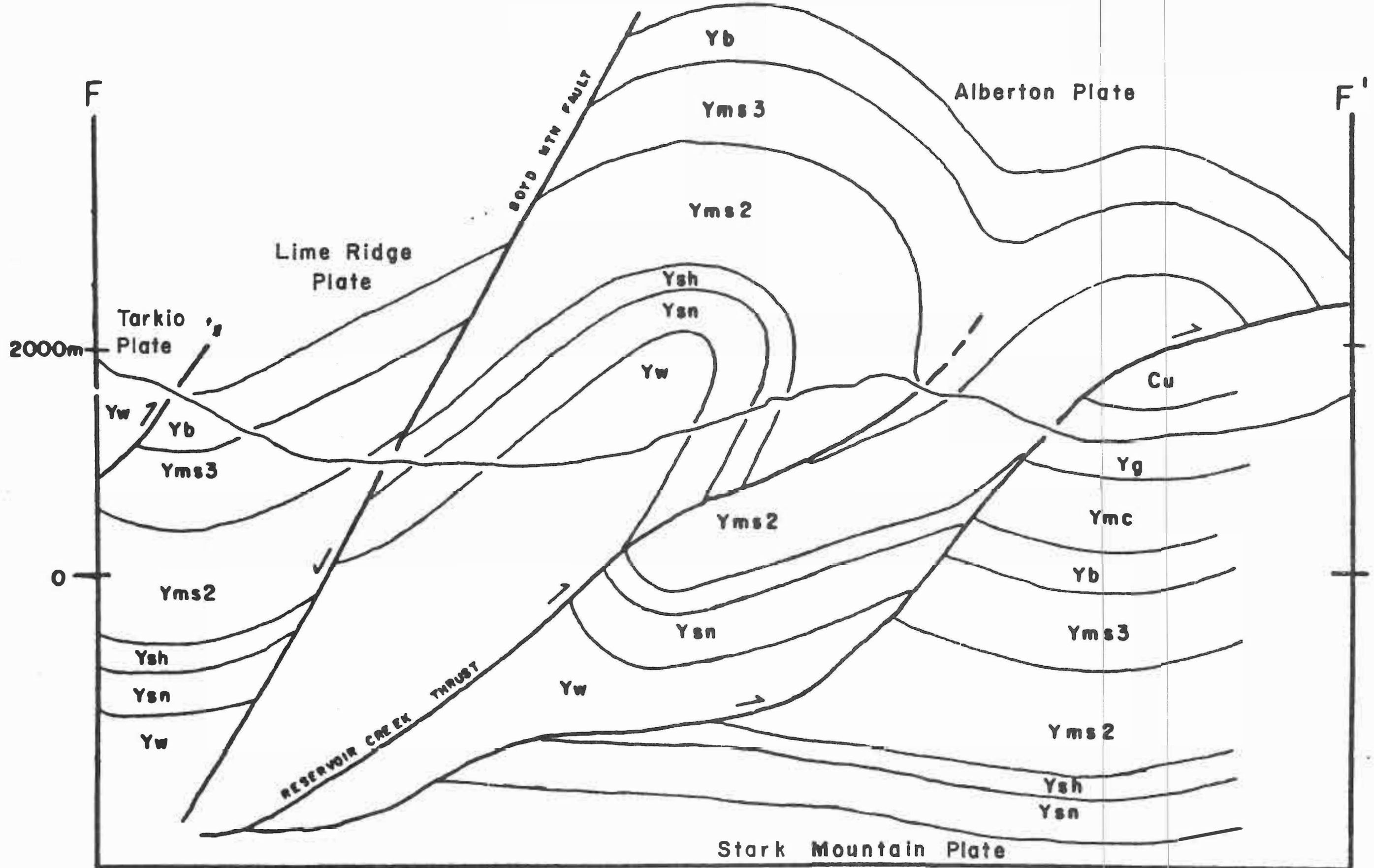

Figure 9. Structure Section FF'.

Unlike rocks in plates to the southwest, the Wallace is penetratively cleaved to the northwest in the mapped extension of the Alberton plate. Therefore, although the Alberton plate was structurally higher during compression than the Stark Mountain plate to the east, it was probably structurally lower than plates to the southwest. The Boyd Mountain fault dropped higher domains down to the southwest and placed these uncleaved rocks adjacent to the Alberton plate (Figure 3). The Lime Ridge plate was probably continuous with the Alberton plate, but was downdropped by the Boyd Mountain fault. Alternately, the Lime Ridge plate may have been structurally higher during compression and dropped to its present level by the Boyd Mountain fault. The Boyd Mountain fault may even be a reactivated thrust that placed the Lime Ridge plate over the Alberton plate.

Reverse movement on the Tarkio fault complex has buried the Lime Ridge plate beneath the Tarkio plate, and the Tarkio plate has in turn been overridden by the Nemote Creek plate (Figure 3). These faults are low-angle and have glided on zones within the Wallace. The Tarkio fault climbs northward into the Mount Shields member 2 (Figure 3, Plate 1).

Calculations based on palinspastic restorations indicate 15% to 48% present crustal shortening. Total compressional shortening must have been greater than this, since it was partly reversed by Cenozoic extension.

Small-scale Structures - Although small-scale structures are sparse in the Tarkio area, cleavage attitudes and bedding-cleavage intersections were measured on the Stark Mountain fault plate (Figure 10). Cleavage attitudes averaged N28W 85SW. The average cleavage attitude is similar to the northwest of the area reported by Laudon (1978). Bedding-cleavage intersections, which parallel the fold axes, plunge 12 S30E. Poles to bedding describe a similar average fold trend, but with variable plunge (Figure 11). These southeast-plunging fold axes appear to be a regional feature extending southeast as far as Drummond, Montana (Sears, 1988). All small-scale compressional features indicate that local compression was consistently oriented northeast-southwest and support the conclusion that all compressive structures reflect a northeast-trending compressional strain, probably produced by a single Cretaceous to Paleocene compressional tectonic regime.

The direction of the Cenozoic extension is less clear. Although the strikes of the normal faults parallel compressional structures, extension may have been either southwest-northeast, or westward, with normal faults localized along planes of weakness created by Cretaceous thrusts.

Structural History - The first tectonic event evident in the Tarkio area, was Cretaceous folding and thrusting from southwest to northeast. In most cases, trusting formed "rootless" hanging wall folds that were formed as hanging wall slabs rode up and over footwall ramps. Only in the Reservoir Creek thrust, did folding appear to have preceded trusting, where the thrust broke through the tightly folded Reservoir Creek anticline.

During compression, axial plane cleavage formed up to the Mount Shields Formation in the Stark Mountain plate as it was deeply buried by the overriding Alberton plate. Axial plane cleavage of the Alberton plate formed up to the Wallace Formation as it was overridden by the Lime Ridge plate. All

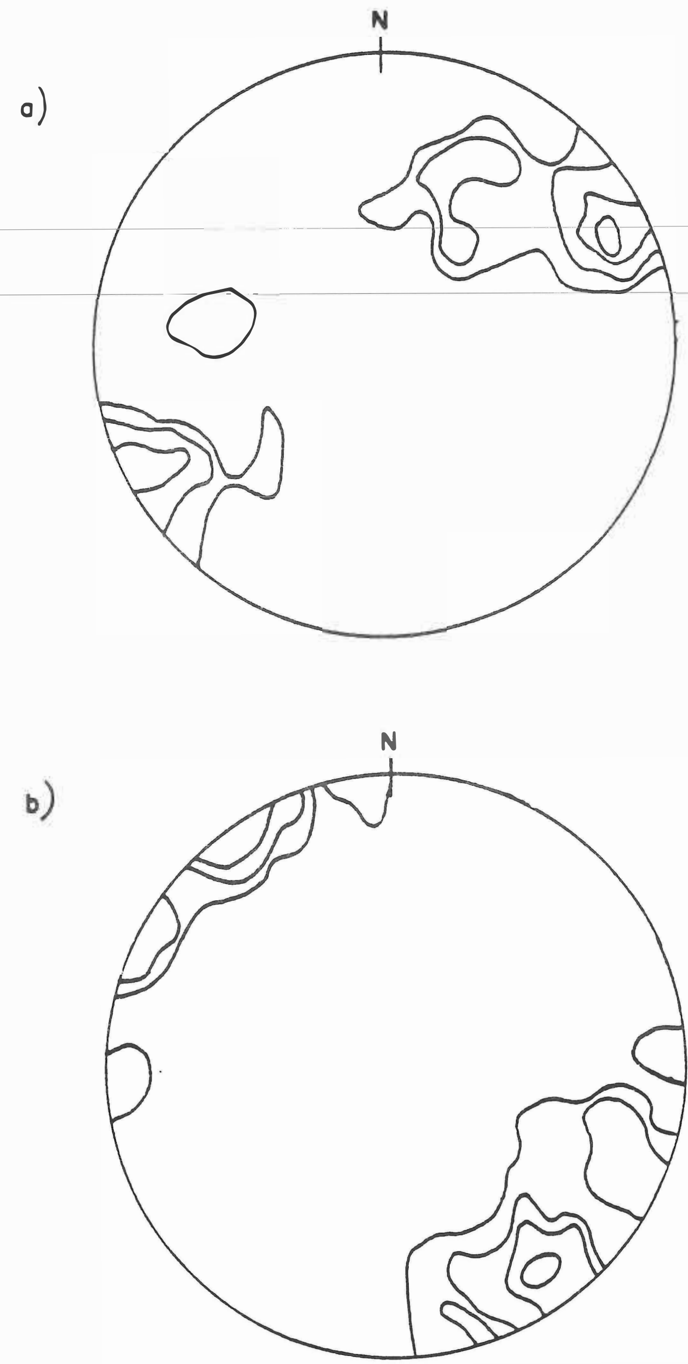

Figure 10. Equal area projections for Stark Mountain plate. a) Poles to cleavage, and b) Bedding-cleavage intersections.

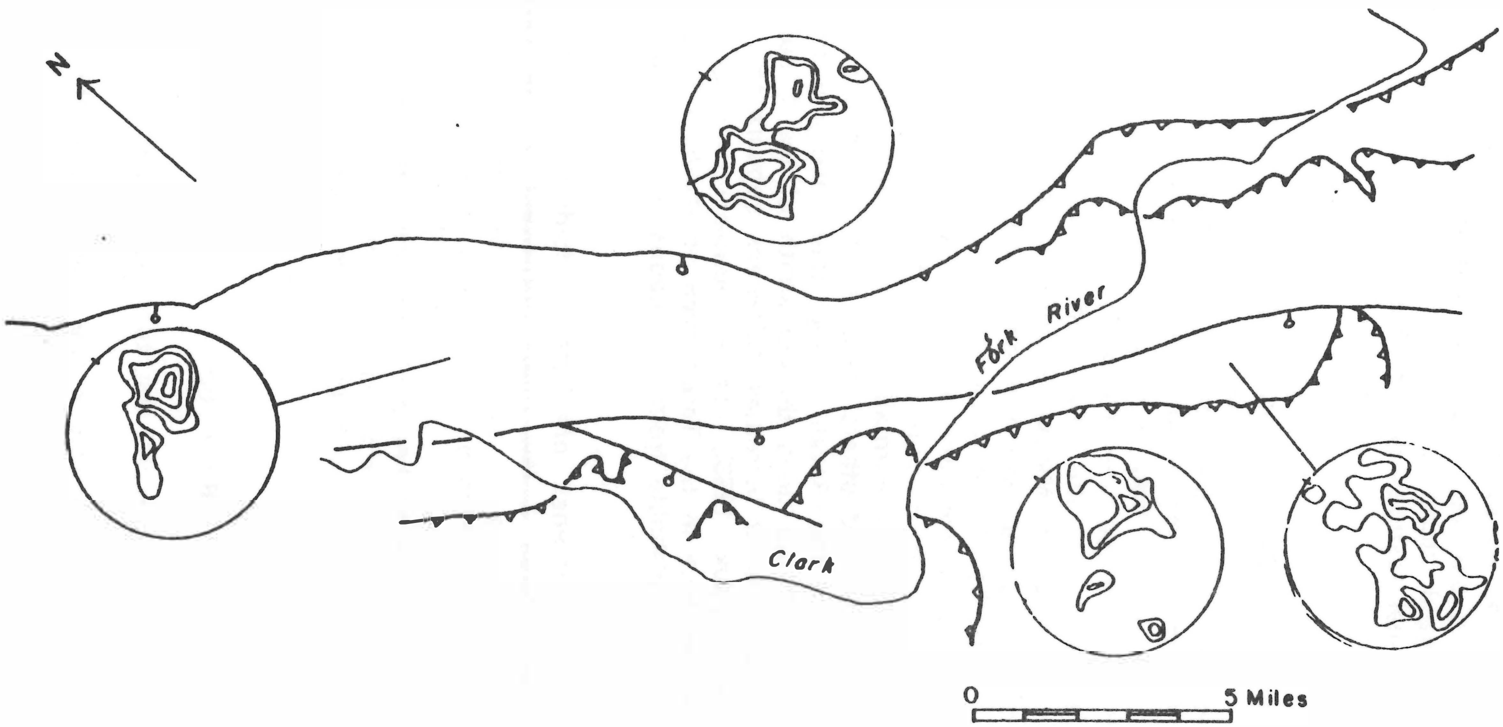

Figure 11. Pi diagram for bedding in parts of the Tarkio map area illustrating the general southeast plunge of fold axes.

cleavage is coaxial and attributable to Cretaceous compression. No cleavage is kinked or folded or otherwise attributable to pre-Cretaceous tectonism.

After thrusting, extension produced normal faults, whose traces parallel the compressional features, and most cut both thrusts and cleavage. Some normal faults were localized along pre-existing thrust surfaces, and the orientation of all extensional features was probably influenced by the pre-existing fabric.

Question of the Lewis and Clark Line and Proposed Pre-Flathead Folding

The Tarkio area lies along the path of the Lewis and Clark line, originally defined as a zone of Laramide en echelon tear faults that connected offset in Cretaceous compression from a more westerly zone north of the line to more easterly belt south of the line (Billingsley and Locke, 1939). Hobbs and others (1965) suggested that the Lewis and Clark line was a structural zone of weakness as early as Middle Proterozoic on the basis of its paralleling the Helena embayment (which it does not). Harrison and others (1974) cited the thick isopachs of the Coeur d'Alene trough (Harrison, 1972) as evidence for the Proterozoic existence of the Lewis and Clark line. These isopachs are in part an artifact of miscorrelation of the whole of the Spokane Formation with only the St. Regis Formation of the Ravalli Group. Winston (1986a) suggested, and Cronin and others (1986) have shown, that the Spokane correlates with the whole of the Ravalli Group, thus changing the isopach patterns. Still, the Ravalli Group does thicken south of the Osburn fault (Winston, 1986d), but the trend of increased thickness appears to follow the east-trending Jocko line (Mauk, 1983), not a southeast-trending Lewis and Clark line. In fact, no evidence in the Tarkio area points to a Proterozoic tectonic fabric that is distinguishable from Cretaceous folding and Cenozoic extension.

Consequently, although intense pre-Flathead folding and tectonism is postulated in the Superior area a few miles northwest of the Tarkio area (Leech and others, 1988), there is no evidence in the Tarkio area for pre-Flathead tectonism. For a discussion of pre-Flathead tectonism in the Tarkio area, see the description for Stop 5 in this road log. The conclusions reached for the Tarkio area are in line with regional interpretations from Belt-Flathead exposures in Montana (Winston and others, 1988), which indicate only gentle warping and high-angle, extensional(?) pre-Flathead faulting.

Road Log

0.0 **Leave parking lot of Red Lion Motor Inn, turn right on Front Street.**
0.1

0.1 **Cross Rattlesnake Creek.** At 1 o'clock one may get a fleeting glimpse of Hellgate Canyon, where Clapp and Deiss (1933) named the Hellgate Quartzite for cliff exposures of fine-grained quartzite at the mouth of the canyon across the river. The Hellgate is now recognized to be part of a large, feldspathic quartz arenite blanket that extends northeast to Glacier Park, where it is included in part of the Mount Shields Formation, and northwest to the Coeur d'Alene district, where it comprises most of the Striped Peak Formation. Winston (1986a) informally designated this unit Mount Shields member 2. Over much of Montana it is underlain by another argillite unit (Mount Shields member 1) and overlain by an argillite containing ripplemarks and salt casts (Mount Shields member 3). Here quartzite beds low in the section bring the base of the Mount Shields member 2 far down, so that it essentially rests directly on the Shepard Formation, which forms the tan-weathering outcrops just above the university physical plant buildings.

0.05

0.05

0.15 **Stop at Van Buren Street. Turn left and proceed through Broadway intersection, through railroad underpass, and beneath I-90.**

0.25

0.4 **Turn left onto ramp of I-90, westbound toward Coeur d'Alene.**

0.2

0.6 View back at 7 o'clock of Hellgate Canyon.

0.5

1.1 Exit 104.

0.2

1.3 Cuts on right expose a fault bringing tan-weathering dolomitic argillite down against purple argillite. Possibly within the Shepard Formation.

1.7

2.9 Cross Bridge. Missoula landfill cuts in the hills at 1 o'clock exposed Early Tertiary mudstone and conglomerate capped by a red-weathered unconformity and overlain by Pleistocene gravel. Cuts in the terrace at the highway level expose Glacial Lake Missoula varved and pebbly mudstone beds. Tan mudstone outcrops on right for the next 9 miles are mostly Tertiary.

3.1

6.0 Milepost 100 on right. Missoula Airport on left is built on the flat surface of Glacial Lake Missoula varved silt and clay into which large airplanes have occasionally sunk.

1.6

7.6 Cross Butler Creek Bridge.

1.9

9.5 Exit 96 to Highways 93 and 200, stay on Interstate 90.

0.6

10.1 Crest of hill. Good view of Clark Fork Valley in foreground and Ninemile Valley beyond. The Clark Fork River flows northwestward and abruptly swings across the geological structural trend, leaving the valley. Ninemile Creek flows southeast to meet the Clark Fork. The Clark Fork-Ninemile fault bounds the northeast side of the valley from 1 to 3 o'clock and is marked by a rather abrupt increase in slope from the Tertiary sediments filling the valley to the middle Belt carbonate rocks of the Squaw Peak Range beyond. Grass tends to cover the drained hills of Tertiary sediments, whereas trees grow on the Belt outcrops and soils.

Middle Belt carbonate rocks of the Squaw Peak Range were mapped by Harrison and others (1986) as the Helena Formation, characterized by fine-grained dolomite beds with "molar-tooth structure" and siliciclastic-to-carbonate cycles. They form the hanging wall of the Rattlesnake thrust, here marking the leading edge of the western fold and thrust belt.

To the west from 9 to 11 o'clock are hills bordering the western side of the valley. The low, brown-weathering hills just above the valley floor are composed of Cambrian Hasmark dolomite, probably structurally continuous with scattered Silver Hill and Flathead outcrops in the valley floor. Higher hills with a slightly reddish hue above and beyond the Hasmark belong to the Stark Mountain plate and are composed mostly of upper Missoula Group, thrust over the Cambrian along the Albert Creek thrust (Hall, 1964).

2.0

12.1 Highway crosses pinkish, gullied slopes of Glacial Lake Missoula silts and clay that are farmed for wheat because they retain moisture.

2.4

14.5 Highway cuts down through Glacial Lake Missoula sediments exposed on right, above the Clark Fork River terraces of the Frenchtown Valley.

1.5

16.0 Exit 89 to Frenchtown. **Stay on interstate.**

4.5

20.5 Exit 85 to Huson. **Stay on interstate.**

1.3

21.8 Milepost 84. Here the Clark Fork River swings westward and leaves the valley. Small knob above the river bend at 11 o'clock used to expose crossbeds of the Pilcher Formation, with their characteristic alternating purple and white laminae. However, the beautiful outcrop was destroyed by the U.S. Corps of Engineers to provide riprap to line the adjacent channel, which they must have realized was being naturally abandoned by the Clark Fork River. The Corps should be thanked for wasting more of the taxpayers' money. This outcrop is on strike with Pilcher outcrops on the southwest side of the river, beyond the railroad bridge. The Flathead there is represented by about 15 feet of glauconitic sandstone. The valley of Sixmile Creek ahead is cut in shale of the overlying Silver Hill Formation above which are resistant light gray dolomite beds of the Hasmark Formation, partly exposed on the right where the highway curves and climbs.

0.4

22.2 Cross Sixmile Creek, Hasmark Formation on right.

0.5

22.7 Green shale float above light tan Hasmark (probably not visible through weed cover) comes from the Dry Creek member of the Red Lion Formation which marks the craton-wide unconformity at the Dresbachian-Franconian stage boundary. Yellowish-weathering limestone above the shale is the Sage Member of the Red Lion Formation of upper Cambrian Franconian and Trempealeauan ages. Its trace along strike can be seen at 10 o'clock in the pinnacles just on the other side of the highway and in the west-dipping cliff across the Clark Fork River.

0.3

23.0 Sign for Exit 82 to Ninemile on right. Dark outcrops just beyond sign are horses of diabase, brought up along the Albert Creek thrust, which crosses the highway at this point and forms the eastern edge of the Stark Mountain plate. On the hanging wall of the Stark Mountain plate is the Garnet Range Formation, which is characterized by dark greenish, hummocky cross stratified, micaceous arenite beds interstratified with darker argillaceous beds.

0.1

23.1 Exit 82. Cuts surrounding interchange expose Garnet Range in the hanging wall of the Albert Creek thrust. Trace of the thrust is marked across the Clark Fork by the gully immediately west of the steeply-dipping outcrop of Red Lion limestone. Garnet Range forms the surrounding mountains for the next 5 miles.

0.5

23.6 Highway descends through cut in Glacial Lake Missoula sediments. Repeated sequences of thick sand beds that grade up to silt were interpreted by Chambers (1971) to record more than thirty drainings of Glacial Lake Missoula.

0.4

24.0 Cross Clark Fork River.

1.5

25.5 Cross Clark Fork again. Cliffs on right expose nearly flat-lying Garnet Range Formation, which here is about 3,000 ft. thick (McGroder, 1984).

1.0

26.5 Green chloritic diabase dike cuts lowermost Garnet Range. Obradovich and Peterman (1968) report a K-Ar age date of 760 m.y. from diabase of this complex.

0.5

27.0 Sign for Exit 77 to Alberton and Petty Creek on right. Quartzite cliff ahead across Clark Fork exposes Mount Shields member 2 caught in a tight, east-verging fold that faces us. Hall (1964) showed that north of the Clark Fork, the fold breaks into the Lothrop thrust. Lonn (1984) in turn showed that compressive offset of the thrust passes northward to normal offset, probably as a result of reactivation of the Lothrop thrust by Tertiary extension. The normal fault has been mapped as the southeastern extension of the Osburn fault (Campbell, 1960).

1.0

28.0 Exit 77.

0.5

28.5 Mineral County line. Cross trace of the Lothrop thrust. View of mountain side through clearing on the right shows two prominently outcropping ledges. Exposed in the lower ledge is reddish, trough crossbedded, tightly cemented quartz arenite mapped by Wells (1974) as Flathead. If it is Flathead, it differs greatly from the green, glacuonitic Flathead of the Missoula Valley plate. Here Flathead talus covers the Garnet Range below. The tree band above the Flathead marks waxy green shale of the lower Silver Hill Formation. The Gray cliff above is middle Silver Hill micritic limestone and contains the Middle Cambrian trilobite genus Glossopleura. Above the limestone is the upper shale of the Silver Hill overlain by Hasmark dolomite at the top of the mountain. The Cambrian ledges terminate to the west against the Lothrop thrust, which here places Mount Shields member 2 on the hanging wall over the Cambrian.

1.9

30.4 Exit 75 to Alberton.

1.4

31.8 Rest area sign on right. **Prepare to stop**.

0.3

32.1 **Pull into rest area.**

0.2

32.3 **Park in rest area.**

Stop 1. To the southeast the Lothrop thrust is well defined between the steep dipslopes of purple Mount Shields member 3 argillite, partly covered with green lichen on the Alberton plate hanging wall, and the nearly flat-lying tan-weathering beds of the Hasmark Formation on the Stark Mountain plate footwall. Thus, the sole of the thrust has climbed northward from the Mount Shields member 2 to the Mount Shields member 3. Since thrust displacement along the Lothrop fault passes northwestward to normal displacement and continues as the Osburn fault, original movement along the Lothrop-Osburn fault may first have been compressional and Cretaceous in age, followed in its northern part by extension of Tertiary age.

This stop will be a one-way traverse, 2.3 miles westward along the interstate, abandoned railroad grade and an ancient road, crossing a variety of Missoula Group and Wallace rocks. We will be picked up at cumulative mileage 34.6.

Walk west along Interstate, across the creek to the first roadcuts of Mount Shields member 3 purple argillite with its characteristic lenticular and even couplets and couples, ripple marks, mudcracks and salt casts. Two kinds of couplets are abundantly represented here: 1) even couplets in which the silt and clay layers are even parallel and continue for a meter or more across an outcrop, and 2) lenticular couplets, in which the lower silty portions of the couplets thicken and thin as silt rippled lenses, and are capped by clay. Both even and lenticular couplets in this purple outcrop are cut by desiccation cracks. Mud cracked polygons were the source of the abundant mudchips that lie in the silty layers.

Even couplets are interpreted by Winston to record sheetfloods across a dry lacustrine mud flat that first deposited very fine sand and silt from traction load. As the flood waters filled the enclosed playa, the lake spread across its surrounding flats and the clay portion of each couplet was deposited from suspension in standing water. Subsequent shrinking of the lake again exposed the flats, drying and cracking the mud. Lenticular couplets are interpreted by Winston (1986b) to record reworking of even couplet sediments by waves, which piled the silt into wave crests. The clay layers then settled out during intervening calm periods. Lenticular coupleted sediments were probably covered by water for longer periods of time than were the even couplets, yet mud cracks in this outcrop indicate that they also were periodically exposed and dried.

Some graded silt-to-clay layers are thicker than 3 cm and are termed couples. Here the lower, flat-laminated sandy and silty parts of the of the couples are comparatively thick, forming most of the couple, and the mud drape is comparatively thin. These couples, like couplets, are interpreted to record sheetfloods that crossed the sand and mudflats, but left a thicker record of very fine sand and silt.

Continue along interstate for about 100 yards to a second outcrop of Mount Shields member 3. Here, interbedded with purple, rippled, mud cracked couples and couplets is an interval of green, lenticular couplets. Notice that these couplets are not cut by so many desiccation cracks and mud chips are comparatively fewer.

Where purple layers grade to green, the lateral color gradation demonstrates that color is a post-depositional product. The silty parts of the half-couplets become green and the clay caps are red, suggesting that the color change correlates with a change in permeability, and that green paragenetically follows red. The alteration of the hematitic composition of the purple argillite, where iron is oxidized, to green chlorite, where iron is in a reduced state, indicates that the alteration of red to green is probably a reduction of oxidized (probably brown and limonitic) mud to reduced mud (now chlorite).

The decrease of mud cracks and abundance of oscillation rippled lenticular couplets concomitant with alteration to green infers that reduced intervals remained covered with water for longer periods of time, perhaps where microorganisms could proliferate and reduce the sediments. Thus the green intervals probably record a large pond on the lacustrine flat or perhaps an ephemeral high stand of the Great Belt Lake. Notice that salt casts persist in the green argillite, indicating continuously saline conditions. Also notice the malachite stains of greenbed copper. Sandy couples above the green interval mark a return to sheetflood deposition. Also notice the slickensides cutting the bedding at a low angle.

Continue the length of the outcrop becoming thoroughly familiar with couples, couplets, ripples and mudcracks and **walk 165 yards through the covered interval and the quartzite along the fence to the end of the fence**.

Stop at this large outcrop of thoroughly fractured, pink, well sorted fine-grained feldspathic arenite of the Mount Shields member 2 with its characteristic beds of the tabular, flat-laminated sediment type. In these outcrops it is difficult to distinguish bedding planes from fracture planes, but in at least one bed in the abandoned railroad cut above the highway crossbed tops and tangential toes reveal that these beds are overturned. This outcrop marks the sole of the Reservoir Creek thrust. The outcrop from here to the end of the stop is overturned and represents the lower limb of the Reservoir Creek anticline.

Continue down railroad grade to the next outcrops of Mount Shields member 2. Here, farther up in the hanging wall plate fractures have not so severely obscured the bedding. Repeated vertical sequences from crossbeds (crossbedded sand sediment type), to flat laminations, to climbing ripples to clay drape characteristic of Mount Shields member 2 confirm overturning. The outcrop is also cut by some small, flat thrusts.

At west end of outcrop turn north and walk 30 meters through trees to abandoned road, possibly the old Mullan Road. **Walk west again along winding track**. First small cuts in green argillite are in the upper part of the Shepard Formation. Although not really calcareous, the argillite is composed of thin lenticular couplets that grade to microlaminae and are characteristic of the formation. **Walk down through the collapsed dugout houses, picket fences with arched gates, rock terraces with iris beds**. Who built them? Chinese?

Among these abandoned habitations the green lenticular couplets of the Shepard grade down into purple even couplets and couples of the uppermost Snowslip Formation. The upper Snowslip over most of the Belt basin appears to be characterized by red and purple quartzite and argillite. In Glacier National Park it has been informally named Snowslip member 5 by Whipple, Connor, Raup and McGrimsey (1984) and represents regional alluvial, sandflat and mudflat progradation (Winston, l986b). It is better exposed at the highway level, where it displays sandy couples and couplets with very thin clay drapes that barely separate the sandy and silty layers.

Below the purple argillite and fine-grained arenite is an interval of "green argillite", possibly belonging to Snowslip member 4 (Whipple and others, 1984). Notice that here the silt layers are dark green and the clay layers are lighter green. Some lenticular couplets contain ripple crests, but the silt layers of other lenticular couplets are low and elongate and appear to represent small-scale hummocky cross stratification. These are common in some green argillite sequences in the Belt and need to be described and analyzed in more detail. Some lenses bow down into the underlying sediments and may be allied to small pinch-and-swell couplets that are more characteristic of the Wallace Formation. Like the Wallace, some clay half-couplets are cut by silt-filled sinuous dikelets. Absence of desiccation cracks, and mudchips indicates continuous subaqueous deposition.

Continue down through the mostly green argillite of the purple and green beds of the lowermost Snowslip, characterized by the mudcracked variety of the even couplet sediment type. Gensamer (1973) described in detail a section through the Snowslip-Wallace boundary from cuts along the Burlington Northern Railroad tracks across the river. Top of the Wallace is marked by tan-weathering, calcareous green argillite composed mostly of thinly-laminated, mudcracked lenticular and even couplets with imbricated mudchips.

Follow highway and walk around bend to dark gray argillite with lighter gray interbeds that is much more characteristic of the Wallace than the beds above. This outcrop also exemplifies the pinch-and-swell couple and couplet sediment types, typical of the Wallace. The fine-grained sand beds one to several centimeters are loaded down into, and in places cut into, the dark agillaceous layers of about the same thickness below them. Most sand beds have nearly flat tops and grade up into dark mud. With their flat tops and loaded bases, the sand beds impart a wavy form to the bedding. Notice the beds with "molar-tooth structure" the abundant squiggly dikelets, and absence of mudchips.

This traverse illustrates a variety of sediment types common in the Missoula Group and Wallace, ranging from crossbedded sand, to flat-laminated sand, to even couple to even couplet, to lenticular couplet to microlaminae and pinch-and-swell couples and couplets. Even couplets and lenticular couplets are common in playa flats and are so interpreted in the Belt by Winston and others. Conversely others interpret them to be marine tide flat deposits. The microlaminae, pinch-and-swell couple and pinch-and-swell couplet sediment types are interpreted to be perennial lacustrine deposits.

Cars will be shuttled to this point, which is 34.6 on the road log below. 32.3 - 34.6 is I-90 log to pickup point.

32.3 **Leave rest area by car.**

0.3

32.6 First outcrop of west-dipping Mount Shields member 3 on right.

0.4

33.0 End of Mount Shields member 3 outcrops.

0.1

33.1 Overturned Mount Shields member 2 on hanging wall of Reservoir thrust on right.

0.4

33.5 Lowermost Mount Shields member 2 in cuts on both sides of highway just before rest area on left. Covered interval beyond is underlain by the Shepard Formation.

0.1

33.6 Uppermost purple quartzite beds of the Snowslip (Snowslip member 5?) on right. Green and purple outcrops mostly of the even couplet sediment type in cuts for the next 0.6 mi are progressively lower units in the overturned Snowslip section.

0.6

34.2 Purple and green argillite beds on the right are lowest Snowslip.

0.1

34.3 Tan-weathering dolomitic green argillite on right is in the uppermost Wallace.

0.3

34.6 **Pickup point for foot traverse from rest area. Group will resume vehicle traverse here.** Northwest-trending valley ahead opens up and follows the extensional Tertiary Boyd Mountain fault that bounds the Alberton plate on the east and separates it from the Lime Ridge plate on the west. Like the Clark Fork-Ninemile fault, the Boyd Mountain fault is long, coalesces with the Osburn system, and is probably listric. Tertiary extension along the northwest-trending Boyd Mountain, Clark Fork-Ninemile and other normal Tertiary faults become strike slip where they curve westward into the Osburn, accounting for the 26 km of right lateral strike slip movement along the Osburn (Winston, 1986d).

0.7

35.3 Cyr Interchange, exit 70 on right, stay on interstate.

0.2

35.5 Cross Clark Fork River. Outcrops on right downstream from brides are vertical to overturned Wallace in the overturned limb of the Reservoir Creek anticline. Boyd Mountain fault lies to the west.

0.2

35.7 **Cross Railroad.**

3.0

38.7 Fish Creek Road, Exit 66. **Turn off I-90 and stop at top of ramp. Turn right.**

0.3

39.0 **Park beyond guard rail. Walk back to overpass for structural overview.**

Stop 2. To the east the Boyd Mountain fault is marked by the green and purple gouge of the Snowslip Formation above which, on the Alberton plate, are tan-weathering outcrops of the Shepard and purple lower Mount

Shields at the top of the hill. To the north are the Scenic Cliffs. The purple argillite with green interbeds are the Mount Shields member 3 of the Lime Ridge plate, brought down against the Snowslip along the Boyd Mountain fault. The abundant green beds in the Mount Shields member 3 probably indicate that this as deposited "lakeward" from the section at Stop 1. The Bonner overlies the Mount Shields at the top of the hill above the cliff. The north-trending valley west of the Scenic Cliffs is cut along the Tarkio fault, which has brought the Tarkio plate, here composed of rocks from the Wallace to the Mount Shields member 2 over the Lime Ridge plate. **Return to cars and continue down road.**

0.3

39.3 **Cross railroad and stop at intersection with old Highway 10. Turn left.**

1.2

40.5 **Cross Clark Fork River and peer down into Alberton Gorge.** Section of Mount Shields member 3 on the right has not yet been measured. Any volunteers?

0.3

40.8 Roadcut in dibase horse caught along the Tarkio fault. Cross onto Tarkio hanging wall plate above the Tarkio fault.

0.2

41.0 Float block of diabase on right. **Continue on road and pass beneath both lanes of I-90.**

0.4

41.4 **Park along roadside between underpass and first house ahead.**

Stop 3. **Cross south Interstate fence and walk east along the fence until bridges come into view. Walk down to first outcrop of red argillite along river below the bridge.** The argillite is Mount Shields member 3, here overlain by tan-weathering dolomite, for the time being assigned to member 3 of the Mount Shields.

In the type section of Mount Shields member 3 in the Jocko Mountains Winston, 1986b), carbonate beds form only two intervals, each less than two meters thick. However to the northwest purple argillite of the member passes to a carbonate unit, mapped by Harrison and Jobin (1963) as Striped Peak member 2 in the Clark Fork Quadrangle. The presence of carbonate here indicates that the siliclastic mudflats represented in the Jocko Mountains pass westward as well as northwestward to lacustrine carbonate. This outcrop is on the Lime Ridge plate east of the Tarkio fault and consequently is structurally continuous with the Mount Shields of the Scenic Cliffs.

Walk downstream about 100 meters to next outcrop of east-dipping, Mount Shields member 3 purple argillite overlain by carbonate. The east dip reflects drag beneath the Tarkio fault 50 meters ahead, where thoroughly brecciated Wallace marks the sole of the Tarkio fault. Large blocks containing pinch-and-swell couples and couplets verifies the Wallace assignment. Many of the breccia clasts are rounded as if they became ball bearings in the fault zone.

Continue walking westward through thick section composed mostly of green and tan-weathering calcareous beds of the uncracked variety of the even couplet sediment type, and dark and tan-weathering beds of the microlamina sediment type. This interval is mapped here as Snowslip, although farther west in the Coeur d'Alene district this interval is included in the upper Wallace on the basis of its carbonate content and lack of redbeds (Winston, 1986a).

Like the Mount Shields member 3, the Snowslip here represents a green, mostly undesiccated facies of the Snowslip, which is more purple and mudcracked at Alberton and Missoula. Again, this facies change may reflect more subaqueous, lacustrine deposition to the west, but the relatively thick sand layers of the couplets suggests a proximal source, possibly still farther west. As the dip flattens, green argillite gives way upward to thick interval of quartzite beds mostly of the even couple sediment type. This unit forms the top of the Snowslip (Snowslip member 5?) and is thicker and sandier than at Stop 1.

The westward increase in sand, deposited by sheetfloods on a sandflat probably indicates transport from continent X west of the Belt basin. The westward increase in subaqueous deposition in the Snowslip below the sand may suggest that the western edge of the Great Belt Lake was a down-to-the-east fault zone, beyond which continent X was uplifted. Thus the Belt rocks from here to Missoula may have been deposited in a giant half-graben.

Return to cars and return to Fish Creek Interchange with Interstate 90.

2.3

43.7 Fish Creek Interchange. **Turn right and return to Intestate 90 headed west.**

0.4

44.1 Bridge over railroad.

0.1

44.2 Bridge over Clark Fork.

1.5

45.7 Quartzite in cliffs on both sides of road belongs to the flat-laminated sand and even couple sediment types and is in the upper Snowslip (Snowslip, member 5?).

0.2

45.9 Tan-weathering outcrop above road cut on right is composed of dolomitic thin lenticular couplets and microlaminae of the Shepard Formation overlain by Mount Shields member 2, which continues to the top of Martel Mountain. Tan-weathering knob on skyline at 2 o'clock is near the top of the Shepard. Tan Shepard talus comes down to highway level.

2.2

48.1 Highway curves to north as Tarkio Valley comes into view. Lake Missoula silt forms the flat valley floor. Gravel in cut on right was deposited on a great point bar by Lake Missoula floods (Harrison, oral communication, 1975).

0.5

48.6 Exit to Tarkio. **Turn off interstate. Stop at bottom of exit ramp and first turn right and then left onto frontage road.**

2.4

51.0 Happy Hollow Ranch on right.

0.2

51.2 Purple quartzite in roadcut on right is Mount Shields member 2. Here it lies just below the Nemote Creek thrust, which has brought the Wallace over the Mount Shields.

0.6

51.8 Abandoned Milwaukee Railroad underpass immediately ahead. **Turn right onto road to Quartz Creek Guard Station.**

0.1

51.9 **Before reaching white house turn left onto dim road that connects to abandoned Milwaukee Railroad bed. Turn right on railroad bed.**

0.2

52.1 **Stop 4**. Purple and green argillite outcropping at railroad level is in the McNamara Formation, which lies below the Tarkio Fault. Follow cow trails around to the right and climb to the top of the cut where Mount Shields member 2 on the hanging wall of the Tarkio fault crops out, thrust over the McNamara along the Tarkio fault. **Return to cars and continue north along <u>abandoned</u> railroad grade** with north-dipping beds of the McNamara cropping out on the right here and there through talus and slump.

0.7

52.8 Quartzite beds in the McNamara exposed on right. These may belong to the progradational phase of the McNamara close to its top. Above this, mostly under covered slopes, is the Garnet Range Formation, still dipping to the north.

0.2

53.0 Cross Micayune Gulch (sign "551" on fence to right). Covered interval on right is probably underlain by Garnet Range and Flathead formations. Lowest Silver Hill limestone beds exposed ahead.

0.1

53.1 **Park cars.**

Stop 5. We are in the footwall just below the Tarkio fault, where Mount Shields member 2 is thrust over Cambrian Silver Hill Formation. **Walk back to Micayune Gulch and up the gulch on the north side for a distance of about one third of a mile, crossing the Garnet Range Formation and reaching the overlying Flathead Formation about 100' vertically above the gulch floor.** The Garnet Range Formation is here earthy-weathering green argillite and siltite of the Garnet Range Formation. It is finer-grained and less micaceous than most outcrops of the Garnet Range, but it contains the low angle hummocky crossbeds characteristic of the formation. Silt-to-clay couplets typical of the rest of the Missoula Group below are rare.

Walk up to fine-medium-grained quartz sandstone of the Middle Cambrian Flathead Formation that lies disconformably on the Garnet Range and forms the crest of the ridge above. The Flathead is characterized by its high quartz content and deep red color, which is imparted by hematite stain that locally takes the form of Liesegang bands, obscuring much of the original bedding. Here the Flathead lies just below the Tarkio thrust, and the dip varies from outcrop to outcrop, but in a general way appears concordant with the Garnet Range below.

Elsewhere in the Superior area where the Flathead overlies the Garnet Range, the relations also appear concordant and Campbell (1960, p. 571) remarked " The unconformable relation of the Bouchard [Garnet Range] formation and the Flathead (?) quartzite is not apparent locally, as the angularity between beds of the two formations is slight". The mapped geologic relations in the Superior area question the interpretation of Leach and others (1988, p. 122) who claim "Precious- and base-metal veins are found throughout much of the Belt basin; however, the largest concentration occurs within an area referred to as the Greater Coeur d'Alene mineral belt, which extends along the Lewis and Clark line from Coeur d'Alene, Idaho to Superior, Montana.... The Lewis and Clark line is defined by a zone of faults that represents a major crustal flaw which has existed since Proterozoic time (Harrison, I972). Movement along the Lewis and Clark line in Proterozoic time (Hobbs et al., I965) may have produced the structures that host the Coeur d'Alene veins. Evidence of widespread pre-Flathead (Middle Cambrian) tectonism in the Belt basin has been summarized by Harrison (1986, 1972)."

Apparently the passages in Harrison, I972, to which Leech and others refer are as follows (Harrison, 1972, p. 1237) "Faulting and fracturing, particularly along the Lewis and Clark line but also at other places in the basin, permitted entrance of fluids that deposited uranium in the Coeur d'Alene district and galena both there and many other areas. Isotopic data are interpreted to indicate a period of mineralization at about 1,200 m.y. or older (Zartman and Stacey, I971), although the possibility of remobilization of lead at a later time is briefly mentioned.... No evidence of faulting in this zone during deposition of Belt sediments has been found.... A reasonable working hypothesis at present (1971) is that the Precambrian lead ores were emplaced post-Belt during the East Kootenay orogeny at about 800 m.y. ago."

In the later reference to Proterozoic tectonism Harrison (1986, p. 629) says "Mapping ... in northwestern Montana ... provides new data for extending the concept of gentle Proterozoic folding throughout most of Belt terrane." McMechan and Price (1982) reassigned the age of compression and folding of the East Kootenay orogeny to about 1,300 to 1350 Ma. They named the 800 to 900 Ma of uplift and block faulting the Goat River orogeny. Therefore, the timing and evidence for pre-Flathead folding is in a state of confusion.

From the Montana point of view the Big Creek anticline is part of the Cretaceous western fold and thrust belt, and that the Proterozoic KAr date of illite in the veins, which provides much of the basis for Leech and others (1988) evidence for Proterozoic folding, can be explained as a product of excess argon created during Cretaceous compression as discussed by Hofmann (1971).

Return to cars.

0.5

53.6 **Turn left off railroad bed onto logging road that immediately joins old Highway 10. Turn left and return to Missoula.**

48.6

102.2 Village Red Lion Motor Inn.

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ROAD LOG NO. 2
A ROADSIDE VIEW OF THE OLIGOCENE HOG HEAVEN VOLCANIC FIELD

Ian M. Lange[1], Arnold J. Silverman[1], and Rick Zehner[2]

Initial point: Polson, Montana, U.S. 93, east end of Flathead River bridge
Distance: Log distance - 49.4 miles. Roundtrip from Missoula - 200 miles.
Highways: U.S. 93, Montana 28, various county roads.
Field stops: 6
- No. 1 - Junction Montana 28 and Flathead Mine Road - milepoint 27.3
- No. 2 - Flathead Mine Road - milepoint 29.4
- No. 3 - Martin Mine dump and adit - milepoint 34.7
- No. 4 - Ridge south of Crossover Road - milepoint 35.9
- No. 5 - Near Sunset Quarry, Little Bitterroot Valley Road - milepoint 41.1
- No. 6 - Sullivan Hill, Little Bitterroot Valley Road - milepoint 46.3

Introduction

Please see Lange and Zehner, this volume, for a geologic summary, and Figure 1 of this report for a geologic map and locations of stops. The Hog Heaven volcanic field is host to the epithermal silver deposits produced at the historic Flathead Mine, which with associated properties is currently under development as the Hog Heaven Mine (see Figure 1). The Hog Heaven Mine could not be included in our itinerary.

Road log

0.0 East side of bridge crossing Flathead River at Polson. **Cross bridge and head north on U. S. Highway 93.**

9.5

9.5 Outcrop of Spokane Formation on south side contains greenbed copper occurrence. **Optional stop. See Appendix 1 for details.**

7.1

16.6 Junction of Montana 28. **Turn left (west) and head towards Hot Springs.**

2.6

19.2 Top of hill composed of Pleistocene glacial moraine material. This moraine apparently blocked the course of the ancestral Flathead River from ravelling down the Big Arm and Little Bitterroot Valley. The road travels through moraine and outwash material for the next few miles.

8.1

27.3 **Stop 1. Turn right on to Flathead Mine Road just past small gravel quarry on left, and stop.** Bedded quartzites and arenites of the Ravalli Group of the Belt Supergroup are exposed in the hills to the south and east.

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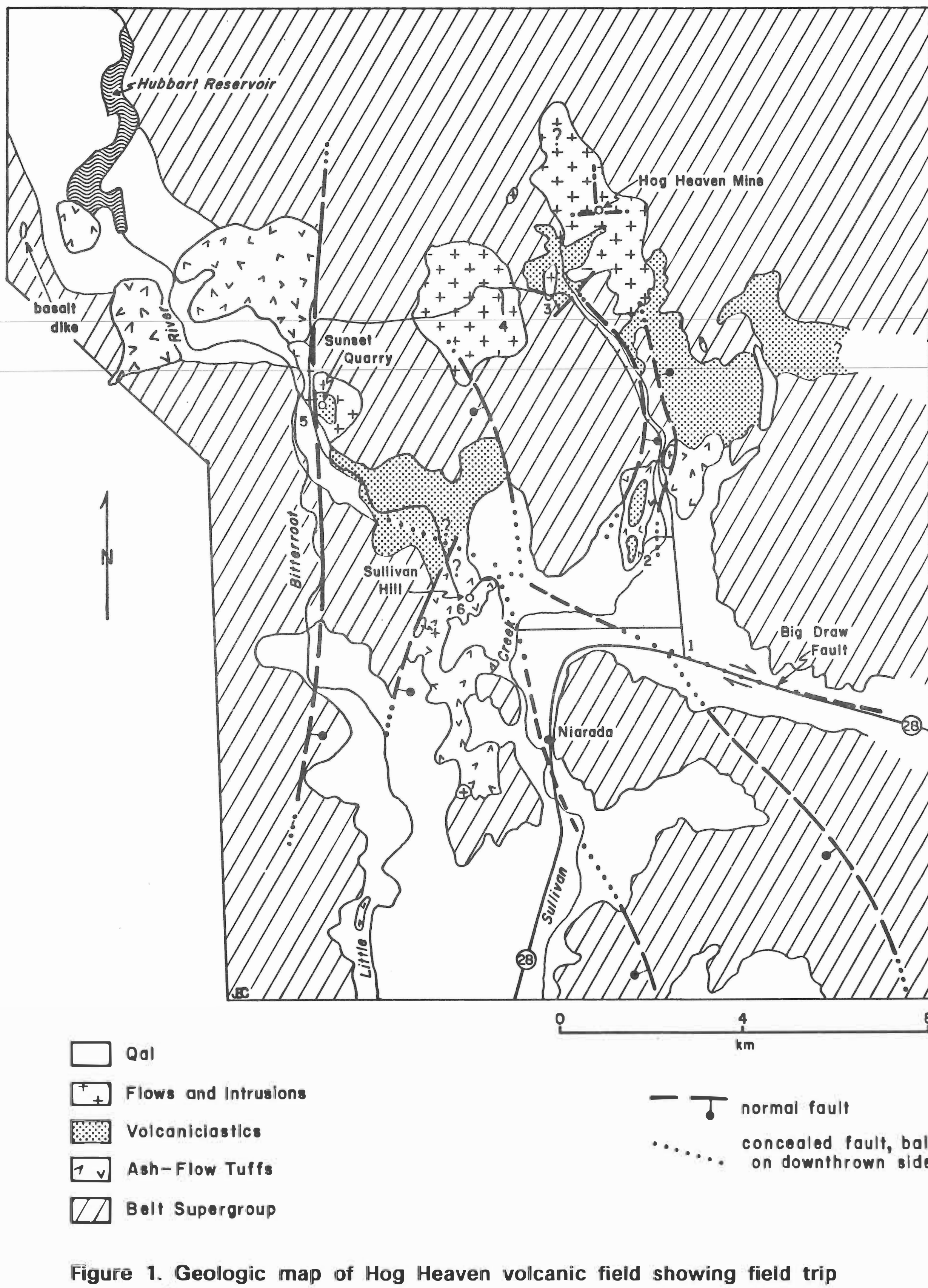

Figure 1. Geologic map of Hog Heaven volcanic field showing field trip route and stops.

Rhyolitic ashflow tuffs of the Hog Heaven volcanics are visible to the north just above the tin barn roofs on the east side of the Flathead Mine Road. These comprise the lowermost unit of the Hog Heaven volcanics. Volcaniclastic rocks overlie the ashflows and are exposed in the hills to the north. The workings of the Flathead Mine can be seen on the skyline to the north just above the blue house; it is hosted in volcaniclastic rocks and rhyolitic flow/domes. From this vantage point the horizontal fossil shorelines of Glacial Lake Missoula are visible on the sides of many hills. **Continue north along the Flathead Mine Road.**

1.6

28.9 **Turn left onto small private road.**

0.5

29.4 **Stop 2. Pull over on flat area at base of hill.** Exposures of the lowermost ashflow and overlying volcaniclastic rocks of the Hog Heaven volcanics. The ash flow(s) are rhyolitic in composition and contain ubiquitous sanidine, plagioclase, and biotite $\pm$ quartz crystals. Welding ranges from poor to moderate in the unit; here it is moderately welded with pumice length:width up to 10:1. The ashflows commonly contain 5%–15% Belt pebbles, but also contain a very small percentage of granite and biotite schist pebbles which have no local source. These probably represent material derived from conduit walls during magma ascent.

The contact with the overlying volcaniclastic unit lies about 50 m up the hill. The unit consists primarily of nonbedded cobble conglomerate with rounded Belt clasts in a volcanic matrix. In some localities, bedding, clast imbrication, point contact between clasts, and sandstone interbeds are found. Note that here the volcaniclastics rest on the welded zone of the ashflow; implying erosion of the upper nonwelded portion of the ashflow occurred before deposition of the conglomerate.

0.5

29.9 **Return to Flathead Mine Road. Turn left and proceed north.**

1.1

31.4 Columnar jointing in the ashflow tuff is visible on exposures to right (east side) of road.

0.1

31.5 Straight ahead is a rhyolite dome which comprises the hill on the east side of the road. This dome is separated from the ashflow by a strand of the Hog Heaven Fault, which parallels the road a hundred meters or so to the east and drops the east side down. This dome may be pre-ashflow as it rests directly on top of the Belt in exposures on its north side.

0.8

32.1 Belt outcrops on right and left side of the road.

0.6

32.3 Cattle guard marking northern boundary of the Flathead Indian Reservation.

0.4

32.7 Outcrop of partly silicified conglomerate on right side of road cut by thin goethite veinlets and near-vertical, north-striking fractures. A second strand of the Hog Heaven fault strikes north and controls this valley. In this vicinity the unit rests directly on top of the Belt, is composed of Belt clasts but has volcanic material in the matrix.

0.3

33.0 Limonite- and hematite-stained breccia unit of volcaniclastic and Belt rocks east of road cut by narrow goethite veinlets. This outcrop has been interpreted as a fossil fumarole such as those found to the north at the Flathead Mine. However, this deposit could have formed from spring emanations containing iron along the Hog Heaven Fault.

0.3

33.3 Cattle guard.

0.2

33.5 Belt outcrops of the Ravalli Group on west side of road.

0.4

33.9 Straight ahead is the dark summit talus slope of Battle Butte. Battle Butte is composed of at least two separate rhyolite or 'rachyandesite' flows that emanated from vents at or around the Flathead Mine. The lower flow has an initial Sr value of 0.739 and a K/Ar age of 30.8 +/- 2.4 Ma.

0.6

34.5 Junction of Flathead Mine Road with Crossover Road. Weathered, matrix-supported volcaniclastic rocks are exposed in roadcuts to left (west and south) of road. **Steer left onto Crossover Road**

0.2

34.7 **Stop 3.** Martin Mine dump and adit on north side; another adit and dump on south side. Note the highly silicified, pyritized sanidine-bearing rhyolitic flow dome rock leached of feldspars in the dump and recent drill holes. The adit on the south side of the road encounters less hydrothermally altered sanidine porphyry which intrudes Belt rocks.

0.6

35.4 East contact of flow dome at west end of small clearing.

0.3

35.7 Road cut on north side of road showing steep but variable northwest striking and thin flow jointing.

0.2

35.9 **Turn south on to small logging road just before cattle gate on ridge crest. Keep left and proceed approximately 0.75 miles to clearing and high point of ridge.**

0.75

36.65 **Stop 4.** Some of the best natural flow dome exposures are found on this ridge and south-facing slope. Complex, steeply dipping flow joint patterns may be seen. The rock contains greater than 5% quartz in places and rare hornblende crystals. Two U.S.G.S. K/Ar dates on this complex are 36.0 +/- 0.8 and 35.5 +/- 0.8 Ma. We believe this complex was the source of much, or most of the ash flows found to the south. The topographical highs within the complex are the centers of individual domes. One sample collected here has an initial Sr value of 0.70465. **Return to the cattle gate and proceed west through the gate.**

0.75

37.4 Numerous exposures, some with flow banding, jointing and free quartz, may be seen for the next 1.3 miles. Soil covering volcanic rocks are yellowish and contain abundant biotite, feldspar and quartz crystals; Belt rocks weather to light gray, very fine-grained soils.

1.3

38.7 Western contact of the flow dome with Belt rocks at the road fork. **Proceed west on the south fork which descends on south side of gully.**

1.6

40.3 Intersection of Crossover road and the Little Bitterroot Valley road. **Turn south on the Little Bitterroot Valley road.**

0.8

41.1 Park on west side of road on grass opposite brightly colored scree slope below Sunset Quarry. An outcrop of flow dome rock is found at the base of the scree slope on the east side of the road. For the hardy, a brief inspection of this outcrop will be followed by a climb up to the quarry. (About 0.45 miles beyond is a road up to the quarry.) In the outcrop above the scree slope and below the quarry, note the increasingly brecciated flow dome which becomes matrix-supported and silificied in places. This represents rubble breccia on the east side of the flow dome. A sharp contact just above places an assemblage of northeast dipping water- worked volcanic sandstones and thin mud flow deposits on the east slope of the dome. Within the quarry walls are vertical,matrix-deficient pebble dikes containing abundant Belt clasts.

The bright colors in the sandstones are due to iron oxide-bearing Liesegang bands. As we walk south down the road, note more rubble breccias and siliceous veinlets in the flow dome rocks and finally the hematitically cemented and young valley fill conglomerate. [The following road log to Mile 39.35 applies for those driving and not hiking up to quarry.]

0.3

41.4 Flathead Reservation Boundary and good outcrop of Miocene (?) conglomerate on east side of road. This conglomerate drapes the sides of the valley which is cut into Belt, flow dome, ashflow and volcaniclastic rocks. Bedding in this conglomerate is subhorizontal and the clasts (Belt and volcanic) appear to have been cemented by Fe-bearing ground waters which emanated at the base of the slope. Remnants of valley fill conglomerate continue along both sides of the valley to the south.

0.15

41.55 Behind log cabin to left (east) is an exposure of weathered rhyolitic flow/dome rock. Walkers can take the trail to the Sunset Quarry which starts at the gate.

0.65

42.2 Sanders County Line. Exposures of an ashflow unit can be found in roadcuts for the next 0.2 miles.

0.3

42.5 The volcaniclastic unit is poorly exposed in roadcuts for the next 3.1 miles.

3.1

45.6 Outcrop of bedded volcaniclastic rock to right (west) of road contains copious tree bark and leaf impressions. The knob to the southwest is composed of a coarse conglomerate resting on top of Belt rocks. It contains large Belt cobbles and boulders and apparently no volcanic clasts.

0.7

46.3 **Stop 6.** Hairpin curve on Sullivan Hill. Good view of ashflow deposit lobes to the east. Lake Missoula silts veneer the bottom of valley east of Sullivan Hill.

Sullivan Hill is composed of nonwelded to poorly-welded rhyolitic ashflow tuff and/or volcaniclastic rocks. These low-density rocks contain 5%-15% Belt clasts together with pebble and cobble-sized, white, poorly vesiculated pumice (?), gray rhyolitic flow/dome rocks, and very rare biotite schists and carbonate rocks with calc-silicate rinds.

Evidence suggesting the rocks of Sullivan Hill at this locality are ashflow deposits includes: (1) vertical dewatering or degassing pipes with hematized walls and central pebble lag concentrations, (2) calc-silicate rinds on the carbonate clasts, (3) very poor welding visible in some thin sections, and (4) higher proportions of crystals to ash in matrix as opposed to pumice clasts.

0.4

46.7 Bottom of Sullivan Hill.

1.0

47.7 Road intersection. **Turn left (east) and continue east to junction with Flathead Mine Road.**

2.8

50.5 Junction with Flathead Mine Road. **Turn right (south).**

0.4

50.9 Junction with Montana Highway 28. **Turn left (east) and retrace steps to Polson and Missoula.**

APPENDIX 1

Optional Stop at Mile 9.5: Spokane Formation greenbed copper occurrence on south side of road. **Park on right.**

This roadcut exposes two green beds within purple beds of the Spokane Formation. This exposure is about the middle of the formation, which is about 1,100 m thick in this area. The Spokane Formation has a northeastern (Canadian Shield) source terrane.

At the western end of the roadcut are two green beds, one about 1.5 m thick and the other about 0.5 m thick. The thicker green bed of laminated argillite and siltite includes a zone of anomalous copper in chalcocite and some malachite staining on joint surfaces. Chip samples cut down the face of this exposure at several places allow the sulfide zone to be traced; it cuts gently downward into the green bed from the contact with the overlying purple beds at the west end and has crosscut bedding almost to the middle of the green bed at the east end. This cross cutting zone is not obvious because small grains of chalcocite are very difficult to identify with a hand lens, particularly if the grains are not accompanied by secondary copper minerals. Chalcocite is always concentrated in the coarser (siltier) parts of the graded beds. Thin sections and polished surfaces show that chalcocite replaced both groundmass (chlorite-sericite-biotite) and detrital grains (quartz-albite) of the host rock. Analyses of chip samples from the mineralized zone show a maximum of 0.3 percent copper and 0.2 oz. of silver per ton in samples representing layers 30 cm thick.

In the thinner green bed, note the basal thin quartzite, green thinly laminated argillite and siltite, and purple thicker laminated argillite and siltite. Note here that the characteristic disturbed bedding of the purple layer below the quartzite has a green top adjacent to the quartzite. This suggests reduction of iron in an original red-bed at a later stage; this reduction was caused by deoxygenated water circulating through the more permeable sandstone.

Conclusion: Both the distribution of copper across the thicker green bed and the altered top of the purple bed below the quartzite suggest circulation of chemically reduced waters that could have mobilized and redistributed copper. Some modification by redistribution of any "syngenetic" copper seems required.

Source: **Harrison, J. E., Lange, I. M. and Harrison, J. P., 1977,** Stratabound copper occurrence in green beds of the Belt Supergroup, western Montana: Geol. Soc. of America, Rocky Mountain Section Field Guide No. 3, Missoula, MT, p. 8-9.

ROAD LOG NO. 3
CHANGES IN LATE CRETACEOUS STRUCTURAL STYLES BETWEEN NINE MILE AND DRUMMOND, MONTANA

James W. Sears[1]

Initial point: Van Buren Street Interchange, I-90 Exit 105, westbound
Distance: 217 miles
Highways: I-90, U.S. 93, Montana 200, Old U.S. 10, various county roads.
Field Stops: 10
No. 1 - McCormick Creek
No. 2 - O'Keefe Creek Valley, U.S. 93
No. 3 - Rattlesnake Canyon
No. 4 - Blackfoot Canyon
No. 5 - Blackfoot Canyon
No. 6 - Blackfoot Canyon
No. 7 - Cramer Creek Road
No. 8 - Clark Fork Canyon East of Bearmouth
No. 9 - Clark Fork Canyon East of Bearmouth
No. 10 - Quarry North of Drummond

Introduction

A large anticlinorium plunges southeast between Nine Mile and Drummond, Montana, revealing a cross section through more than 20 km of a Late Cretaceous thrust system. In the deep part of the system near Nine Mile, the lower part of the Proterozoic Belt Supergroup deformed plastically, while in the upper reaches of the system near Drummond, Cretaceous limestones failed brittlely. The brittle/ductile transition zone crops out near Missoula.

The area lies along the overlap zone between two major thrust plates, called the eastern and western slabs on Figure 1. The western slab overrode the eastern slab during Campanian (Late Cretaceous) time, forming most of the fabrics we will examine on this field trip. The eastern slab overrode the Montana disturbed belt in Paleocene time, rotating the older fabrics of the overlap zone and producing the regional plunge observed along the field trip route.

Late Cretaceous cleavage fabrics can be traced continuously through the structural section: phyllitic schistosity in the Proterozoic rocks at depth gives way to spaced pressure-solution cleavage in the Upper Cretaceous foreland basin deposits at the top of the section. All fabrics relate statistically to large scale folding and thrusting which disturbs Campanian-aged deposits but is cross-cut by slightly younger Campanian-aged plutons (see Ruppel and others, 1982; Sears, 1988).

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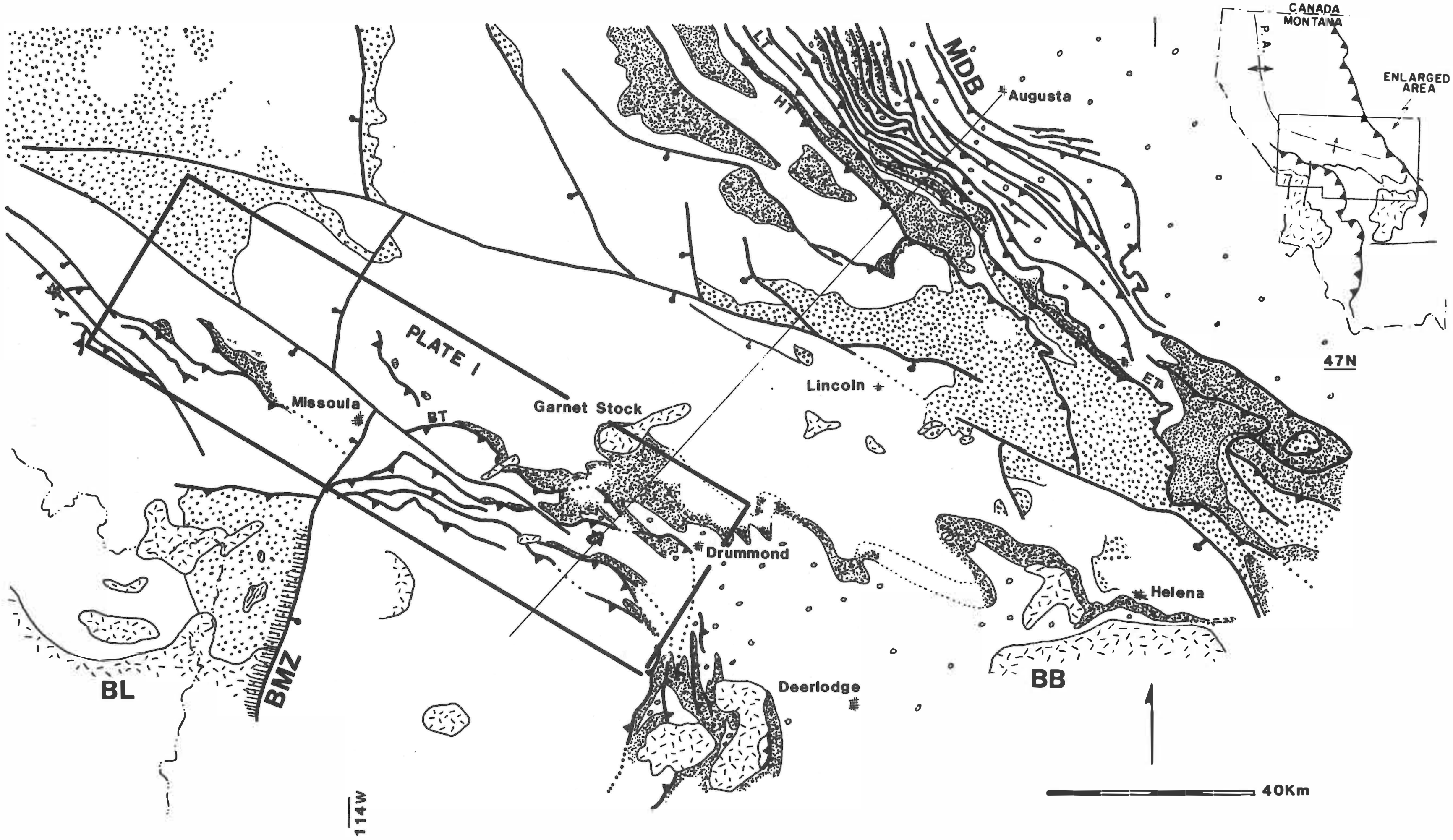

Figure 1. Location map for area of field trip. Symbols: Open stipple, lower part of Belt Supergroup (Prichard and Ravalli); unpatterned, upper part of Belt Supergroup; heavy stipple, Paleozoic section; circles, Mesozoic rocks; chicken tracks, Late Cretaceous plutons; horizontal lines, Bitterroot mylonite zone. Abbreviations: BB, Boulder batholith; BL, Bitterroot lobe of Idaho batholith; BMZ, Bitterroot mylonite zone; MDB, Montana disturbed belt. After Sears, 1988.

The field trip and road log (Plate 1) follow the system from the deep levels to the shallow. Two major thrust faults cut the upper part of the section along the leading edge of the western slab. We will trace the lower fault, the Blackfoot thrust, from its ductile roots in greenschist facies rocks near Missoula to its apparent terminus as a kink fold in unmetamorphosed Mississippian limestones near Bearmouth. The upper fault, the Bearmouth thrust, lies structurally above the Blackfoot thrust, and, between Missoula and Drummond, climbs hangingwall and footwall ramps from the Belt Supergroup into the Mesozoic section.

The structural development of the region is treated in more detail in Sears (1988), and Ruppel and others (1982).

Road Log. Leg 1: Missoula-Nine Mile-Evaro Hill-Rattlesnake Creek

0.0 **Start in Missoula at Van Buren Street Ramp for I-90 W (Exit 105). Travel west on I-90**. The interstate follows the trend of the Tertiary Missoula Valley for the next 20 miles. The Missoula Valley is a half-graben (TQ of Plate 1) with a triangular map pattern, elongate to the WNW. The Nine Mile/Clark Fork fault zone forms the northeastern boundary, and the Mount Sentinel down-to-the west normal fault forms the eastern boundary. The Nine Mile/Clark Fork fault zone has right-lateral, down to the southwest oblique-slip displacement, and is one of a family of faults making up the Lewis and Clark "line". Middle Eocene volcanics and Tertiary Renova Formation sediments in the valley dip to the northeast, with dips increasing systematically with proximity to the trace of the Nine Mile/Clark Fork fault zone. The valley apparently formed after middle Eocene, but before late Miocene time: the continuity of middle Eocene volcanics is broken by the basin, while laterite soils thought to be of middle Miocene age cap the tilted Renova Formation. The Miocene/Pliocene Six Mile Creek Formation, a locally derived fanglomerate, overlies the laterite and forms some relict alluvial fans.

0.8

0.8 Overpass above Orange Street. Large roadcut to right exposes a north trending normal fault in the lower part of the Missoula Group on Waterworks Hill.

0.4

1.2 Red soils in roadcuts on the right are probably middle Miocene laterites.

1.6

2.8 Excavations around the landfill to the right reveal an angular unconformity beneath Miocene/Pliocene alluvial gravels of the Six Mile Creek Formation. The beds below are lateritized conglomerates of the Renova Formation. Granitic cobbles are thoroughly weathered relicts.

0.7

3.5 Thin lacustrine limestones of the Renova Formation crop out in the road cut. A thin coal seam occurs near the exit ramp.

0.4

3.9 Bridge over Grant Creek. Pit on right is in Quaternary outwash gravels.

1.7

5.6 A large remnant of Glacial Lake Missoula lacustrine sediments forms the terrace on the left on which the airport is located.

1.6

7.2 Cross Butler Creek outwash plain.

2.0

9.2 Overpass. Cross under U.S. 93.

0.8

10.0 Stone Container plant is on the left. The cliffs behind the plant are Cambrian Hasmark Dolomite. The higher elevations behind are a large thrust plate of the Missoula Group. The thrust is at the break in slope. This thrust may be the western continuation of the Bearmouth thrust. It dies out about 12 miles west of here in a syncline near the Nine Mile Ranger Station.

0.8

10.8 Road cuts on the right, along the frontage road, are the best exposures of Tertiary strata in the Missoula Valley.

2.2

13.0 Weighing station on the right.

1.1

14.1 Glacial Lake Missoula sediments are on the right.

2.9

17.0 Frenchtown Pond is on the right.

0.7

17.7 Nine Mile Valley lies ahead. The Nine Mile fault trace is at the break in slope on the right. The ridge on the left is Nine Mile Divide, tilted into the Missoula Valley half-graben. Some middle Eocene volcanics overlie the tilted Nine Mile Divide block, and dip under the valley fill.

2.6

20.3 Huson overpass, Exit 85.

1.0

21.3 Near Milepost 84. Pilcher Formation crops out in quarried hill on the left, beside the Clark Fork River. Across the river in the distance is a prominent cliff of the Cambrian Red Lion Formation. The more distant hills are an overlying thrust plate of the Missoula Group.

1.4

22.7 Interstate crosses thrust placing Missoula Group over Cambrian rocks. **Take Exit 82**. Precambrian diabase forms the outcrop at the exit ramp.

0.1

22.8 Stop Sign. **Turn right on Nine Mile Road.**

0.3

23.1 Contorted Garnet Range Formation crops out.

0.4

23.5 Clark Fork River turns left and leaves the Missoula Valley to enter Alberton Gorge, a narrow and steep bedrock valley.

0.2

23.7 Garnet Range Formation crops out.

0.3

24.0 Lake Missoula sediments crop out.

0.2

24.2 **Turn right on Remount Road.**

1.7

25.9 Yellow frame buildings on the left are the "Schoolhouse Teacherage". Hasmark Formation crops out on the right. Pilcher Formation forms hill ahead and on left.

0.5

26.4 Pavement ends. Enter Nine Mile Valley.

0.4

26.8 Nine Mile Ranger Station. **Turn left on Nine Mile Road.**

0.3
27.1 View ahead is Nine Mile Divide.
2.1
29.2 Pass ranch buildings.
0.2
29.4 Bridge over Nine Mile Creek is on the left.
2.3
31.7 Kennedy Creek is on the right.
0.1
31.8 Cross Butler Creek.
0.5
32.3 Garnet Range Formation crops out.
0.9
33.2 Nine Mile Community House is on the right.
0.4
33.6 Kennedy Creek Road is on the right.
1.1
34.7 McCormick Creek Road (USFS Road 392). **Turn right. Drive up McCormick Creek past placer workings of various ages.**
1.9
36.6 Green sign, "392".
0.5
37.1 Elbow curve to left at creek. **Park on right just before reaching culvert. Walk across culvert to road sign "5496" on right. Take this narrow logging road for a distance of about half a mile to Stop** 1.

Stop 1. Upper Prichard Formation. The outcrops along the road expose the laminated phyllites of the upper part of the Prichard Formation. The cleavage is axial planar to the large folds of the Boundary Divide. It intersects bedding laminations at a high angle, forming a lineation which plunges southeast. This cleavage can be traced upward through the plunging structures of the Boundary Divide and Jocko Mountains into Cambrian rocks. It conforms to structures dated stratigraphically as post-middle Cretaceous. The cleavage planes here have a strong down-dip stretching lineation. Quartz shadows on pyrite grains are elongate with aspect ratios of from 3:1 to 10:1. Further along the road are incipient sheath folds, where the bedding laminations form wavy patterns on the cleavage planes, rather than straight lines.

The upper part of the Prichard Formation is one of the more ductile units in the Belt Supergroup. Underlying parts of the Prichard Formation are hornfelsic, quartz-rich turbidites which deformed more brittlely. This is the deepest part of the structure we will visit on the field trip.

Return to I-90 and proceed east toward Missoula.
27.9
65.0 **Take Exit 96.**
0.2
65.2 **Turn left on Highway 93N.** Traverse Lake Missoula and Tertiary sediments.
4.0
69.2 Mouth of canyon of O'Keefe Creek at beginning of steep grade. **Park at far end of chainup area. Cross Highway 93 to roadcut outcrop by power pole.**

Stop 2. Wallace Formation. This large outcrop of calcareous pelites and quartzites is on the southwest limb of the same large anticline we visited at Stop 1, but we are now about 6 km higher in the section. Here, we are in the middle part of the structural section, in the ductile/ brittle transition zone. Cleavage is very strong in calcareous and pelitic lithologies, but is absent in interlayered quartzites, indicating this part of the rock package was in the ductile field for pelite, but the brittle field for quartzite. Cleavage refracts through lithologies of contrasting ductile strength. It nearly parallels bedding in limestone layers, lies at a shallow angle to bedding in pelites, and steepens with increasing quartz content in graded beds.

Return to I-90 and proceed east to Missoula.

13.0

82.2 **Take Exit 105.**

0.3

82.5 **Turn left at stop sign on Van Buren Street and proceed North up Rattlesnake Creek.** Rattlesnake Drive follows the outwash plain of Rattlesnake Creek for the next 4 miles. Waterworks Hill on the west side of the valley exposes Snowslip and Wallace Formations; Mount Jumbo on the east side is mostly Mount Shields Formation, with Shepard Formation near the base. Right hand turn in the road at Lincolnwood subdivision is approximately at the trace of the Nine Mile/ Clark Fork fault. Canyon narrows in Wallace/Helena Formation.

4.1

86.6 **Turn left on Sawmill Gulch Road to trailhead of Rattlesnake National Recreation and Wilderness Area.**

0.3

86.9 **Park in parking area. Hike north along trail in valley bottom approximately 0.2 miles to large cliff face of Wallace/Helena Formation** at Stop 3.

Stop 3. Wallace/Helena Formation on overturned limb. Calcareous pelites of the Wallace/Helena Formation are highly sheared in this outcrop and in most outcrops along Rattlesnake Creek and for several miles to the northwest. These rocks occupy the lower limb of a large nappe that is overturned to the northeast. The bedding parallels cleavage, and there is a strong stretching lineation in the transport direction. This nappe appears to be the same anticline that we visited at Stops 1 & 2, but here it is more strongly overturned. This nappe apparently passes upward into the Blackfoot thrust fault, a major structure of the Garnet Range.

Return to I-90.

4.4 miles.

91.3 I-90, Exit 96, Eastbound entrance. **Turn left**.

Road Log, Leg 2: Missoula - Blackfoot Canyon

0.0 **Restart mileage at I-90, eastbound entrance. Proceed east on I-90 toward Butte.**

0.3

0.3 Interstate 90 crosses the Mount Sentinel Tertiary normal fault and enters Hellgate Canyon. The eastern block rose at least 5 km relative to the western block, which forms the Missoula Valley. Shepard Formation calcareous argillites form the brown weathering outcrops at the west edge of the canyon. Cambrian Hasmark dolomite dips under the Missoula Valley Tertiary fill west of Missoula. The Mount Sentinel fault abuts the Clark Fork-Nine Mile fault north of here in the saddle behind Mount Jumbo, the large grassy mountain forming the north wall of Hellgate Canyon.

1.1

1.4 Mount Shields formation crops out on the left. Hellgate Canyon exposes a continuous section of the lower Missoula Group, from the upper part of the Shepard Formation through the lower part of the McNamara Formation. These rocks form the footwall of the Bearmouth thrust. Pelitic layers locally exhibit east-dipping phyllitic schistosity.

2.7

4.1 **Take Exit 109, proceed east on Montana 200.**

1.0

5.1 Bridge over Blackfoot River, entering Milltown. Continue on Montana 200.

0.4

5.5 **Bear left, remain on Montana 200 east.**

0.4

5.9 Town of Bonner, Champion plywood mill is on the left. The Blackfoot thrust crops out at the base of Bonner Mountain, the forested mountain on the right. This important fault places Wallace Formation and Missoula Group over Missoula Group and Paleozoic rocks. At Bonner, the Wallace Formation on the southwest flank of Bonner Mountain (near the Letter "B") is very strongly sheared on the overturned limb of the Bonner Mountain anticline. A good outcrop along the abandoned railway behind Bonner Elementary School shows the Wallace bedding transposed into the shear foliation.

0.7

6.6 Highway 200 passes through a notch in a tight curve to the right. **Proceed around curves.**

0.2

6.8 **Park on wide left shoulder. Walk back to notch.**

Stop 4. Blackfoot thrust. The Blackfoot thrust crops out in this long roadcut. The trace of the fault is under the highway, but because the fault dips to the southeast, small klippen occur on the north side of the road. The south side of the road is highly sheared Mount Shields Formation quartzite and argillite in the hangingwall. The north side is mostly the footwall, here a vertical diabase sill in the upper part of the Mount Shields Formation. Shearing along the fault converted the diabase into a chlorite-actinolite-epidote mylonite, with a strong mineral lineation trending northeast. Metamorphic temperatures were at least 350 degrees C during thrust faulting here. The mylonitic foliation dies out within a few meters below the Blackfoot fault plane.

Vertical beds of the footwall are obvious on the north side of the Blackfoot River. The finely bedded rocks are the Mount Shields Formation, and the rounded, grassy ridge is the diabase sill. The tilted beds form the steep southwestern limb of the Wisherd syncline, the major fold of the Garnet Range. The Wisherd syncline plunges southeast, and contains Paleozoic rocks east of here. Further southeast, related structures involve middle Cretaceous shales of the Blackleaf Formation. The

Blackfoot fault cuts through the vertical limb of the syncline, and has about 5 km of displacement here.

The sill forms an important structural marker for about 40 km in the Garnet Range and Jocko Mountains. **Continue east on Montana 200.**

0.2

7.0 The Bonner Quartzite crops out on the north side of the river on the prominent ridge.

0.5

7.5 McNamara Formation crops out in road cuts and across river.

0.7

8.2 **Park on the right side of the highway in the parking area just beyond the Blackfoot Tavern. Cross the highway, and cross the Blackfoot River on the swinging footbridge. Climb to the old railway berm, and walk toward the left (downstream) about 1/4 mile to Stop 5.**

Stop 5. Garnet Range Formation on steep limb of Wisherd syncline. The Garnet Range Formation contains broad channel sandstones and olive green micaceous shales, unlike the characteristic planar-bedded Belt units. The deformational style is different, too. This outcrop displays fairly typical small-scale structures of the Garnet Range Formation, which are more intricate than those of most Belt formations. Note at least two nearly isoclinal synclines, with axial planar cleavage in pelitic layers. Sandstones are uncleaved, but bedding and fault planes in sandstones have prominent slickensides. These rocks were in the ductile field for shale, but the brittle field for sandstone when they were folded into the Wisherd syncline. Most of the mesoscopic structures define a unique fabric associated with the southeast-plunging fold system. There is only one deformation recorded here, and it is Laramide.

Return to vehicles. Proceed east on Montana 200.

1.6

9.8 Float of Pilcher Formation is on the right.

1.2

11.0 Bridge over Blackfoot River.

0.6

11.6 Sign for rest area on the right. Cross the axial trace of the Wisherd syncline in Garnet Range Formation.

0.6

12.2 **Park on shoulder of highway on the right. Cross the highway and climb up to the abandoned railway berm for Stop 6.**

Stop 6. Garnet Range Formation on northeast limb of Wisherd syncline. This railroad cut exposes the interrelationships among thrusting, folding and cleavage. There are large northeast-facing kink folds of bedding and small northeast-directed thrusts. One thrust in a sandstone bed near the left end of the outcrop passes into an asymmetric anticline in overlying shales. The anticline has axial plane cleavage consistent with cleavage throughout the Garnet Range, Jocko Mountains and Boundary Divide. The Blackfoot traverse lies along the transition between more plastic structures at deeper levels to the northwest, and more brittle structures at shallower levels to the southeast.

Return to vehicles. Proceed east on Montana 200.

1.8

14.0 Large roadcut in McNamara Formation. **Turn around at far end in school bus stop and return to I-90.**

2.4

16.4 Rest area entrance on left. Historic marker in rest area discusses the Big Blackfoot Railway, built around the turn of the century by Marcus Daly's Anaconda Copper Mining Company. The original railroad brought logs to McNamara's landing about five miles upriver, where they were dumped into the river during high water and floated to the Bonner sawmill. One of the specially geared logging locomotives is on display in the park at Bonner (right side, near mill entrance).

7.0

23.4 Entrance to I-90. **Take left branchto o‵‵verpass and I-90 East toward Butte.**

Road Log. Leg 3: Bonner - Drummond

0.0 **Restart log at entrance ramp for I-90 East, Exit 109, Miles 23.4 above.**

0.5

0.5 Enter I-90 eastbound.

0.3

0.8 View to right of Milltown Dam. Excavation on south side of dam exposes the sill in the Mount Shields Formation. Note several small faults.

1.0

1.8 Interstate follows the trace of the Nine Mile/ Clark Fork fault zone for next 10 miles. This fault is a major component of the Lewis and Clark "line". It is a Tertiary right-lateral strike-slip fault. It has larger displacement west of the Mount Sentinel fault.

4.3

6.1 Sill in the Mount Shields Formation on the left is highly sheared. The Clark Fork fault offsets the sill from the Milltown dam on the south to here on the north.

2.6

8.7 Very large quarry on the left is in the Bonner Formation. It is highly brecciated along the Clark Fork fault zone. Several steep southwest-dipping fault planes can be seen in the west quarry wall.

2.6

11.5 Exit 120, Clinton. **Continue ahead.** Interstate 90 curves to the right and leaves the trace of the Clark Fork fault zone, which continues into the mountains. Late Cretaceous granodiorite of the Clinton stock crops out in the Wallace Creek drainage to the left, where it cuts the Blackfoot fault.

3.5

15.0 Interstate 90 crosses the Bearmouth thrust fault zone. Brecciated Bonner quartzite forms outcrops along steep ridges on left.

0.8

15.8 Large roadcut on left reveals a rotated thrust fault.

5.0

20.8 **Take Exit 130 (Beavertail Hill Road).**

0.2

21.0 **Stop sign. Turn left and cross under I-90.** Hills ahead and to right are middle Eocene shallow intrusives. They post-date the thrust structures.

Turn left, proceed under I-90.
0.4
21.4 **Turn left, proceed up hill on secondary road.**
0.3
21.7 Cambrian Hasmark Dolomite crops out on right, in footwall of Bearmouth thrust.
0.2
21.9 **Park in saddle.**

Stop 7. Bearmouth Thrust. **Traverse east along Cramer Creek Road.** The Bearmouth thrust is an important fault that overlies the Blackfoot thrust in the Garnet Range. It has exclusively brittle fabrics associated with it, in contrast with the Blackfoot thrust. At this locality, McNamara Formation argillites and siltites overrode Hasmark Dolomite. Three miles farther up Cramer Creek, the Blackfoot thrust also places McNamara Formation over Hasmark Dolomite. The Clark Fork fault zone cross-cuts the Bearmouth thrust 2 miles east of here. **Return to I-90**
1.0
22.9 **Turn left on to I-90 East.**
0.8
23.7 Roadcut on the left is in Eocene granite with a picturesque basaltic dike.
1.4
25.1 Power station for the abandoned Milwaukee Railroad is across river.
1.9
27.0 Eocene granite is on the left.
1.5
28.5 At Milepost 136 is a good view east to the Bearmouth thrust, placing Bonner Formation over Hasmark Dolomite.
0.7
29.2 Nimrod Hot Spring tufa mound is on the left.
1.1
30.3 **Take Bearmouth area Exit 138.**
0.2
30.5 **Stop sign. Turn left, go under I-90.**
0.2
30.7 Cross Clark Fork River.
0.1
30.8 **Turn right.**
0.4
31.2 Bearmouth Chalet is on the right.
2.0
33.2 Road follows approximate trace of Bearmouth thrust, which here places McNamara Formation over Mesozoic shales.
0.6
33.8 Cretaceous Kootenai Formation limestone is in the roadcut on the left.
0.2
34.0 Limestone of the Mississippian Madison Group crops out at right-hand curve in fault slice.
0.5
34.5 Eocene Bearmouth volcanics overlap the trace of the Bearmouth thrust.
0.3
34.8 Bonner Quartzite in the hangingwall of the Bearmouth thrust crops out in road cut and to the right along the river.

0.4
35.2 Quarries are in the Eocene Bearmouth volcanics.
0.3
35.5 Eocene volcanic breccia.
1.0
36.5 Bear Gulch gold placer dredge tailings.
0.7
37.2 Mississippian Madison Group limestones cut by deep canyon.
0.8
38.0 **Stop at top of hill on shoulder of road to view kink fold.**

Stop 8. The large kink fold across the canyon is in Madison Group limestones. It may represent the terminus of the Blackfoot thrust system, which rises in the section in both footwall and hangingwall from the lower part of the Missoula Group near Bonner to the Paleozoic section in Bear Gulch. The climb in section is revealed by the steady southeasterly plunge of the structure in the Garnet Range.

Proceed east on old highway.
0.9
38.9 The road traverses upsection through steeply tilted beds into the Cretaceous Kootenai Formation.
0.5
39.4 Long roadcuts are in the middle limestone member of the Kootenai Formation.
1.4
40.8 The gap is in middle Cretaceous Blackleaf Formation shales in the core of the Mulky Gulch syncline.
0.6
41.4 **Stop at wide shoulder on right near Milepost 6.**

Stop 9. Small-scale thrusts in the Kootenai Formation. At the top of the large outcrop are two small thrust ramps in the middle limestone member of the Kootenai Formation. In the lower part of the outcrop spaced cleavage is well-developed in calcareous pelites. Note that the cleavage wraps around diagenetic limestone nodules. This cleavage formed at the same time as the thrusts, and is related to the map-scale Mulky Gulch syncline. It is the same generation of cleavage as we have seen at the other stops on the field trip.

Proceed east.
1.9
43.3 Near Milepost 4 is a good view to the east of a thrust that places Madison limestones over Mesozoic shales. This may be the Bearmouth thrust, which, like the Blackfoot thrust, rises in the section in the down-plunge direction. Eocene volcanics cover this thrust so its linkage with the Bearmouth thrust is uncertain.
2.0
45.3 Flint Creek Range lies ahead on the horizon. These mountains contain high-level late Cretaceous batholiths that intrude thrust and fold structures which curve to the south from here.

1.3

46.6 Kootenai Formation limestone on left has anastomosing cleavage normal to bedding. This is the same generation of cleavage as seen at other stops on this field trip.

0.6

47.2 **Go under I–90, turn left into Drummond.**

0.1

47.3 "D" ahead is in core of an anticline outlined by the gastropod limestone member of the Kootenai Formation.

0.8

48.1 **Turn left at the end of town, go under I–90, proceed through pole plant.**

0.4

48.5 **Take high road to left, cross cattle guard, proceed ahead.**

0.2

48.7 **Stop at quarry for Stop 10.**

Stop 10. Gastropod limestone member of the Kootenai Formation. The large dipslope is held up by a bed of gastropod-rich limestone. A prominent spaced cleavage set intersects the bedding plane with a southeasterly plunge. The limestone is thrust over Blackleaf shales at the east end of the quarry. These shales have a pencil cleavage.

Return to I–90 and Missoula.

49.9

98.6 Village Red Lion Motor Inn.

Summary

On this field trip we have seen the changes in structural style which accompany changing structural level on a large plunging anticlinorium. Cleavage provides a unifying fabric which changes in character, but links deeper and shallower levels. Because the cleavage cuts late Cretaceous rocks (Campanian) east of here and is cut by Campanian stocks in the Garnet Range, its formation is tightly bracketed between 82 and 78 Ma.

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ROAD LOG NO. 4
ECONOMIC GEOLOGY OF THE JOHN LONG MOUNTAINS AND FLINT CREEK RANGE, MONTANA

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Initial point: Van Buren Exit/Entrance (#105) to Interstate 90
Distance: 220.0 miles
Highways: Interstate 90, U.S. 10A, and county roads
Field stops: 9
No. 1-Near Wall City in Pioneer district-milepoint 64.9
No. 2-Reservoir Gulch-milepoint 67.4
No. 3-Pilgrim Bar-milepoint 73.5
No. 4-Granodiorite of Henderson Creek stock-milepoint 111.5
No. 5-Sunrise mine and mill-milepoint 112.0
No. 6-Black Pine mine and mill-milepoint 116.3
No. 7-Flint Creek Valley viewpoint-milepoint 119.8
No. 8-Granite-Bimetallic mine-milepoint 131.6
No. 9-True Fissure mine-milepoint 136.7

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Introduction

The purpose of this field trip is to provide a forum for discussion of economic geology of the region southeast of Missoula and of some of the classic placer- and lode-mining districts in western Montana (Fig. 4-1). Eastward from Missoula, the first part of the trip is a long drive between the Sapphire Mountains on the south and the Garnet Range on the north to Drummond and then past the north end of the Flint Creek Range to the Pioneer placer mining district. For your early morning entertainment, the road log provides short narratives of localities of geologic and economic interest between Missoula and Drummond. The first stops are on the north flank of the Flint Creek Range at placer mines of the Pioneer District. After back-tracking to Drummond and heading south, the next stops will be in the John Long Mountains and include visits to the Henderson Creek area and the Black Pine district. The final stops will be in the Philipsburg district, on the west flank of the Flint Creek Range.

Geology

The John Long Mountains (Fig. 4-1) form a north-south chain of relatively low-relief ridges, peaks, and valleys, all heavily timbered, between Rock Creek and the Flint Creek Valley. Geologic mapping by Maxwell (1965), Desormier (1975), and Hughes (1970) established many of the principal stratigraphic and structural elements of the northern John Long Mountains, and later mapping by Biaskowski and others (1983), Reitz (1980), Lidke and others (in press), and Wallace and others, (1986) refined stratigraphic and structural data. Most of the John Long Mountains are underlain by sedimentary rocks of the Belt Supergroup (Middle Proterozoic), but the northernmost part is underlain by Paleozoic and Mesozoic sedimentary rocks and Tertiary sedimentary and volcanic rocks and deposits (Fig. 4-2). The oldest rock unit in the John Long Mountains is the Helena Formation, which includes about 3,000 m of calcareous argillite and siltite, and abundant impure limestone beds.

Stratigraphically above the Helena Formation, the Missoula Group (including the Snowslip, Shepard, and Mount Shields Formations, the Bonner Quartzite, the McNamara and Garnet Range Formations, and the Pilcher Quartzite) consists of a sequence of red and green argillite, siltite, quartzite, and carbonate-bearing clastic rocks about 6,700-m thick. Rock units of the Missoula Group are thicker and coarser grained on the Sapphire thrust plate than to the north and northeast in the Montana fold and thrust belt and the Rattlesnake thrust plate. Paleozoic rock units, defined by Emmons and Calkins (1913) from the west flank of the Flint Creek Range, are Middle Cambrian to Permian in age, and are composed mostly of thick units of limestone or dolomite and thin units of carbonate-rich shale, siltstone, and sandstone. Mesozoic rocks are red and green shale, siltstone, and sandstone and gray limestone of the Upper Jurassic Morrison(?) and Early Cretaceous Kootenai Formations (Kauffman and Earll, 1963; Maxwell, 1965).

The John Long Mountains show two contrasting structural styles: (1) structures in the central and southern part are dominated by stacked thrust sheets of Middle Proterozoic rocks that have been broadly folded and faulted, and (2) structures in the northern part are dominated by imbricate, anastamosing, listric thrusts and tight and overturned folds in Middle Proterozoic, Paleozoic, and Mesozoic rocks. Based on structural style, structures in the central and southern John Long Mountains are included in the thrust-sheet terrane of the Sapphire thrust plate, whereas structures in the northern John Long Mountains are considered part of the frontal imbricate zone of the Sapphire thrust plate (Fig. 4-3; Lidke and others, 1987). The frontal imbricate zone probably represents thrust slices that formed near the toe of stacked thrust sheets. The Miners Gulch stock (granodiorite with a K-Ar age of about 81 Ma, Obradovich, J. D., unpub. data) penetrates thrust faults of the thrust-sheet terrane, so emplacement of thrust sheets occurred before about 81 Ma.

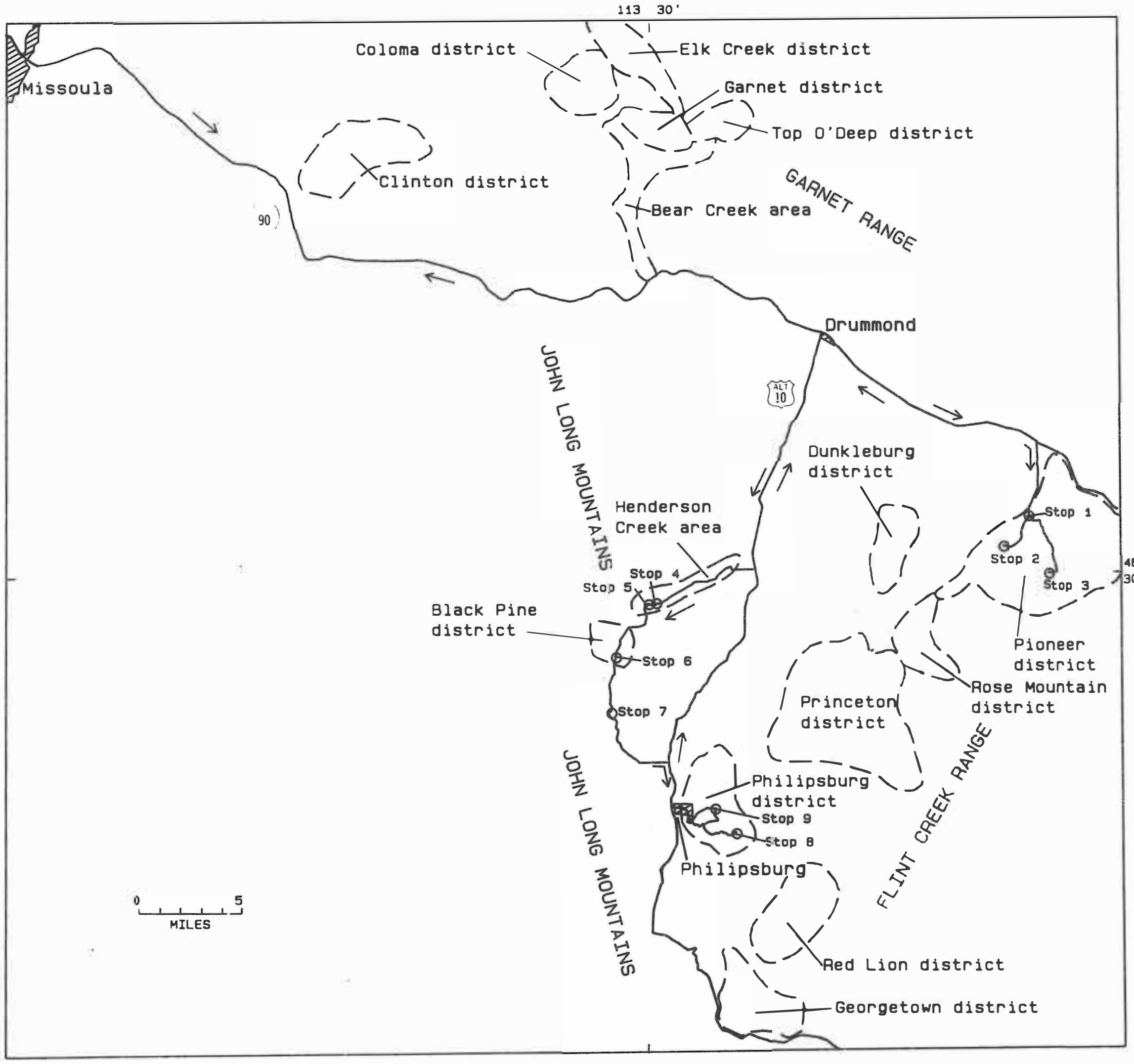


FIGURE 4-1. Route of field trip and location of major mining districts in the Garnet Range, Flint Creek Range, and John Long Mountains.

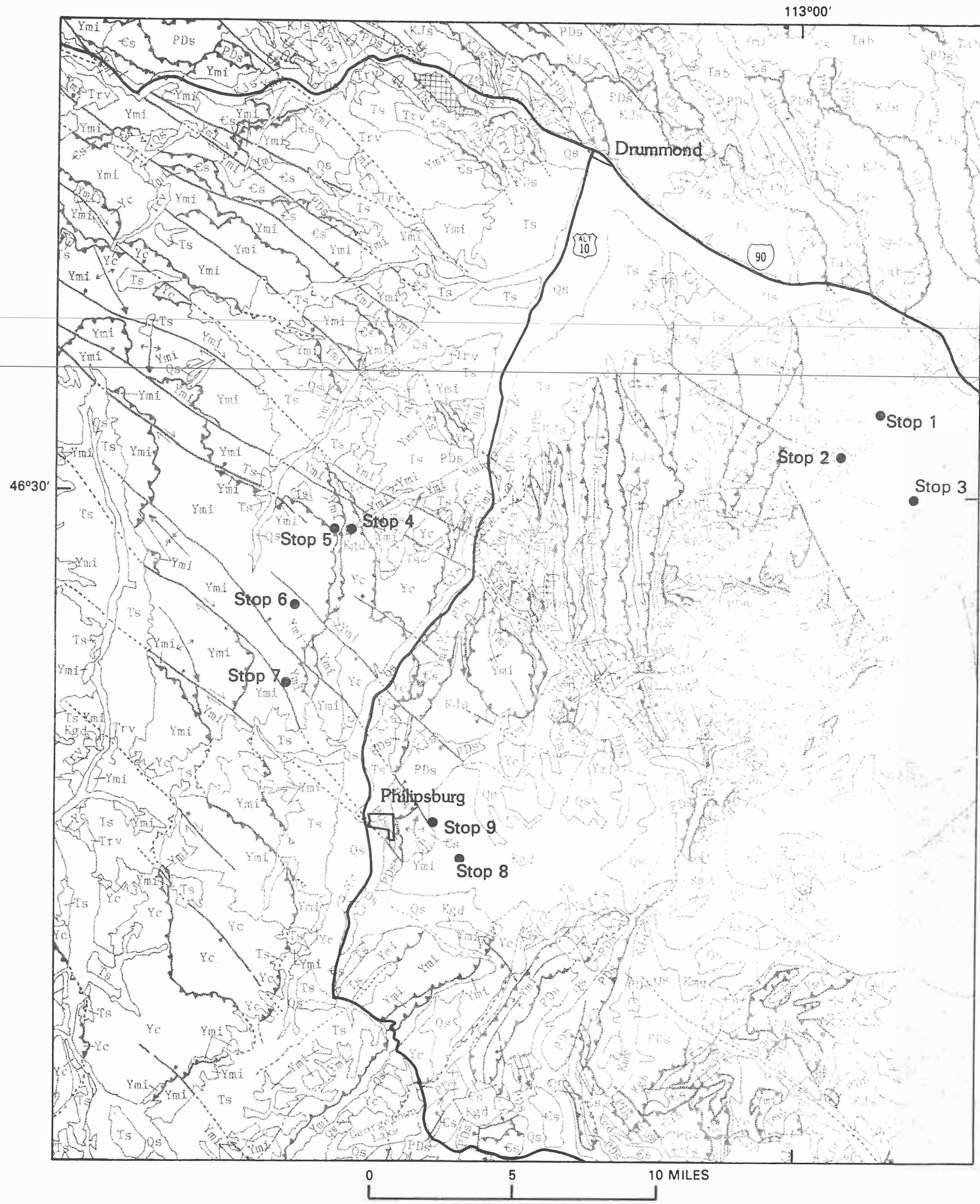


Figure 4-2. Generalized geologic map of John Long Mountains and Flint Creek Range showing field trip stops and major highways (geology from Wallace, 1987b).

Figure 4-2. EXPLANATION

LIST OF MAP UNITS

MAN-MADE DEPOSITS

Placer tailings

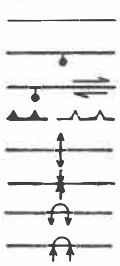
SEDIMENTARY AND VOLCANIC ROCKS

Qs	Surficial deposits (Holocene and Pleistocene)
Ts	Sedimentary deposits and rocks (Tertiary)
Trv	Rhyolitic volcanic rocks (Miocene, Oligocene, and Eocene)
Tab	Andesitic and basaltic volcanic rocks (Oligocene and Eocene)
Tlc	Lowland Creek Volcanics (Eocene)
KJs	Sedimentary rocks (Cretaceous and Jurassic)
PDs	Sedimentary rocks (Permian, Pennsylvanian, Mississippian, and Devonian)
Cs	Sedimentary rocks (Cambrian)
CYs	Sedimentary rocks (Cambrian and Middle Proterozoic)
Ymi	Missoula Group of Belt Supergroup (Middle Proterozoic)
Yc	Middle Belt carbonate of Belt Supergroup (Middle Proterozoic)

INTRUSIVE ROCKS

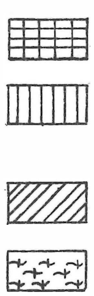
Tmg	Granitic rocks (Tertiary)
Kmg	Granitic rocks (Late Cretaceous)*
Kgd	Granodioritic rocks (Late Cretaceous)*
Kgb	Gabbroic rocks (Late Cretaceous)*
Kmd	Monzodioritic rocks (Late(?) Cretaceous)

EXPLANATION OF SYMBOLS



Contact
Normal fault
Strike-slip or oblique-slip fault
Thrust fault
Anticline
Syncline
Overturned anticline
Overturned syncline

Zone of imbricate thrust faults



In Middle Proterozoic strata

In Mississippian, Pennsylvanian, Permian, Jurassic, and Cretaceous strata

In Cambrian and Middle Proterozoic strata

Silicified shear zone--In Mississippian and Devonian strata

*Intrusive units of the same general age

Near the mining camp of Garnet, the Garnet stock (granodiorite with a K-Ar age of about 82 Ma, Obradovich, J. D., unpub. data) cuts faults of the frontal imbricate zone, so at least part of the frontal imbricate zone pre-dates about 82 Ma (Fig. 4-3). Faults of the Lewis and Clark line, a regionally extensive, east and southeast-trending system of strike-slip, dip-slip, and oblique slip faults, cut thrust sheets and faults of the frontal imbricate zone. A principal strand of the Lewis and Clark line, the Ninemile fault, follows some segments of the Clark Fork canyon east from Missoula and crosses the north part of the John Long Mountains east of Rock Creek. Other south-east-trending splays from the Lewis and Clark line cross the John Long Mountains farther to the south, such as the Mt. Sentinel fault zone, one strand of which extends into Boulder Creek on the west flank of the Flint Creek Range, and the Ranch Creek fault, which may offset Paleozoic rocks near Philipsburg (Fig. 4-3; Wallace and others, 1985; Wallace, 1987a).

The Flint Creek Range consists of a north-south elongated region of sharp peaks and ridges, glacially sculpted valleys, and extensive, heavily timbered pediments. The southwestern part of the Flint Creek Range was mapped in the early 1900's by F. C. Calkins, and reports from that work (Emmons and Calkins, 1913; Calkins and Emmons, 1915) established a local stratigraphic and structural framework for the range. Most of the remaining Flint Creek Range was mapped during the late 1950's by graduate students from Princeton University under the supervision of J. C. Maxwell. The series of map reports (Gwinn, 1961; McGill, 1959; Mutch, 1961; and Csejtey, 1962) from those studies helped to understand the complexities of the geologic framework of the Range, even though some aspects of the stratigraphy and structure remained uncertain or contradictory (McGill, 1965). Later mapping by Wallace and others (1986) refined previous maps and provided regional continuity that resolved some of the problems found by the Princeton group.

In contrast to the John Long Mountains, most of the Flint Creek Range is underlain by Mesozoic and Paleozoic sedimentary rocks and isolated klippen of Middle Proterozoic rocks; these have been intruded and metamorphosed by plutonic rocks of Late Cretaceous age which range in composition from gabbro to monzogranite (Fig. 4-2; Wallace and others, 1986). The plutons range in size from small stocks to moderate-sized batholiths such as the Philipsburg batholith (Fig. 4-3). The Paleozoic sedimentary rocks consist mainly of limestone and dolomite, and lesser amounts of calcareous shale, siltstone, and sandstone. The Jurassic and Cretaceous sedimentary units are primarily shale, siltstone, and sandstone, and lesser amounts of limestone, bentonite, and volcanic ash (Kauffman and Earll, 1963; Gwinn, 1961; Gwinn and Mutch, 1965). The Ellis Group (Middle and Late Jurassic), Morrison(?) Formation (Late Jurassic), and Kootenai Formation (Early Cretaceous) form the lower part of the sequence, and the Blackleaf Formation (Early Cretaceous) and the Coberly, Jens, Carter Creek, and Golden Spike Formations (Late Cretaceous) form the upper part of the sequence. Middle Proterozoic rocks are represented mostly by the Helena Formation (middle Belt carbonate) and the overlying Missoula Group that consists of the Snowslip Formation, Mount Shields Formation, Bonner Quartzite, McNamara Formation, and Garnet Range Formation. Lithofacies of Middle Proterozoic sequences in klippen suggest that these rock units are very similar to rock units in a high-level thrust sheet in the southwestern Sapphire Mountains. The main plutons in the Flint Creek Range are the Philipsburg batholith (granodiorite with a K-Ar age of about 79-73 Ma, Hyndman and others, 1972), the Royal stock (granodiorite with a K-Ar age of about 66 Ma, Obradovich, J. D., unpub. data), and the Mount Powell batholith (monzogranite with a K-Ar age of about 63 Ma, Obradovich, J. D., unpub. data). All of these plutons cut deformed thrust faults in the Flint Creek Range. Most mineral deposits occur near the borders of plutons where Paleozoic and Mesozoic host rocks of favorable composition are present.

Although the structural style of the Flint Creek Range appears different from that of the John Long Mountains, both ranges are characterized by areas of deformed thrust sheets and by areas of tight folds and imbricate thrust faults (Fig. 4-2; Wallace and others, 1986). The significance of specific structures, the sequence of development of structures, and integration of structures with regional tectonics remains a subject of uncertainty and controversy in the Flint Creek Range (McGill, 1965; Hyndman, 1980; Wallace and others, in press). In our interpretation of regional data, Paleozoic and Mesozoic rocks in the Flint Creek Range, which were considered para-autochthonous by Hyndman (1980), form a principal thrust sheet that is bounded by decollements. The Paleozoic and Mesozoic rocks are overlain by a thrust sheet of Middle Proterozoic rocks, as well as underlain by a thrust sheet of Middle Proterozoic rocks. The overlying thrust sheet is represented by klippen in the central and eastern parts of the range. The large-scale parallel folds that deform the klippen, the bounding decollements, and rocks of the lowest thrust sheet suggest the presence of a deeper "blind" decollement (Dunne and Ferrill, 1988) beneath the lowest exposed thrust sheet. The deeper decollement, above which thrust sheets of the Flint Creek Range are folded, is exposed at a deeper structural level directly to the south in the Anaconda Range (Emmons and Calkins, 1913, Lidke, 1985). We suggest that a ramp formed along a decollement near the present location of the Philipsburg Valley to explain the close proximity of the differently stacked thrust sheets in the John Long Mountains and in the Flint Creek Range. Rocks of the Belt Supergroup apparently moved eastward up that ramp and along a decollement over Paleozoic and Mesozoic rocks into the area of the present Flint Creek Range. Exposures of the Georgetown and Philipsburg thrusts (Emmons and Calkins, 1913) may be the western roots of the upper decollement in the Flint Creek Range (Emmons and Calkins, 1913; Csejtey, 1962), and these two thrusts may be located near the buried ramp (Lidke, 1985). Southeast-trending faults of the Lewis and Clark line, which were prominent features in the John Long Mountains, show little offset of rocks in the Flint Creek Range. Preliminary structural analyses suggest that the Bald Butte and St. Marys-Helena Valley faults, which form the northernmost faults of the Lewis and Clark line (Fig. 4-3), accommodated most right slip during Cretaceous time because the Boulder batholith formed a buttress that diverted slip north of the Flint Creek Range and Boulder Mountains.

The development of sedimentary basins during Cenozoic time controlled the location of gold placers in the region of the John Long Mountains and Flint Creek Range (Loen, 1986, 1987). Ancestral ranges of the John Long Mountains and Flint Creek Range appeared before middle Eocene time, probably during early phases of normal faulting in this region. Ancestral Clark Fork and Blackfoot rivers drained this region toward the west and northwest before middle Eocene time, and the volcanics of the Bearmouth area and the Garnet Range Volcanics (about 44-48 Ma) (Carter, 1982; Chadwick, 1972) were erupted over the present Garnet Range and into valleys along the Clark Fork and Blackfoot drainage systems. Upper Eocene conglomerate was deposited in the Flint Creek and Anaconda Ranges, and in the southern Sapphire Mountains (Emmons and Calkins, 1913; Poulter, 1956; Csejtey, 1962) on pediments that formed before late Eocene time; these conglomerates probably mantled most mountain flanks in this region. Lake deposits of early Oligocene age are not exposed at the surface in the areas adjacent to the John Long Mountains and Flint Creek Range, but late Oligocene lake, marsh, and fluvial deposits of the Cabbage Patch beds (Rasmussen, 1977) are widely exposed. Middle and late Miocene lake, marsh, and fluvial deposits unconformably overlie upper Oligocene deposits; these younger sedimentary units have been locally named the beds of Squaw Gulch and the overlying beds of the Pioneer district by Loen (1986), or the beds of Flint Creek and the overlying beds of Barnes Creek by Rasmussen (1977). Deposits as young as Late Miocene are faulted and folded locally near Drummond and are unconformably overlain by unconsolidated gravel of probable Pliocene age. According to Loen (1987), the warm and humid climate and relative tectonic quiescence during the Eocene and Oligocene promoted weathering of gold-bearing deposits in adjacent mountain ranges, and rejuvenated tectonic activity during the Miocene and Pliocene increased erosion rates. As a result, gold was released from lode deposits and transported in streams to be concentrated in alluvial fan deposits that flanked the mountains. Glaciation during the Pleistocene also had a profound effect on the removal of gold from lode source areas and the transportation of gold to valleys and basins bordering the mountains however, with few exceptions, this did not result in the concentration of gold into placer deposits. During the waning of glaciation, gold was reconcentrated from till in outwash deposits and during the Holocene a large number of placer gold deposits were formed along modern drainage systems.

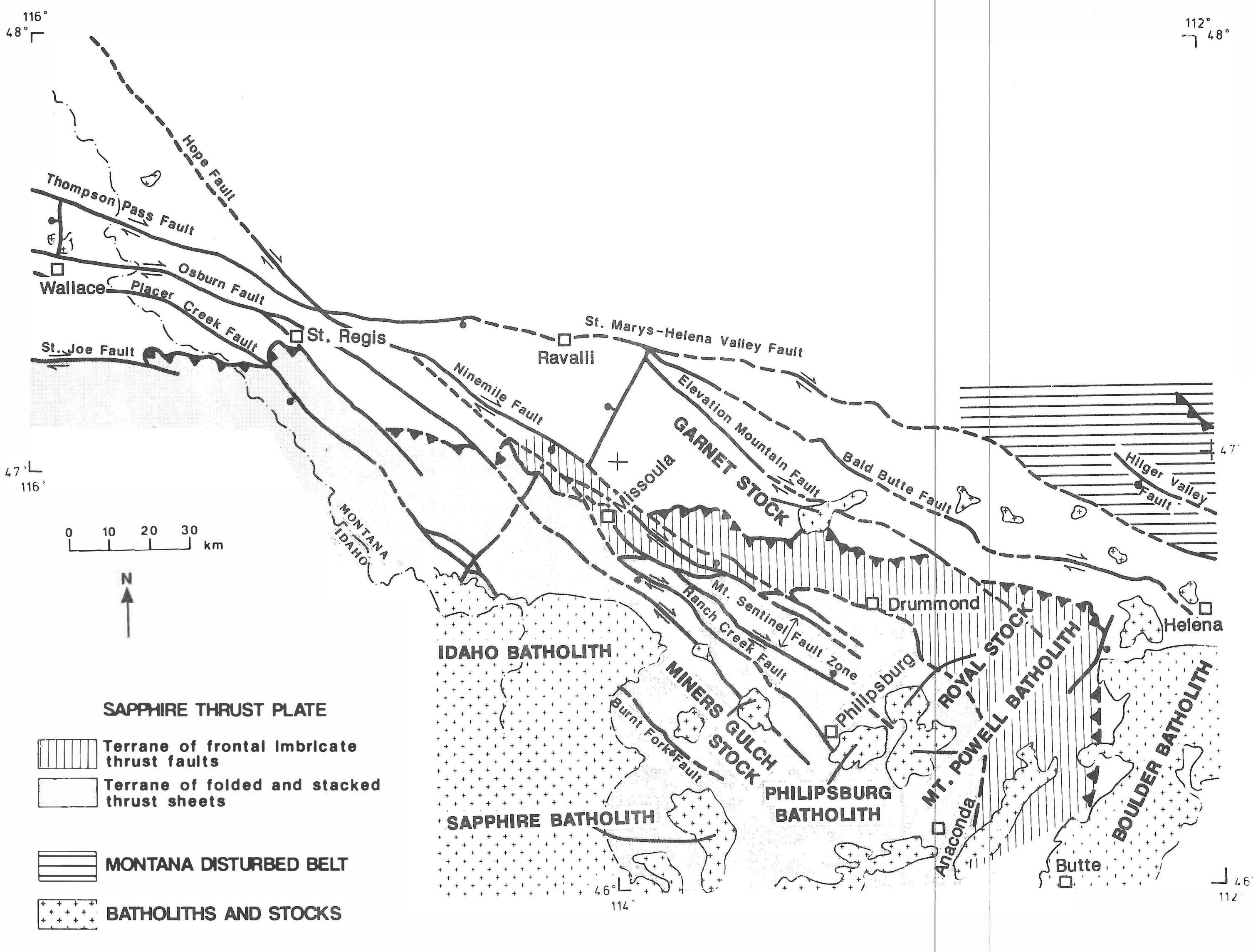


Figure 4-3. Principal structures and plutons of the Sapphire thrust plate, western Montana.

Mining history and mineral deposits

The John Long Mountains and Flint Creek Range occupy part of one of the most highly mineralized regions of the U.S. and important mining districts and mineral deposits are found in many parts of both ranges (Elliott and others, 1986). The most important districts in total value of production in the Flint Creek Range are the Philipsburg, Georgetown, Pioneer, Princeton, and Dunkleberg districts. In the John Long Mountains, the most important are the Black Pine district and the Henderson Creek area. Types of deposits that have been mined include vein and replacement deposits of base metals, precious metals, manganese, and tungsten; sedimentary phosphate deposits; and placer gold and tungsten deposits. The estimated total value of production (at the time of mining) for the Flint Creek Range is approximately $115 million with the Philipsburg district accounting for about $91 million of this total. The principal commodities produced (in approximate order of importance) in the Flint Creek Range were silver, manganese, gold, zinc, lead, copper, phosphate, and tungsten. For the John Long Mountains the estimated total value of production is approximately $24 million with most of this coming from the Black Pine mine. The most important commodities produced from the John Long Mountains were silver, gold, copper, lead, and tungsten.

This region has had a long and colorful history of mining starting with the first discovery of gold in what was to become Montana Territory. This event took place in the northern end of the Flint Creek Range where Francois Finlay discovered gold in 1852 near the mouth of Gold Creek (Emmons and Calkins, 1913). Although Finlay did not find deposits rich enough to mine, news of his discovery led others to prospect in the area which later became known as the Pioneer district. The discovery of rich placer gold deposits near Bannack in 1862 and Alder Gulch in 1863 led to a great influx of eager prospectors into Montana and, in the next few years, all of the important placers, as well as many important lode gold and silver deposits were found (Knopf, 1913). Important lode deposits were discovered in the Philipsburg and Georgetown districts during the 1860's. The Hope mine was located in 1864 and, in 1867, a mill was built to treat the ores from this mine. This was the first silver mill be be built in Montana (Emmons and Calkins, 1913). In 1866, the Cable mine, one of the most famous lode gold mines in the Georgetown district, was discovered (Emmons and Calkins, 1913). The peak period of prosperity for mining in the region occurred during 1880-1900 when mines such as the Granite-Bimetallic, Hope, and Cable mines were most productive. Mining activity generally declined after 1900; however, the Philipsburg district became the country's leading producer of manganese during World War I and continued to be a principal producer until the 1960's. The Henderson Creek placer deposit was a notable producer of tungsten as well as gold during the 1940's and 1950's. During recent years, the Black Pine mine has been one of the most important underground mines in Montana. It has operated nearly continuously since 1974. The ore is valuable mainly for silver but copper, gold, lead, and zinc are also recovered. This mine, also known as the Combination mine, was a significant producer during the period of 1888-1964

Road log

0.0 **Enter** I-90 eastbound at Van Buren Exit/Entrance

[Notes on geology between Missoula and Drummond are adapted from Schmidt and others, 1983]

0.8

0.8 To the right, on the south side of the Clark Fork river, is an exposure of interbedded argillite and quartzite of the lower member of the Mount Shields Formation. On the Sapphire thrust plate, the Mount Shields Formation is composed of three informal members; a lower argillite-siltite-quartzite sequence, a middle quartzite sequence, and an upper argillite-quartzite sequence

12.0

12.8 To the left is a quarry in the Bonner Quartzite; this quartzite sequence overlies the Mount Shields Formation. The Bonner Quartzite is sheared and shattered due to proximity to the Ninemile Fault, one of the principal faults of the Lewis and Clark line.

3.0

15.8 To the east lies the Clinton district (Fig. 4-1). Mines in this district produced moderate quantities of ore containing copper, silver, lead, zinc, and gold. Ore was mined from veins that are associated with the Wallace Creek granodiorite stock (Cretaceous), and these veins are found both in the stock and in Cambrian and Middle Proterozoic sedimentary rocks surrounding the stock.

4.3

20.1 In the road cut on the left, some of the structural complexities of the Sapphire thrust plate are displayed. The Bonner Quartzite occurs at the west end of the exposure and vertical and overturned beds of the McNamara Formation are at the east end of the cut. These two units are separated by a near-bedding-plane fault that has cut out transitional beds normally present between the McNamara and Bonner. Numerous other faults also cut the Bonner.

1.4

21.5 McNamara Formation is exposed on the north side of the highway. Garnet Range Formation is exposed in the lower part of the hills to the south; the Helena Formation overlies the Garnet Range Formation above a thrust contact.

4.7

26.2 A hornblende-biotite granodiorite plug is exposed on the north side of the highway; this body may be part of the feeder system for hypabyssal volcanics exposed in the area.

5.4

31.6 Sheared Hasmark Formation (Cambrian) is exposed on the north side of the highway. At the base of the Hasmark cliff, recent hot spring activity has formed a tufa deposit.

0.6

32.2 Bonner Quartzite has been thrust over Hasmark Formation.

3.6

35.8 Kootenai Formation (Cretaceous) faulted over McNamara Formation. To the east, the Madison Group (Mississippian) is thrust over the Kootenai.

1.4

37.2 Volcanic rocks near the Bearmouth mining district overlie Bonner Quartzite. These volcanics are a bimodal eruptive sequence dated by the K-Ar method at about 44-48 m.y. (Williams and others, 1975).

1.7

38.8 Placer tailings on north side of highway are from dredging operations along Bear Creek. Bear Creek and its tributary Deep Creek form one of the most famous and productive placer districts in Montana. This area has produced an estimated 430,000 oz of gold (Elliott and others, 1986). Bear Creek and Deep Creek drain the Garnet and Top O'Deep districts. These and other districts including the Coloma and Elk Creek districts (Fig. 4-1) occur along the southwest and south margins of the Garnet granodiorite stock (Late Cretaceous). Vein, replacement, and skarn deposits, important mainly for gold, silver, and copper, occur in granodiorite and in Cambrian and Middle Proterozoic sedimentary rocks adjacent to the stock. The total estimated value of production from all lode and placer deposits in the Coloma, Elk Creek, Garnet, and Top O'Deep districts and the Bear Creek area is about $16.4 million (Elliott and others, 1986).

1.0

39.8 Lodgepole and Mission Canyon Limestones of the Madison Group on both sides of canyon are intricately folded. Red colors are from Snowcrest Range Group (Mississippian), which was deposited in caves in paleokarstic upper part of the Mission Canyon Limestone or is included as matrix in collapse breccias in the upper part of the Mission Canyon Limestone.

1.6

41.4 Folded and thrust-faulted Kootenai Formation exposed in roadcuts for some distance.

1.0

42.4 Lacustrine deposits from glacial Lake Missoula exposed along north side of river. These beds are the easternmost known deposits from this lake.

0.7

43.1 On the skyline at about 1 o'clock, the Madison Group in the cliff has been thrust over the Kootenai Formation, which is exposed in low hills at the base of the cliff.

1.8

44.9 On north side of highway is an apparently unfaulted section of Madison Group, Snowcrest Range Group (in swale), Quadrant Quartzite (Pennsylvanian), Ellis Group (Jurassic), and Kootenai Formation, all of which dip steeply south.

3.5

48.4 Continue east on I-90 past exit for Drummond. The major mountain range southeast of Drummond is the Flint Creek Range.

12.6

61.0 Take Goldcreek exit. **Turn right** at stop sign and continue south through Goldcreek and Wall City.

The gold placer mines of the Pioneer district are located throughout 30 sq mi of dissected benchlands underlain by Tertiary deposits that extend northeastward across an intermontane basin, which is separated by faults from the Flint Creek Range to the southwest and west (Fig. 4-2). Since mining commenced in 1862, the placers have yielded about 300,000 oz of gold and 30,000 oz of silver (Loen, 1986), worth more than $140 million at 1988 prices. Gold occurs in a variety of placer deposits in Tertiary fanglomerate and gravel, Pleistocene outwash and till, and Holocene alluvium and colluvium (Fig. 4-4).

News of the first mining of the placers along Gold Creek in 1862 spurred a gold rush to the area, however, water shortages hampered mining operations until 1869, when the completion of a 16-mi-long ditch made possible the large-scale mining of high-level placers on the sides and tops of interfluves as well as low-level placers along drainages. The early mining was conducted mainly on the Tertiary gravels of the interfluves however, by about 1875, the most easily accessible high-level placers had been mined, and most operations shifted to modern valleys to mine Quaternary outwash and alluvial deposits along the valley bottoms. Three dredges mined outwash in Pioneer and Reservoir Gulches at various times between 1905 and 1957.

Research by J.T. Pardee in 1916, on the origin of the placers (published in 1951), concluded that many of the high-level placers were derived from reconcentrating of gold from a layer of glacial drift that had been spread throughout the basin by early Pleistocene glaciers (Pardee, 1951). However, evidence for an early Pleistocene glaciation could not be confirmed during a detailed study of the Pioneer district by Loen (1986), who correlated the high-level placers with the Miocene and Pliocene Sixmile Creek Formation (the younger of two sedimentary basin-fill sequences in western Montana that comprise the Bozeman Group; Fields and others, 1985).

3.9

64.9 **Stop 1.** Near Wall City. The mountains of the Flint Creek Range on the horizon to the south are underlain by folded and thrust-faulted sedimentary rocks of mainly Paleozoic and Mesozoic age, and granodiorite of the Royal stock (Late Cretaceous), which has intruded and metamorphosed and was locally responsible for mineralization of these sedimentary rocks. Gold- and silver-bearing vein and replacement deposits in the northern part of the range presumably were the source for placer gold in the Pioneer district.

Dense forests in the distance to the southwest grow mainly on Pleistocene glacial till of as many as four ages (Loen, 1986). These till deposits generally mark the southern limit of the productive placer mines in the Pioneer district. Many of the tree-covered areas on the low hills to the south mark gold placer mines that were developed on thin (1-10 ft thick) layers of upper Tertiary gravel that overlie pediments, which cap many of the ridges. The white, tuffaceous sedimentary rock that underlies high-level gravel deposits on most hills are part of the Oligocene-early Miocene Cabbage Patch Beds (Gwinn, 1961;Rasmussen, 1977); this sequence contains no known gold placers.

Pioneer Gulch is the prominent central valley in which most of the dredging took place. The ghost town of Pioneer, once the hub of mining activities in the district, is located along the east side of the gulch near the upper limit of dredge tailings. The low, thickly wooded hill on the west side of Pioneer Gulch, which was extensively mined during the late 1800's, is Pioneer Bar. Ballard Hill is the high hill with the flat front on the west side of Pioneer Gulch. Ballard Hill is underlain by Tertiary alluvial fan gravels that are in fault contact with Paleozoic sedimentary rocks on Emery Ridge (alpine ridge on horizon). These Tertiary fanglomerates were locally mined using hydraulic methods.

0.6

65.5 Mines along the low hills to the left are in shallow surficial deposits that overlie the Cabbage Patch Beds. These placers were reworked from Tertiary gravel, which consists mainly of quartzitic rocks that were eroded from the contact zone overlying the Royal stock prior to unroofing of the pluton.

0.2

65.7 The pond on the left is the final resting place for the Mosier dredge, which produced most of the tailings in Pioneer Gulch, and was, in its day, the largest Yuba dredge in Montana. This dredge was equipped with 78 9-cu-ft buckets, and cut a strip approximately 65 yd wide and 4 to 15 yd deep (J.T. Pardee, field notes, 1930's). During 1933-1940, the Mosier produced 43,600 oz of gold and 4,780 oz of silver (U.S. Bureau of Mines, 1933-1940; Pardee, 1951). The overall grade of the material was about 0.005 oz/cu yd (Pardee, 1951).

The hills to the east are underlain mainly by buff siltstone beds that contain many discontinuous pebble gravel channels that were locally mined for gold. Tertiary gold-bearing gravel locally forms the crests of these hills. The siltstone beds are at least partly of Barstovian (middle Miocene) age, according to identification of fossil vertebrates by C.A. Repenning (U.S. Geological Survey; Loen, 1986).

1.4

67.1 This ridge, Pioneer Bar, was one of the most productive placer deposits in the district. The average grade of the deposit, as calculated from the estimated total material mined, and a total production of 50,000 oz gold (Pardee, 1951), was about 0.1 to 0.15 oz/cu yd (Loen, 1986). Pardee (1951) described Pioneer Bar as a series of alluvial terraces that were cut during interglacial intervals. Based on Pardee's description, Schumm (1977, p. 230) suggested that the terraces may represent a case of episodic erosion that resulted from the convergence of three high-gradient streams directly above the bar.

Indeed, Pioneer Bar is terraced, but there is little evidence that the terraces were formed by fluvial processes. An alternate possibility suggested by Loen (1986) is that the terracing was the product of the sluicing operations. Perhaps the miners had to terrace their workings in order to circulate water from ditches farther down this mile-long ridge.

0.3

67.4 **Stop 2.** The bottom of Reservoir Gulch contains Pleistocene outwash that was locally mined by sluicing and dredging. The dredge, used during 1955-57, remains in a dry pit at the end of a 0.6 mi-long line of tailings that began in Pioneer Gulch. The dredge was equipped with 75 3-cu-yd buckets. It produced about 2,600 oz of gold (then worth $91,000), from about 580,000 cu yd of gravel (ave. grade, 0.0045 oz/cu yd).

Drive back down Pioneer Gulch to stop 1; **turn right** and drive up Pikes Peak Creek.

2.2

69.6 Placers of many types and ages were mined along Pikes Peak Creek and on surrounding hills, and some placers were very productive. The largest volume of gravel mined was from the Tertiary sequence. Sparse deposits of outwash along Pikes Peak Creek were also mined. Mixed alluvial and colluvial deposits reworked from Tertiary gravel were locally mined, particularly on the slopes along the east side of the creek. The hills on both sides of the creek consist mainly of Tertiary sedimentary rocks that have been mildly deformed by folding, faulting, and landsliding.

3.9

73.5 **Stop 3.** Pilgrim Bar is one of the best examples of the high-level gold placers. The bar overlies a nearly planar pediment surface, having a gradient of about 340 ft/mi. Gold-bearing, clast-supported gravel on this surface overlies mudstone and siltstone of the Cabbage Patch Beds. Note the abundant percussion marks on clasts of Quadrant Quartzite in the gravel.

J.T. Pardee (field notes, 1916, 1923) reported that the total production from Pilgrim Bar was about 35,000 ounces (then worth $600,000). Two miners reportedly recovered about 4,000 oz each (then $70,000) from part of the deposit (Pardee, 1951). A calculated grade for the deposits, based on the estimated production of 35,000 oz and the volume of workings (about 1,638,000 cu yd, as measured from photographs), is 0.021 oz/cu yd. However, the actual grade of individual gravel beds may be greater because the beds contain interlayered silt units that contain little or no gold (Loen, 1986).

Return to Goldcreek exit/entrance to I-90.

7.6

81.1 Goldcreek exit/entrance to I-90. **Turn left** to enter westbound lanes of I-90. Drive west to Drummond.

11.5

92.6 Exit at Drummond (east side of town). Drive west through town to intersection with highway 10A.

1.2

93.8 Intersection with highway 10A. **Turn left** at stop sign toward Philipsburg.

0.9

94.7 To the southeast, pediments on the northwest flank of the Flint Creek Range have been cut on extensive gravel deposits of probable Pliocene age; these gravel deposits overlie a pediment cut on deformed Oligocene and Miocene lacustrine and fluvial deposits (Rasmussen, 1969). The Pliocene gravel deposits southeast of Drummond are similar to late Miocene or Pliocene gold-bearing gravels deposited on pediments in the Pioneer district (Loen,1986). Gold has been detected in panned concentrate samples collected from the gravel deposits southeast of Drummond (Campbell and others, 1982) indicating some undetermined potential for placer gold deposits in these gravel deposits. The remains of a hydraulic placer-mining operation can be seen on the east side of the Highway 10A about 7.5 mi south of Drummond.

11.4

106.1 **Turn right** at Stone. Follow gravel road to Henderson Creek.

1.6

107.7 Enter area of dredge tailings. Gold was discovered in placer deposits along Henderson Creek in 1866 and by 1913 the total prduction from placer mines was estimated at more than one million dollars (Emmons and Calkins, 1913). In 1933, scheelite was identified in black sand concentrated from the placer operations and later, during the period of 1942 to 1949, a dredge recovered both scheelite and gold from alluvium along Henderson Creek. A total of 142 tons scheelite concentrate containing 63 percent WO_3 (8,946 short ton units) and an estimated 20,800 oz of gold were recovered yielding about $940,000 (Walker, 1960). This operation was allowed to continue during World War II in spite of government restrictions on gold mining because the operators were recovering scheelite, an ore mineral of tungsten, which was of strategic importance during the war.

3.8

111.5 **Stop 4.** Granodiorite of Henderson Creek stock is exposed in bulldozer cuts. Here it is porphyritic, altered, and has stockwork quartz veining. Samples of the granodiorite are anomalous in molybdenum and tungsten. The stock has been explored for a possible porphyry molybdenum system by mining companies and has been investigated for tungsten resource potential by the U.S. Bureau of Mines (Hundhausen, 1949). The tungsten occurs as scheelite, which is sparsely distributed in quartz-scheelite veins that cut the granodiorite. The stock is probably the principal source of scheelite for the Henderson Creek gold-scheelite placer deposits.

0.5

112.0 **Stop 5.** View of Sunrise mine and mill. The Sunrise mine, also known as the Queen mine, was discovered in 1890 and is estimated to have produced $120,000 in gold (about 6,000 oz) from 40,000 tons of ore mined between 1892 and 1903. Intermittent operations after 1903 produced an additional 1,569 oz of gold plus significant quantities of silver and copper (Cole, 1950). All of the production has come from the Queen vein, a replacement quartz vein that is nearly conformable to bedding in the Helena Formation which hosts the deposit. The vein varies in thickness from 1 to 10 ft and averages 3 ft; it dips to the west with an average dip of 18^{o} (Emmons and Calkins, 1913).

4.3

116.3 **Stop 6.** Black Pine mine. The Black Pine mine, also called the Combination mine, was discovered in 1882 and between 1888 and 1964 produced over 2 million oz of silver plus large quantities of copper and lead and minor quantities of gold, zinc, and tungsten with a value of about $2.1 million (Elliott and others, 1986). The mine is owned and operated by Black Pine Mining Company, a wholly-owned subsidiary of Inspiration Consolidated Copper Company, and, since 1974, has produced approximately 1 million tons of ore. Current reserves are approximately 2 million tons. Mill-head grades average 5 oz silver per ton. Copper, lead, and zinc are also recovered during milling and smelting (Waisman, 1985). Nearly all of the ore is from the Combination vein, a gently-dipping quartz vein hosted by quartzite of the middle member of the Mount Shields Formation. This vein occupies a pre-mineralization thrust fault that dips 10^{o}-20^{o} southwest. The mineralization may be related to igneous activity in the area similar to the Henderson Creek stock and may be distal to a mineralized porphyry system (Waisman, 1985).

3.5

119.8 **Stop 7.** View of Philipsburg Valley. The valley is bordered on the west by the southern part of the John Long Mountains and on the east by the Flint Creek Range. The peaks in the distance to the south are part of the Anaconda Range whose crest is the Continental Divide. The town of Philipsburg and the Philipsburg mining district can be seen to the southeast along the west flank of the Flint Creek Range. Roadcuts at this stop expose beds of the upper member of the Mount Shields Formation, an interbedded sequence of red argillite and tan-weathering siltstone and sandstone.

4.8

124.6 Intersection with highway 10A. **Turn right** at stop sign and proceed south on highway 10A.

2.1

126.7 **Turn left** onto paved road leading into Philipsburg. Proceed through town. **Turn right** one block past stoplight.

The Philipsburg mining district has been a large producer of manganese, silver, zinc, lead, copper, and gold. The district is underlain by a folded and faulted sequence of sedimentary rocks (Proterozoic to Jurassic) which is in contact with granodiorite of the Philipsburg batholith (Late Cretaceous). Mineral deposits occur as: 1) steeply dipping quartz veins, 2) quartz veins along bedding, 3) manganese-rich replacement bodies, and 4) skarns. The most important deposits are west-trending veins in granodiorite and northwest- and west-trending veins and replacement bodies in Paleozoic carbonate rocks. Principal sedimentary host rocks are carbonate beds of Cambrian Silver Hill, Hasmark, and Red Lion Formations and Devonian Maywood and Jefferson Formations.

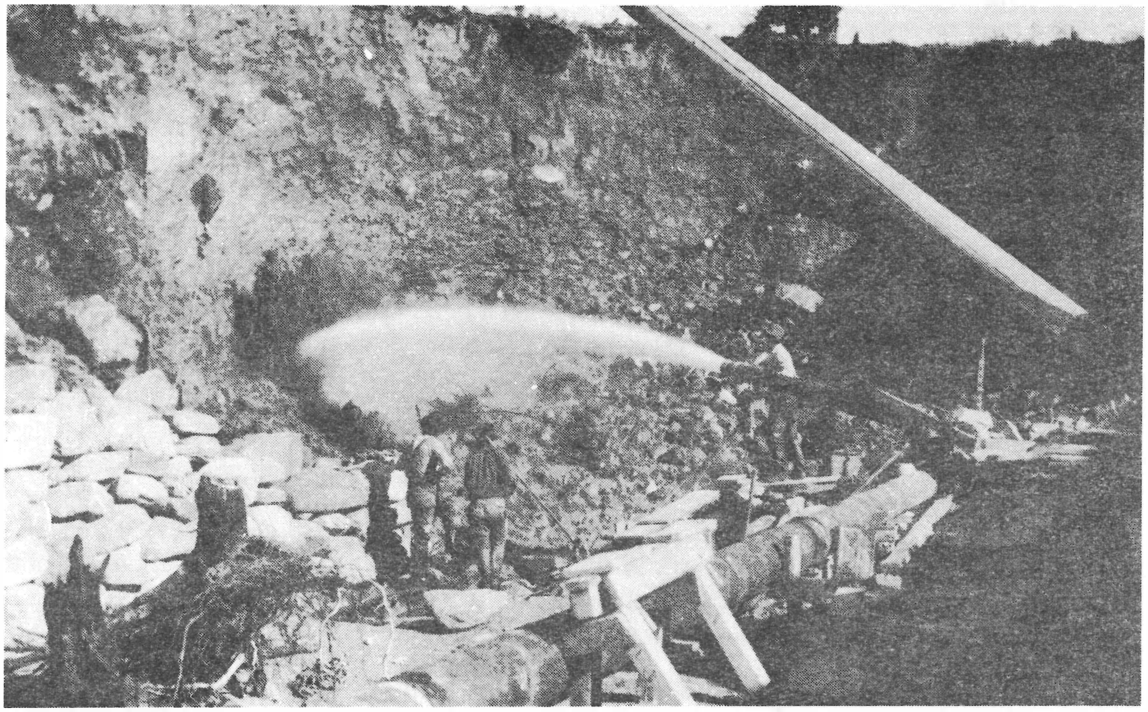


Figure 4-4. Hydraulic operation at Kohrs and Bielenberg mine. The water is being directed at a lower zone of gravel that contained the gold. Photo by J. T. Pardee, July 21, 1916 (from Pardee, 1951, p. 77).

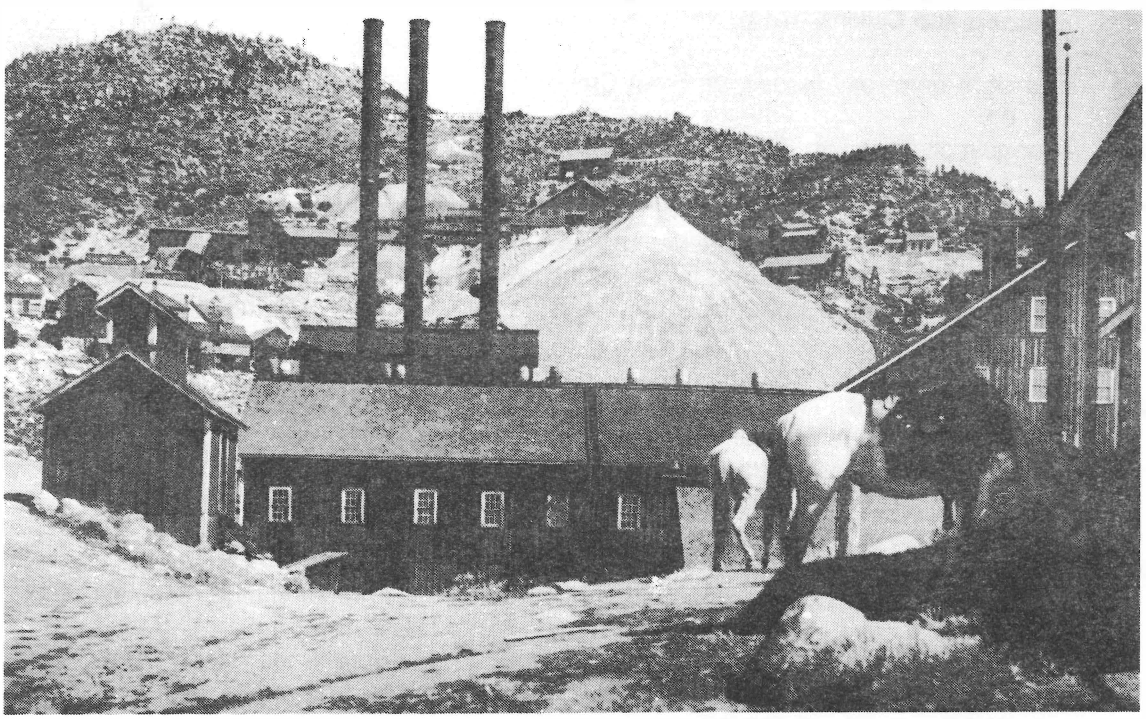


Figure 4-5. Granite-Bimetallic mine. Bimetallic mine in foreground and Granite Mountain mine in background. Photo by F. C. Calkins ca. 1907 (from Emmons and Calkins, 1913, pl. VII-B).

1.2

127.9 Take road on right at Y junction. After junction stay on road which angles uphill to left toward Frost Creek.

0.6

128.5 **Turn right** onto road to Granite.

3.1

131.6 **Stop 8.** Granite-Bimetallic mine. Originally worked as two separate mines (the Granite Mountain and Bimetallic mines), until their consolidation in 1898, the Granite-Bimetallic mine produced a total of more than $32 million in silver and gold prior to 1907 (Emmons and Calkins, 1913; Fig. 4-5). Most of this production occurred during the period of 1884-1893 with the Granite mine producing more than three-fourths of the total. The Granite mine was located in 1872 but the rich silver ore for which the mine became famous was not found until development and exploration reached a depth of about 200 ft below the surface (Emmons and Calkins, 1913). Most of the ore was mined from a zone of secondary enrichment where the primary sulfide ore is fractured and fractures are filled with pyrargyrite-proustite, argentite, and tetrahedrite. This zone, extending commonly from about 300 to 800 ft below the surface, contained ore which assayed from 50 to 1,000 oz silver and 0.2 to 0.4 oz gold per ton. Primary sulfide ore from deeper levels of the mine contains 20 to 30 oz silver and .075 to .15 oz gold per ton. The primary ore consists of the sulfide minerals pyrite, arsenopyrite, stibnite, tetrahedrite-tennantite, galena, and sphalerite in a gangue of quartz, rhodochrosite, and calcite (Emmons and Calkins, 1913).

Several intersecting veins, which traverse the granodiorite of the Philipsburg batholith and join at small angles, compose the Granite-Bimetallic lode deposits. The Granite vein is the largest and richest of these with an average width of about 6 ft and maximum width of 20 ft; its average strike is about N78°E and its dip is about 75°S. The Granite vein has been mined for approximately 4,500 ft along strike and as deep as 2,600 ft below the surface (Emmons and Calkins, 1913).

3.1

134.7 **Turn right** onto road leading up Frost Creek.

0.9

135.6 Algonquin shaft on left. This was one of the principal production shafts in this part of the district for manganese and silver-zinc ore from vein and replacement deposits in the Hasmark and Silver Hill Formations. From about 1929 to 1960 the Algonquin and adjacent Trout mines were operated together and production from the Algonquin vein was credited to the Trout mine. The Algonquin is one of the principal west-trending veins; manganese replacement bodies occur adjacent to the vein. Turn left onto road that circles uphill above the shaft.

0.6

136.2 Trout mine on right. This is one of the largest and most productive manganese mines in the district. Much of the manganese ore was mined from oxidized manganese replacement bodies in the Hasmark Formation. Silver-zinc ore was mined from the west-trending Pocahontas vein in the Hasmark and Silver Hill Formations.

0.5

136.7 **Stop 9.** True Fissure mine. This is one of the principal production shafts in this part of the district. Ore produced from this shaft came from the northwest-trending Mountain View and Headlight veins and from the west-trending True-Huffman, Horton, and Saunders veins. The deposits occur as veins and replacement deposits in the Hasmark, Red Lion, Maywood, and Jefferson Formations. Rocks in mine dump show minerals and textures typical of these mineral deposits.

Follow road along Camp Creek to Philipsburg. Proceed through town to junction with highway 10A.

2.8

139.5 **Turn right** at stop sign and proceed north on highway 10A.

30.6

170.1 Intersection of highway 10A with I-90. **Turn left** and enter westbound lanes of I-90.

49.9

220.0 Van Buren Exit to Missoula.

End of Road Log

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BELT ROCKS AND STRUCTURAL GEOLOGY OF THE TARKIO AREA, MONTANA

Don Winston[1] and Jeff Lonn[1]

Belt rocks of the Wallace Formation and Missoula Group in the Tarkio area display the following sediment types, representing a series of depositional environments: 1) crossbedded sand - braided streams, 2) flat-laminated sand-lower alluvial apron sheetflood surfaces, 3) even couple - alluvial sandflats, 4) even couplet - exposed and submerged mudflats, 5) lenticular couplet-exposed and submerged mudflats, 6) microlamina - perennial lake, 7) pinch-and-swell couple — perennial lake, 8) pinch-and-swell couplet - perennial lake.

In the Tarkio area the crossbedded sand and flat-laminated sand sediment types characterize Mount Shields member 2 and the Bonner Formation; even couple, even couplet and lenticular couplet types characterize the Snowslip, Mount Shields member 3, and the McNamara Formation; the microlamina type characterizes the Shepard Formation, and the microlamina, pinch-and-swell couple, and pinch-and-swell couplet types characterize the Wallace. The lacustrine interpretation of these Belt units is based chiefly on: 1) the sequential relationship of floods crossing dried flats followed by standing water on the expanded playa lake in an enclosed basin and, 2) the similarity of microlaminae to lacustrine varves and oil shale.

The Tarkio area is divided into the following plates separated by thrusts and extensional faults: 1) Stark Mountain plate, 2) Alberton plate, 3) Lime Ridge plate, 4) Tarkio plate, and 5) Nemote plate. Structural analysis indicates that all folding and thrusting can be attributed to Cretaceous to Paleocene compressional stress. Compression was followed by later Cenozoic extension, which reactivated some of the thrusts, producing local normal fault relations. There is no evidence in the Tarkio area suggesting a Proterozoic age for movements along the so-called "Lewis and Clark line", or for intense pre-Flathead folding.

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GEOLOGY OF THE HOG HEAVEN VOLCANIC FIELD, NORTHWESTERN MONTANA

Ian M. Lange[1] and Rick Zehner[2]

The 36–31 Ma Hog Heaven volcanic field is located 20 km west of Flathead Lake in northwestern Montana near the crest of the Purcell anticline. The Oligocene volcanic field is approximately 50 km^2 in size and rests unconformably on gently folded Ravalli Group arenites of the Late Proterozoic Belt Supergroup. The nearest Tertiary volcanic rocks with dates of 36 and 27 Ma occur 180 km to the southeast near Lincoln, Montana. This volcanic field is the setting of the historic Flathead Mine, which is currently under development by CoCa Mines as the Hog Heaven project.

The volcanic assemblage consists of poorly to moderately welded basal ashflow tuffs, an overlying sequence of bedded and nonbedded volcaniclastic rocks, and the source of the ashflows, flow-dome complexes. A few alkalic diabase dikes are present which cut the ashflow and volcaniclastic units. Eruptions apparently began after north-northwest-striking basin and range normal faults affected the region producing, for example, the Little Bitterroot Valley and creating relief and a paleotopography apparently similar to that presently found in the region. The small flow-dome complexes tend to be situated along the north-northwest-striking normal faults.

The three largest flow-dome complexes are each approximately 3 km in diameter. They are aligned along a northeast trend, which may represent a deep-seated basement structure, and occur where the trend intersects north-northwest basin and range faults. Prominent flow jointing is present in some of the domes and demonstrates their complexity and multiple stages of growth. The bulk of the tuff and volcaniclastic material erupted from these larger complexes and traveled south into lowland areas. The old Flathead Mine and several smaller mines and prospects are located in the easternmost dome complex.

The ashflow tuffs contain several types of clasts. Poorly vesiculated pumice, rhyolite flow rock, and Ravalli Group and Prichard Formation clasts, both of the Belt Supergroup, are very common. Rare quartz monzonite and very rare biotite schist clasts also occur. Because their sources do not outcrop in the area, they are interpreted as samples taken from rocks at depth.

The volcanic rocks are very homogeneous geochemically and plot as high-K dacites or rhyolites with silica compositions ranging from 63%-69%. Sanidine and biotite phenocrysts are ubiquitous. No obvious differentiation trends are present. REE patterns show LREE enrichment and HREE depletion relative to MORB. No Eu anomaly is present. Ba and Sr values are high,

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averaging 1980 and 1280 ppm, respectively, and Ni averages 7 ppm. Normative quartz-albite-orthoclase plots indicate that Hog Heaven rocks originated as a partial melt of an intermediate to felsic host. Galena lead from the Hog Heaven Mine is unradiogenic and distinct from all other Belt Supergroup-hosted deposits. Surprisingly, inital Sr values are low (0.7039 and 0.7046).

The general paucity of outcrops and chemical homogeneity of the volcanic materials have made correlations between ashflow units and vents difficult. Furthermore, neither the process of magma generation or magma source is known and any model of magma genesis at Hog Heaven must take into account the somewhat disparate geochemistry. Two models which attempt to reconcile the data are partial melting of non-sialic Archean basement rocks or younger andean arc intermediate intrusive rocks. Support for both models includes the low initial Sr values and chemistry of the rocks. Additional support for the first model includes the fact that the ore lead 207/204 versus 206/204 values lie on the 2.5 Ga secondary isochron of Doe and others (1982) derived from the Yellowstone region basalts to the southeast.

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INFLUENCE OF MAGMATIC HEAT ON LATE CRETACEOUS STRUCTURE OF WEST-CENTRAL MONTANA

James W. Sears[1]

Changing geothermal conditions associated with widespread igneous activity strongly influenced the Late Cretaceous structural evolution of west-central Montana. Before about 82 Ma cool, brittle rocks formed a typical fold and thrust system, as the rigid Belt Supergroup overrode Paleozoic and Mesozoic rocks along an imbricate thrust fan on the north and east sides of the Sapphire and Pioneer Mountains.

Between 82 and 76 Ma, heat associated with rising magma elevated the brittle/ductile transition zone into the evolving thrust system. Temperatures at depths of less than 6 km were locally as great as 250 to 350 C, near Missoula, Philipsburg and Melrose, corresponding to conditions of high temperature/low pressure (Abukuma facies series) metamorphism.

When the temperatures exceeded critical values, pelitic and calcareous rocks lost their plastic strength, and were unable to sustain any stress differential. The thrust system then apparently failed under its own weight in a short period of ductile flow beginning about 82 Ma, producing a regional cleavage system. This cleavage system affected high level sills and 82 Ma volcanic flows, but predated larger 78 Ma plutonic bodies in the region between Missoula and Helena. Near the Pioneer Mountains, deformation began after 80 Ma, but ended before 76 Ma. Deformation may have been in a diachronous pulse which swept across the region from northwest to southeast. Late Paleocene thrusting transported and rotated the Late Cretaceous structures, and Tertiary block faulting further disrupted the thrust system.

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POLYPHASE DEFORMATION AND A REGIONAL PERSPECTIVE ON THE SAPPHIRE THRUST PLATE, MONTANA

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The Sapphire thrust plate is a major component of the fold and thrust belt in southwest and south-central Montana, and the plate includes most of the area between the Idaho and Boulder batholiths (fig. 1). Middle Proterozoic, Paleozoic, and Mesozic sedimentary rocks of the plate were thrust eastward during Late Cretaceous time. The thrust system is preserved principally as (1) stacked thrust sheets in the interior of the plate (thrust-sheet terrane) and (2) tight folds within a zone of anastomosing imbricate thrust faults along the leading edge of the plate (frontal imbricate terrane). Isotopic ages of plutons that cut thrust faults and folds indicate that thrust sheets and at least some thrust faults and folds of the frontal imbricate terrane are older than about 81-82 Ma, although late-phase thrust faults may be as young as about 78 Ma (Wallace and others, in press).

The thrust-sheet terrane preserves the best evidence of polyphase compressional deformation; the frontal imbricate terrane of the Sapphire thrust plate does not preserve as clear a record of polyphase deformation because the different phases of deformation may have formed faults and folds that appear similar but are of differing relative age. In the thrust-sheet terrane, the characteristic sequence of polyphase deformation consists of three main phases: (1) overthrusting, (2) regional folding, and (3) late-phase thrust faulting. Individual thrust sheets are separated by decollements that generally parallel bedding and separate differing stratigraphic sequences that range in thickness from about 1500 m to 4500 m. The thrust sheets form stacks, in which thrust sheets and decollements separating them are folded harmonically into the regional fold system; and these folds and folded decollements are broken and offset by late-phase thrust faults that are cut by plutons as old as 78 Ma. We interpret the decollements to represent the flat segments of overthrust faults that formed as flat and ramp structures. The folded overthrusts are cut and offset by late-phase thrust faults, which consist of (1) moderately to steeply dipping faults that cut forelimb, backlimb, and axial plane regions in tightly folded overthrust sequences of rock, (2) moderately to steeply dipping faults that coalesce to form anastomosing zones, and (3) moderately to steeply dipping single faults.

During the early phase of deformation when overthrusts formed, supracrustal rocks were thickened by the stacking of thrust sheets along an evolving network of decollements connected by widely spaced ramps. Episodic movement along different pieces of the fault network stacked thrust sheets by undercutting and piggybacking ramps of overlying decollements and by locally ramping through flats of overlying decollements to produce some thrust sheets that put younger rocks on older rocks and omit stratigraphic section (Lidke

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other geologists who have studied small areas of the thrust-sheet terrane reflect principally local complexities that are predictable consequences of polyphase compressional deformation characteristic of the thrust-sheet terrane. Small areas of study in the thrust-sheet terrane limit the resolution of relations among regional structures of differing relative age, and the prevasiveness of polyphase deformation in this region limits the usefulness of balancing cross sections in a single-state. Methods of the multi-staged, sequential balancing technique (Ford, 1987) can be appalied to regional cross sections in the thrust-sheet terrane, and these methods can be modified to incorporate an evolving system of overthrusts balanced at each stage of deformation: the later phases of deformation can also be balanced sequentially to produce balanced structure sections in a manner similar to the generalized restoration shown by Wallace and others (in press).

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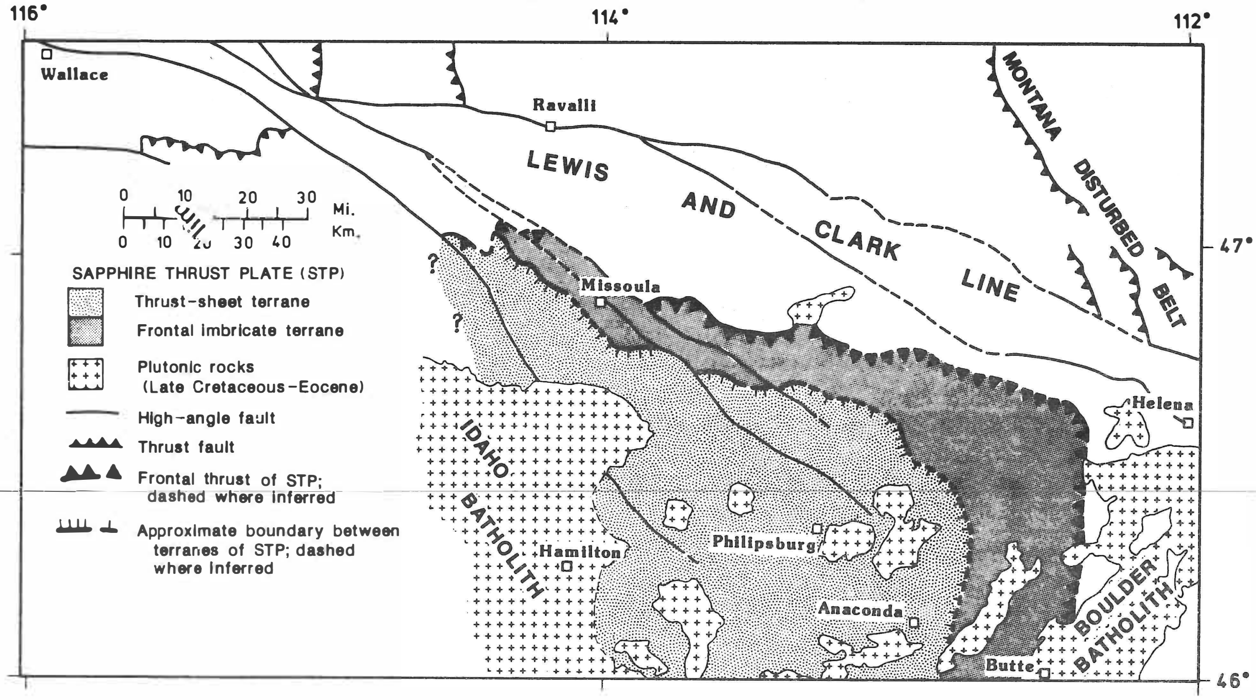

Figure 1. Tectonic sketch map of the Sapphire thrust plate.

and others, 1987: Wallace and others, in press). The decollements of the overthrusts that omit stratigraphic section could be considered second-generation overthrusts or out-of-sequence overthrusts, which overstep an older overthrust that has classic older-on-younger stratigraphic relations. The later phases of compressional deformation, which consisted of regional folding and late-phase thrust faulting, probably record the migration of movement to decollements at deeper levels. Therefore, retional folding and late-phase thrust faulting may record deformation from movement on a deeper "blind" decollement, above which the overlying thrust sheets were folded harmonically and then cut by the late-phase thrust faults that probably join the "blind" cecollement at depth.

Polyphase deformation as a regional concept in the thrust-sheet terrane affects structural interpretations from small map areas, and affects the methods used to analyze and restore structural elements. The regional fold pattern has more continuity than it would appear to have (Emmons and Calkins, 1913, p. 142), because the folds are cut into segments and displaced by the late-phase thrust faults. But in small areas, the continuity of the fold system may be obscure, especially in areas where segments of folds have been greatly displaced. Furthermore, some of the late-phase thrust faults show younger-on-older stratigraphic relations because they cut and displace folded stratigraphic sequences and folded overthrusts, and these relations commonly divert attention from structural and plutonic relations, which establish that the regional folds were segmented principally by late-phase compressional faults prior to about 78 Ma. Based on regional geologic mapping of the Sapphire thrust plate (Wallace and others, 1986), we conclude that structural and stratigraphic uncertainties that frustrated McGill (1965, p. 132) and

MULTIPLE DUPLEX STRUCTURE AT SANDY HOLLOW, MADISON COUNTY, MONTANA

Thomas E. Hendrix[1]

A spectacular, three-tiered duplex structure is completely exposed in the 27-meter-thick gastropod member of the Kootenai Formation (Cretaceous) on the steep, eastern limb of an asymmetrical anticline at Sandy Hollow in the southwestern corner of Madison County, Montana.

The structure consists of three packages of tight-to-open, concentric ramp anticlines and synclines bounded internally by sigmoidal-shaped thrust faults. Disjunctive spaced cleavage occurs sporatically in 15-30 centimeter-thick micrites at the base of competent packstone-wackestone units which themselves contain Stearns-type conjugate shear joints and tensional ac and bc joints as well.

Each duplex package consists of one competent packstone/wackstone unit 5-8 meters thick and one incompetent black shale unit of approximately equal thickness. Three major decollements - one exposed and two inferred- separate the duplexes from each other and from a thick basal unit which is undeformed. Shortening by folding, thrusting and cleavage formation in the lowest duplex is 58 percent. The middle duplex has been shortened 32 percent by similar processes; the upper duplex has experienced 14 percent shortening.

The duplex structure is approximately 800 meters long from the point of impingement of the causitive Sandy Hollow allochthon at the northwestern (hinterland) end to the tip line at the southeastern (foreland) end. The intensity of deformation decreases steadily southeastward from the hinterland for the first 400 meters. There is a 350 meter-long middle segment where folding and thrust faulting die out in the middle and upper duplex and are replaced by small reverse thrusts in the competent units. In this segment the lower duplex has regularly-spaced (24-50 meters) shingle or ramp faults of small displacement (6-20 meters of right-normal slip). The last 50 meters of the structure are marked by two major duplex packages that appear to have developed upward from the basal decollement along a pair of complex thrust faults.

Preliminary work on calcite twinning cleavage, ooids, and gastropods in the competent limestones, as well as analysis of the many folds and faults and joints in the structure indicates the following sequence of deformation:

i. Pre-fold/fault stage (layer parallel shortening)
   1. Pressure-solution disjunctive spaced cleavage formed in competent limestone units

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2. Minor calcite twinning in the packstones
3. Very local, minor flattening of ooids and gastropods

ii. Fold—fault stage

1. Formation of the duplex structure (folds, faults) in each duplex package with deformation moving from hinterland to foreland in each duplex and upward from the lowest to the highest duplex
2. Formation of the Stearns type I, II, and III shear joints and the ac and bc extension joints in the competent units
3. Formation of disharmonic folds in the incompetent units
4. Rotation of disjunctive spaced cleavage in lift-off anticlines and ramp synclines

iii. Late (flattening) stage

1. Axial plane cleavage locally in shales and micrites in the cores of tight lift-off anticlines
2. En echelon tension gashes perpendicular to ac in packstones in the lowest duplex
3. Several widely-spaced, out-of-sequence thrusts that cut the whole structure

In each of the duplex packages the shape and orientation of folds, and the attitude and slip direction of the thrusts are impressively uniform and consistent with the measured attitude and slip direction of the Sandy Hollow allochchon, suggesting that the multiple duplex structure was formed by impingement of the allochthon on the nose and eastern limb of the Sandy Hollow anticline. The allochthon, moving upward and eastward across a flat in the Sandy Hollow thrust, collided with the gastropod member of the Kootenai formation, peeled the upper 27 meters of this member loose from its competene base and pushed it southeastward as three more or less independent duplexes separated by incompetent shales.

CRUSTAL THICKNESS AND STRUCTURE IN SOUTHWESTERN MONTANA

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Regional crustal thickness and structure provides a framework for more detailed structural and economic geologic studies. Seismic refraction analyses have been the most widely used method in Montana for determining deep crustal structure and crustal thickness as defined by the Moho, but these tend to average inhomegenities within the survey. Recent studies using deep crustal reflection suggest the Moho boundary is a more complex, transitional package of alternating layers. Previous estimates of crustal thickness in western Montana were based on relatively sparse data from a few refraction profiles. Until the investigation by Sheriff and Stickney (1984), which indicates a 30 km thick crust and an 8.0 km/sec Pn (refracted mantle wave) velocity near Butte, previous estimates suggested the crustal thickness to be 40 to 50 km, with a relatively high Pn wave velocity from 8.1 to 8.3 km/sec (Allenby and Schnetzler, 1983).

Recent calculations show the Moho dipping to the west with an approximate crustal thickness of 30 km near Butte, thickening to approximately 50 km near Wallace, Idaho. This conclusion is based on three refraction profiles with considerable shot point data. The crust near Butte is much thinner than previous estimates but typifies a Basin and Range Province which has undergone crustal thinning due to extension (Sheriff and Stickney, 1984).

The initial investigation obtained 22 good seismograph recordings using Butte mine blasts. This forward profile extended northwest from Butte to Wallace. The mantle velocity obtained here was 7.6 km\sec, unexpectedly low for a mantle (Pn) wave. Based on results by Sheriff and Stickney (1984), it was initially assumed that this low velocity represented an apparent velocity of a west-dipping Moho with a true mantle velocity of 8.0 km/sec.

Subsequent refraction investigations proved the above assumption and estimate to be correct. Refraction data were obtained using blasts and earthquake aftershock data from the Challis, Idaho area along a profile extending north to Missoula. These data indicate an apparent mantle wave velocity of 7.75 km\sec, almost an exact fit for the apparent velocity in this direction for the northwest-dipping Moho model. Blast recordings extending south from Clinton, Montana were used to obtain data in reverse direction. Extensive modeling using a synthetic seismogram program showed an excellent fit betweem real data and expected arrivals from wide angle reflections. Excellent correlation was also obtained using additional computer modeling based on the Asymptotic Ray Theory (ART). This program takes into account velocity gradients within the crust and mantle.

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Other refraction data obtained from studies by Ballard (1980), DeBeor (1985) and Stickney (1985) also support this crustal model. Although some workers (Stickney, 1985, Ballard 1980) seem to discount these analyses for a variety of reasons, the prominent wide angle reflections from the Clinton line further verify the results and discount a significant thickness of any "hidden layer" not picked up by our surveys.

The Clinton line crosses the Sapphire tectonic block (Hyndman, 1983). Other, large amplitude phases are evident from the Clinton data but are difficult to correlate across all the traces for this profile. This is probably because of the large average station spacing of 10 km along this line. More stations may provide the resolution needed to determine if these phases are a response from intermediate crustal layers.

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GEOLOGY AND MINERALIZATION OF THE BLACK PINE MINE, GRANITE COUNTY, MONTANA

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The Black Pine Mine is located 15 kilometers northwest of Philipsburg, Montana, in the John Long Mountains. The mine produces Ag-Cu-Pb-Zn ores from the Combination Vein, a gently west-dipping quartz-sulfide vein in the Precambrian Mount Shields Formation of the Missoula Group. The vein occupies one thrust fault in a subparallel group of four mineralized thrust faults that cut bedding by 10 to 15 degrees. This structural setting occurs at four mines within the Sapphire allochthon: the Black Pine, Blue Jay, Sunrise, and Mountain Ram mines, a group of deposits that define a region-wide thrust structure.

K-Ar age dates from the nearby Henderson-Willow Creek intrusive trend overlap a K-Ar sericite age date for mineralization in the Combination Vein of 63.9 +/- 3.2 Ma. These data indicate that thrusting in the area ended prior to mineralization and support the hypothesis that thrusting ceased 73 Ma in the Philipsburg region. A sequence of thrusting, intrusive activity and mineralization occurred in the Sapphire allochthon within a short time interval. This sequence occurred at various places in the allochthon but possibly at slightly different times.

Data indicating that the Black Pine mineralization is related to igneous activity include the occurrence of tungsten in both the Henderson stock and local vein systems, the chemistry of the Combination Vein, which is compatible with an hypothesized mineralized porphyry intrusive system at depth, and the spatial and temporal relationships between the intrusive trend and mineralization.

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GEOLOGY, GEOPHYSICS AND VERMICULITE DEPOSITS OF THE SKALKAHO AND RAINY CREEK MAFIC-ALKALINE COMPLEXES, WESTERN MONTANA

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The mid-Cretaceous Skalkaho pyroxenite-syenite complex near Hamilton, Montana, intruded the calc-silicate/quartzose, mid-Proterozoic Wallace Formation of the Belt Supergroup. The metasedimentary host rocks are situated within the western or trailing edge of the allochthonous Sapphire Tectonic Block, which post-dates the complex. Hyndman (1980) suggested that the block was transported on an infrastructure of Belt units along a mylonite detachment zone and off-loaded from west to east during intrusion of the Idaho Batholith, some 75-80 million years ago during the late Cretaceous. But, Garmezy and Sutter (1983) proposed instead that movement occurred along a reactivated detachment zone in an extensional environment during Eocene time, some 45 million years ago.

The Skalkaho Complex covers about nine sq. km, with an oblong, east-west trending core of pyroxenites surrounded by two alkali syenite-syenite bodies that lack nepheline. The pyroxenites consist of irregularly distributed mica (mostly biotite), amphibole and anhydrous (almost entirely salite) varieties. The coarse mica pyroxenite is the most abundant kind, whereas the fine-grained anhydrous one is the least. The intrusion was emplaced in the upper few kilometers of the crust, probably as a co-magmatic, immiscible system (Lelek, 1979).

An impression of the subsurface configuration of the Skalkaho Complex was gained through forward modeling of gravity data. In the modeling process, the pyroxenite core was delineated with respect to the outlying syenites and host rocks. Bouguer anomaly values ranged from -169 to -185 milligals over the area, with the highest anomalies centered over the pyroxenites. Modeling profiles perpendicular to the longitudinal trend of the complex show that the pyroxenite body is shaped like a narrow, inward-dipping cone which thins from east to west, and not a sill or outward-dipping cone. Approximate depths for the pyroxenite range from 1000 to 200 meters east to west. Magnetite is irregularly distributed within the Skalkaho rock units. Magnetic susceptibilities vary from 0.000023 to 0.0051 cgs units, which correspond to volume percents of magnetite from 0.01 to 3.0 (Snyder, 1985).

The remarkably similar, contemporaneous Rainy Creek Complex is 275 km to the north of Skalkaho near Libby, Montana. It covers some 17 sq. km and was also intruded into Wallace Formation metasediments that are allochthonous (Harrison et al., 1980). The Rainy Creek complex consists of a concentrically-zoned, composite pluton, roughly circular in plan, composed of zones

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of magnetite pyroxenite, biotite pyroxenite and biotitite, arranged in an inward succession. It also contains an irregularly-shaped syenite body, which lies along the southwest side of the ultramafics and extends into the magnetite and biotite pyroxenite zones. A small outlying body of nepheline syenite is exposed about 150 meters southwest of the syenite (Boettcher, 1967). Like the Skalkaho, the Rainy Creek was also shallowly emplaced.

A rubidium/strontium date by Boettcher (1967) on fresh biotite from the biotitite zone put the Rainy Creek age at 94 million years. 87 strontium/86 strontium isotopic compositions of whole rock syenite and pyroxenite samples at Skalkaho and Rainy Creek define a age of 106.7$\pm$ 16 m.y. or mid-Cretaceous for both complexes along a combined isochron (Futa and Armbrustmacher, 1983). Interestingly, K-Ar dates on muscovite and biotite samples from the Haines Point syenites (90 km south of Rainy Creek) are put at 106$\pm$ 3 and 107$\pm$ 4 m.y., respectively (Marvin et al., 1984). 87 strontium/86 strontium isotopic ratios at Skalkaho and Rainy Creek range from 0.7035 to 0.7082. Large variations in rubidium and strontium concentrations for each complex, strontium and neodymium isotopic ratios, and trace element concentrations suggest independent sources for co-magmatic pyroxenite-syenite intrusions at Skalkaho and Rainy Creek (Futa and Armbrustmacher, 1983; Futa and Armbrustmacher, 1985). In any case, the dating shows that intrusion of both complexes occurred before they were disturbed (for the most part by accretionary tectonism) during the late Cretaceous (Mudge, 1982). Carbonate rocks from Rainy Creek considered by some to be carbonatites have significantly higher 87 strontium/86 strontium ratios, generally higher strontium content, but about the same rubidium content as the syenites and pyroxenites. This suggests a source for the carbonates different from that of the intrusive (Futa and Armbrustmacher, 1983).

Vermiculite is mined at Rainy Creek by W. R. Grace and Co. over a 3.2 sq. km area centered around the biotitite core. The vermiculite is more or less vertically, but not horizontally continuous and is strip-mined from 200 foot thick "shells." Vermiculite and biotite are closely related, the essential difference being that the vermiculite unit cell contains a layer of water, while biotite contains a layer of potassium. Hydrobiotite is a layered mixture of the two minerals. According to Boettcher (1967), most of the biotite in the inner body of pyroxenite has been altered to hydrobiotite and vermiculite. He suggests the vermiculite is a product of leaching of the biotite by ground waters, whereas the hydrobiotite may represent a higher temperature alteration product. Of course, hydrothermal activity could be responsible for alteration of pyroxene (to amphibole and then) to high grade biotite deposits, which were later altered to vermiculite by meteoric waters (Lefond, 1983).

Presently at Rainy Creek, the stripping ratio is about 1:1. Grade is 24% at a +65 mesh cutoff with a 55% recovery. Six percent is ultimately marketed from all mined material and two million tons/year of ore is produced. Tremolite and carbonates comprise about one percent of the ore, occurring mostly as stringers, though some is interstitial.

Stansbury Mining is developing the vermiculite deposits at Skalkaho, which occur along two more or less northeast-trending finger ridges. The two deposit exposures cover a total of some 0.2 sq. km. The vermiculite is centered in the pyroxenite core among biotite-rich zones, where replacement of pyroxene by amphibole is evident. As with Rainy Creek, asbestos-form mineralization and carbonates are manifested in stringers, but seemingly to a lesser extent. No interstitial material is reported. The vermiculite appears to occur in inward-dipping conic features with some vertical, but no horizontal continuity. Overall grade is 11% and the stripping ratio would be less than 1:1.

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ASBESTOS ANALYSIS AND SAMPLING STRATEGY FOR STANSBURY MINING CO. WESTERN VERMICULITE PROJECT, RAVALLI COUNTY, MONTANA

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In 1977 Western Vermiculite obtained an operating permit to produce vermiculite from a deposit east of Hamilton, Montana. Mining and milling ceased in 1979. Subsequently, Stansbury Mining Company acquired the property and on June 18, 1987 submitted an amended plan of operation to the Department of State Lands and the US Forest Service. During the life of the project, 84 rock samples from both core and surface material have been analyzed for asbestos. In addition, air samples were collected during operations in 1979 and subsequently during the fall of 1987.

These samples were analyzed using polarized light or scanning electron microscopy. Fifteen of the samples contained asbestos, ranging in value from a single fiber to trace amounts. Due to the apparent low concentrations in the deposit, it was not felt that a more rigorous analysis was necessary for permitting the operation. However, in response to public concern and in light of new asbestos standards adopted by the EPA and currently under review, a decision was made to quantify the amount of asbestos within the ore body.

A new sampling project conducted during the spring of 1988 was undertaken jointly by the US Forest Service and the Department of State Lands. It was designed to 1) quantify the amount of asbestos within the volume of material to be mined, 2) determine if a vertical structural system exists with elevated asbestos content, and 3) determine the asbestos content in a calcite-actinolite dike believed to cut the deposit. Thirty samples from 15 vertical drill holes and two angle holes were analyzed using a combination of polarized light microscopy, scanning electron microscopy and transmission electron microscopy. Data from these analyses are currently being evaluated.

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