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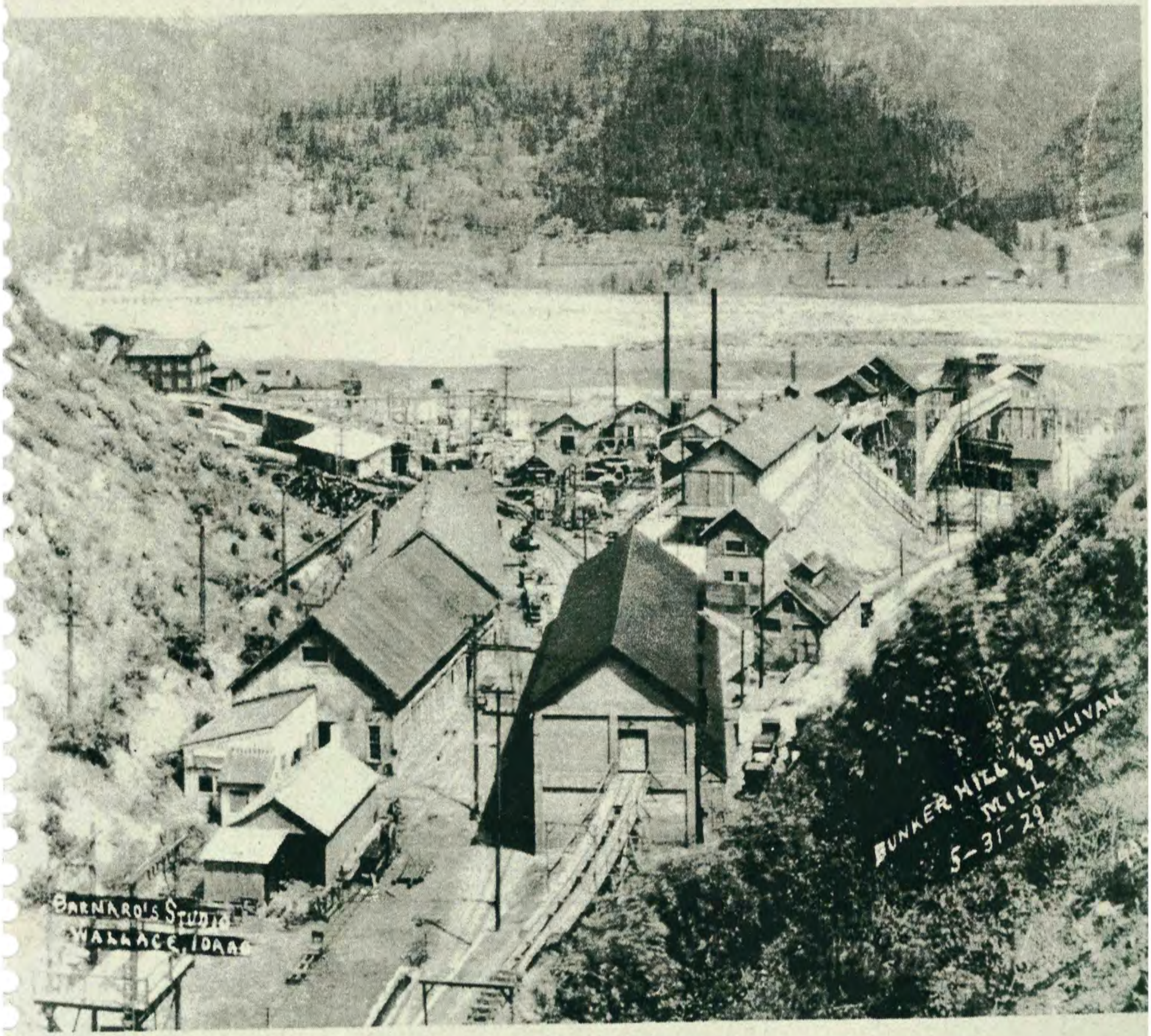

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The Tobacco Root Geological Society, Inc.

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Conference Organizers

Reed Lewis
Larry Johnson
Ann Marie Gooden

Cover: Looking north at the Bunker Hill and Sullivan mill, Kellogg, Idaho, 1929. Photo is from the Barnard-Stockbridge collection, University of Idaho (photo no. BSC8-X940B).

Northwest Geology
Volume 30

Tobacco Root Geological Society

26th Annual Field Conference

August 2-5, 2001
Elks Club, Downtown
419 Cedar Street
Wallace, Idaho

Out of the Flood and into the Panhandle: Northern Idaho Geology

Conference Schedule

THURSDAY, AUGUST 2
Elks Club Meeting Room

BOARD MEETING

REGISTRATION
4:00-6:00 PM

ICEBREAKER
6:00-9:00 PM
Cocktails and hors d'oeuvres will be served

FRIDAY MORNING, AUGUST 3
TECHNICAL SESSION PRESENTATIONS

8:00	Introduction and Announcements- Larry Johnson, TRGS President
8:15	Overview of the geology of the Coeur d'Alene area (Reed Lewis, Idaho Geological Survey)
8:35	History of the Coeur d' Alene Mining District (Earl Bennett, University of Idaho)
9:00	Analysis of digital geologic and mineral resource data of the Revett Formation in the western Montana copper belt, Idaho and Montana (David Boleneus, USGS Spokane and Larry M. Applegate, Spokane consultant)
9:25	Seismotectonics and active displacements across the northern Rocky Mountains (David Lageson, MSU-Bozeman; Mike Stickney, Montana Bureau of Mines and Geology)
9:45	New applications of geologic maps of northern Idaho (Mike Zientek, USGS)
10:05	BREAK
10:20	Metals in the surficial environment in and downstream of the Coeur d'Alene Mining District (Steve Box and Art Bookstrom, USGS Spokane)
10:45	Overview of cleanup and the Superfund process in the Coeur d'Alene basin (Doug Parker, ASARCO)
11:05	Water quality and remediation effectiveness in the S. Fork Coeur d'Alene River (Geoff Harvey, Idaho DEQ)
11:30	Emplacement chronology of the Paradise Pluton, implications for the development of the Bitterroot mylonite (Sam Coyner, University of Florida)
11:55	Petrography and mineralogy of the Pickett Pin PGE deposit, Stillwater Complex, Montana: Preliminary results (John Corkery, University of Montana)

FIELD TRIP – Friday Afternoon

#1	**1:30 PM**	Metals in the surficial environment in and downstream of the Coeur d' Alene Mining District (Art Bookstrom and Steve Box, USGS Spokane)

BARBEQUE - 6:30 PM (Gene Day Park , aka Shoshone Park)

Directions: Take the Osburn Exit (Exit 49) and turn South. At the stop sign (next to the Texaco Station) take a right. Heading west there will be an S curve left then a long straight stretch. The road will form a Y with the right leg curving to the right. Continue on the straight (left) leg of the Y. The park is almost at the end of this road on the left hand side. Our gazebo is on the east end of the park but the park road goes one way to the right so you will need to go all the way around the park to get to it.

SATURDAY, AUGUST 4
FIELD TRIPS

(Lunch is provided, transportation is your responsibility, so think **car pool**!)

#2	**8:15 AM**	Overview of cleanup and the Superfund process in the Coeur d'Alene basin (Doug Parker, ASARCO; Geoff Harvey, Idaho DEQ)
#3	**6:30 AM**	Underground tour of the Lucky Friday (Gold Hunter) mine. (Jon Carlson, Hecla Mining Co.) Limit 12 - sign up early!! Be prepared to take another trip if this one is full.
#4	**7:00 AM**	Belt structure and stratigraphy in Alberton Gorge, west-central Montana (Jeff Lonn, Montana Bureau of Mines and Geology) (RIVER RAFT TRIP) Details will be included in pre-registration packet. Limit 30. Height and weight required on registration form. Cost is $75.

SUNDAY, AUGUST 5
FIELD TRIPS

(Lunch is provided, transportation is your responsibility, so think **car pool**!)

#5	**8:15 AM**	Glacial Lake Missoula flood deposits and related geomorphic features of the Rathdrum Prarie (Roy Breckenridge, Idaho Geological Survey)
#6	**8:15 AM**	Belt Supergroup exposures along the North Fork of the Coeur d'Alene River (Mark McFaddan, University of Idaho; Reed Lewis, Idaho Geological Survey; Russel Burmester, Western Washington University)

Earn Professional Credits for Attending!!

REGISTERED ENGINEERS CAN ATTEND PRESENTATIONS AND FIELD TRIPS AND EARN CREDIT HOURS! VISIT THE REGISTRATION TABLE AT THE CONFERENCE FOR MORE INFORMATION.

Technical Session
- Papers -

OVERVIEW OF THE GEOLOGY OF THE COEUR D'ALENE AREA, NORTHERN IDAHO

Reed S. Lewis – Idaho Grographical Survey, University of Idaho, Moscow, Idaho 83844-3014

The oldest and most abundant rocks in the Coeur d'Alene area are Precambrian in age (Figure 1). These include low-grade metasedimentary rocks of the Belt Supergroup and high-grade (amphibolite facies) metamorphic rocks whose protolith is either the Belt Supergroup or basement rocks that predate the Belt metasedimentary rocks. The high-grade rocks are predominantly schist and gneiss exposed in a metamorphic core complex west of Coeur d'Alene (Priest River complex). An excellent section of the Belt Supergroup is exposed in the eastern half of the Coeur d'Alene quadrangle. The lowermost Belt unit is the Prichard Formation, which is overlain by the Ravalli Group (Burke, Revett, and St. Regis Formations). These are in turn overlain by the Wallace, Striped Peak, and Libby Formations.

The Striped Peak and Libby Formations are preserved in a broad syncline east of the Magee fault zone (Figure 1). Prevously unmapped, deformed granitic rocks (orthogneiss) of probable Cretaceous age are present in the Priest River complex. Plutonic rocks of Cretaceous age are also present as intrusions to the east within the low-grade Belt Supergroup. Relatively undeformed Eocene igneous rocks are exposed as plutons in the northwestern part of the map area and as a few rhyolite and dacite dikes in the central part. Flows of Miocene Columbia River basalt cover parts of the western part of the quadrangle, and in places these flows are covered with Miocene sediments. Abundant Quaternary gravels in and near the Rathdrum Prairie are the result of catastrophic floods derived from glacial Lake Missoula.

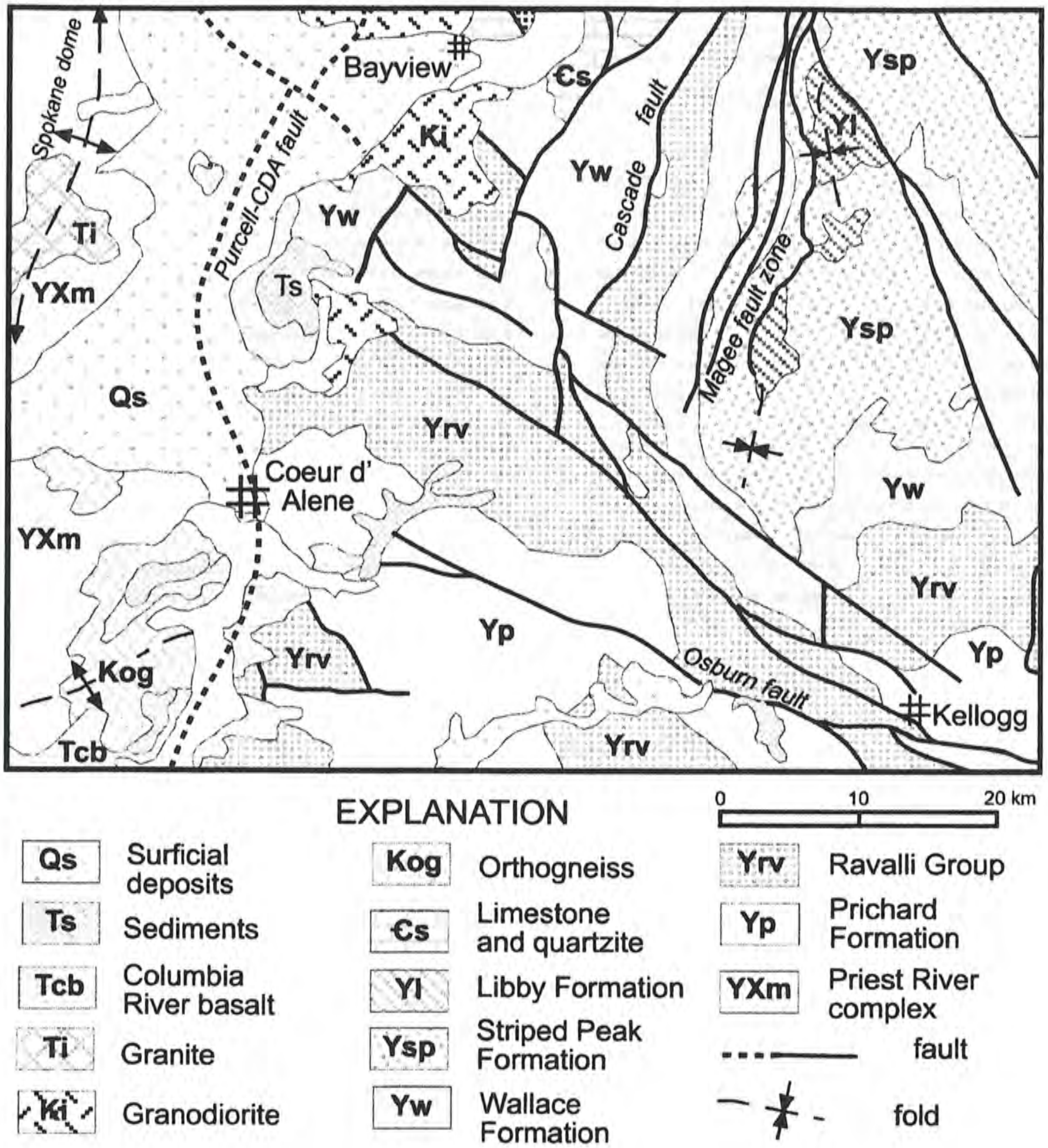

Figure 1. Simplified geologic map of the Coeur d' Alene 30' x 60' quadrangle.

THE HISTORY OF THE FABULOUS COEUR D'ALENE MINING DISTRICT

Earl H. Bennett - College of Mines and Earth Resources, Mines Building, University of Idaho, Moscow, ID 83844

If the United States designated national treasures, then the fabulous Coeur d'Alene Mining District (CDA) would be very near the top of the list. Nestled in the "Silver Valley" of north Idaho's panhandle, the district lays claim to the greatest recorded silver output in the world. Bragging rights include the world's largest single silver mine (Sunshine Mine), the most extensive zinc/lead mine in the U.S. (Bunker Hill with over 150 miles of underground workings) and the deepest mine in the county (Star-Morning, at 7,900 feet, equal to the maximum relief in Hells Canyon, the deepest river gorge in North America). Over 90 mines dot the district and 11 of these had over 3 million tons of production.

The story began with the discovery of gold on the South Fork of the Coeur d'Alene River by Andrew Prichard in 1878, followed by his better-known discovery near his namesake town, Prichard, on the North Fork of the river in 1882. This gold rush only lasted a few years, but on May 22, 1884, John Carten and Almeda Seymore staked the Tiger mine, the first of the major lead/zinc/silver discoveries. Within a year, almost all of the mines that would be major producers had been found, and with the coming of the railroads and electric power at the turn of the century, the district was on the road to world-class status. Names like Hecla, Hercules, Standard-Mammoth, Tiger-Poorman, Bunker Hill, Page, Sunshine, Galena, Coeur, Mineral Point, Frisco, Lucky Friday, Crescent, Dayrock and Star-Morning would forever be synonymous with Idaho and our national mining history.

But, the CDA's story is far more than just mining. Mine owners competed with labor in what would become a snapshot of the nation's labor story complete with violence and labor wars. Developments in extractive metallurgy greatly improved metal recovery and increased production, but led to environmental damage, which sparked debate and concern that still rages today under the onus of "Superfund." And then there are the people. What were they like and how did they live? From the lowest paid miner to the richest mine owner, the CDA produced as fascinating a cast of characters as could be imagined. From May Awkwright Hutton (rags to riches) to Charles Siringo (real-life turn-of-the-century James Bond), the cast of the CDA story is perhaps the most fascinating part of this modern industrial saga.

So with such a long and colored past, what will the future of the district be? Only two companies, Coeur the Precious Metals Company (Galena Mine) and Hecla Mining company (Lucky Friday Mine) still have operating mines. With the railroads gone and environmental issues galore, it looks somewhat bleak. However, the district's history has witnessed many ups and downs. Perhaps hidden veins and new resources will add continuing chapters to the story of the fabulous Coeur d'Alene.

ANALYSIS OF DIGITAL GEOLOGIC AND MINERAL RESOURCE DATA OF THE REVETT FORMATION IN THE WESTERN MONTANA COPPER BELT, IDAHO AND MONTANA

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Larry M. Applegate - North 8920 Prescott Road, Spokane, Washington, 99208

ABSTRACT

Analysis of digital geologic and mineral resource data for strata-bound copper-silver deposits of the Middle Proterozoic Belt Supergroup reveals new insights into the occurrence of these deposits. The strata-bound deposits occur within the Revett Formation in Western Montana Copper Belt (WMCB) of western Montana and northern Idaho (fig. 1). We compiled databases concerning the geology and mineral resources of the Revett Formation, including: (1) a digital geologic map of lower to middle Belt strata over the 85-mile by 100-mile study area, (2) a table of descriptive information on 56 copper-silver deposits and occurrences, (3) lithostratigraphic and mineralogic data from 122 measured sections and diamond drill cores totaling over 146,000 feet of strata, and (4) a spatial database of locations of the mineral resources, indicated mineralization, inferred mineralization, and mineralized outcrops.

Analysis of subsurface mineral zonation, thickness, and grain size of the Revett Formation suggest that sedimentology and diagenesis early in the history of the formation controlled emplacement of strata-bound copper-silver deposits. Study of authigenic, redox-like *mineral zones* in upper and lower members confirm mineralization occurs along a study-area-wide boundary between the chalcopyrite-ankerite and pyrite-calcite zones. These observations are consistent with work completed by Timothy Hayes at the Troy mine. Strata in the upper member are most prospective at the Troy mine while those of the lower member are most prospective at the Rock Creek deposit. These boundaries must cut obliquely across strata because the geographic arrangement of mineral zonation of the upper member differs from that of the lower member. Mapping shows the wide, non-prospective lavender zone is generally aligned from north to south across the eastern part of the study area corresponding with the direction of thinning of Revett strata. Further west, a north-south-aligned band of the pyrite-calcite zone occupies the central part of the study area and is turn flanked on the west and east by a pair of chalcopyrite-ankerite bands.

Isopach mapping of strata within the upper, middle, and lower members shows that faulting affected sedimentation during Revett time along the Osburn and Hope faults. Strata of the Revett Formation accumulated north of the Osburn Fault at about one-third to one-half of the rate as that located to the south. Strata of each member of the Revett Formation also thicken north of the northwest-southeast-trending Hope Fault, although to a much lesser degree than that in the vicinity of the Osburn Fault. Above-average thickness that persists from member to member in the formation defines *local basins* throughout the study area. Recurrent activity along faults during Revett time, principally along the Hope and Osburn faults, seems to adequately explain the differential rates of sedimentation.

Sand percentage, or isolith mapping of upper and lower member strata of the Revett Formation associated with known strata-bound deposits delineates broad, tens-of-miles-wide, thick coarse-grained clastic units (vitreous quartzite), including those associated with Troy mine and Rock Creek deposit. Narrower coarse clastic units, on the order of miles wide, located at Trout Creek, Vermilion River, Sims Creek, Clear Peak, Military Gulch, and Snowstorm were also identified. The overall pattern suggests

that Revett paleogeography consisted of four or five northeastward-trending and prograding estuarine-like systems interlaced among wide mudflats that terminated along a coastal, estuary-barrier-island-tidal-delta complex as suggested by earlier work at Troy mine. The coarse-grain-dominated area identified by the >60th-percentile isolith encompasses: known Revett-like strata-bound copper-silver deposits; other indicated or inferred mineralization; and mineralized outcrops. Isopach maps also show thickening to generally coincide with the >60-percentile isolith region. A site-by-site comparison of isolith and mineral zone data shows that strata-bound copper-silver mineralization occurs in proximity to thick, coarse-grained quartzite units within the Revett Formation, where intercepted by the boundary between the chalcopyrite-ankerite and pyrite-calcite zones.

Based on the foregoing, we suggest untested areas as sites for exploration of strata-bound deposits where the interaction occurs between the >60th-percentile isolith and the calcite-pyrite-to-chalcopyrite-ankerite boundary. The untested areas extend from outcrop to an arbitrary depth of 8000 feet. Other concepts developed here can be applied to refine target areas.

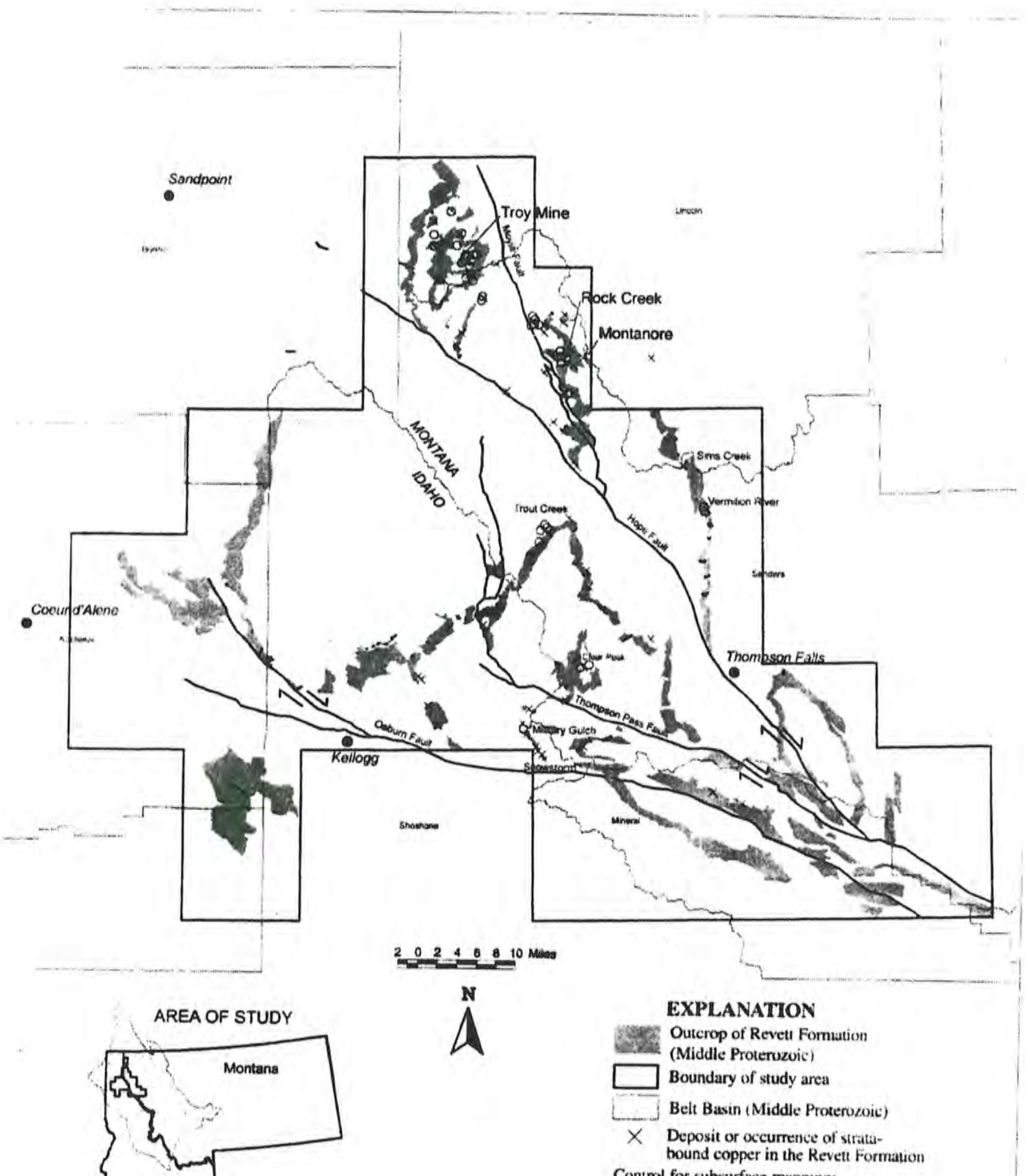

Figure 1. Map showing location of study area and control for mapping

SEISMOTECTONICS OF NORTHWEST MONTANA AND THE NORTHERN BASIN AND RANGE

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Michael C. Stickney - Earthquake Studies Office, Montana Bureau of Mines and Geology Montana Tech of the University of Montana, Butte, MT 59701-8997 MStickney@mtech.edu

ABSTRACT

The intermountain seismic belt (ISB) defines the eastern limits of extending crust in the western contiguous United States. Since 1982, over 2300 earthquakes have occurred in northwest Montana at the northern end of the ISB, defining a belt of seismicity up to 150 km wide that abruptly ends in the northern Flathead Valley (at south end of the Rocky Mountain trench). The vast majority of earthquake fault-plane solutions in northwest Montana display strike-slip or oblique-slip focal mechanisms on NW-striking faults (dextral) or NE-striking faults (sinistral), with N-S compression (P-axis) and E-W tension (T-axis). Two types of earthquake sequences characterize northwest Montana, discrete-event earthquakes followed by a decaying sequence of aftershocks, and earthquake swarms in a specific area that span weeks to months.

Notable earthquakes during the 20th century in northwest Montana include the 1935 Helena series, the 1945 and 1952 Flathead Lake earthquakes, the 1969 and 1971 swarms near the southwest shore of Flathead Lake, and the 1975 quake southeast of Kalispell. The largest northwest Montana earthquake since 1982 (the time since the Montana Bureau of Mines and Geology began to catalog earthquakes) occurred in 1985 in the southern Swan Range (M 4.9) and the most significant swarm during this same period occurred in 1995 at Kila, southwest of Kalispell. Recent seismicity is conspicuously absent in the vicinity of the down-dip projection of the southern Mission fault, despite 7-m-high Holocene fault scarps. Several earthquakes located within or near the Lewis and Clark zone have fault-plane solutions that are consistent with continuing dextral-slip on steeply dipping, WNW-trending faults that characterize the LCZ.

Our regional tectonic model places the apex of the "real" northern Basin and Range at the north end of the Flathead Valley, in the southern Rocky Mountain trench. South of this point, the Northern Rockies are extending westward in five semi-coherent crustal domains bounded by right-lateral strike-slip and oblique-slip accommodation and transfer zones, with each south-side domain having translated further west than those to the north. These domains are the Flathead zone, Lewis and Clark zone, Big Belt zone, Madison-Lost River zone, and the Idaho batholith. We propose that westward extension is accompanied by clockwise rotation for the region between northwest Montana and the eastern Snake River Plain. Furthermore, the Lewis and Clark zone is one of several northwest-striking dextral-slip accommodation zones that distribute rotation and extension of the northern Basin and Range from the eastern Sierra Nevada to western Montana. GPS will be the test this model over the next several years.

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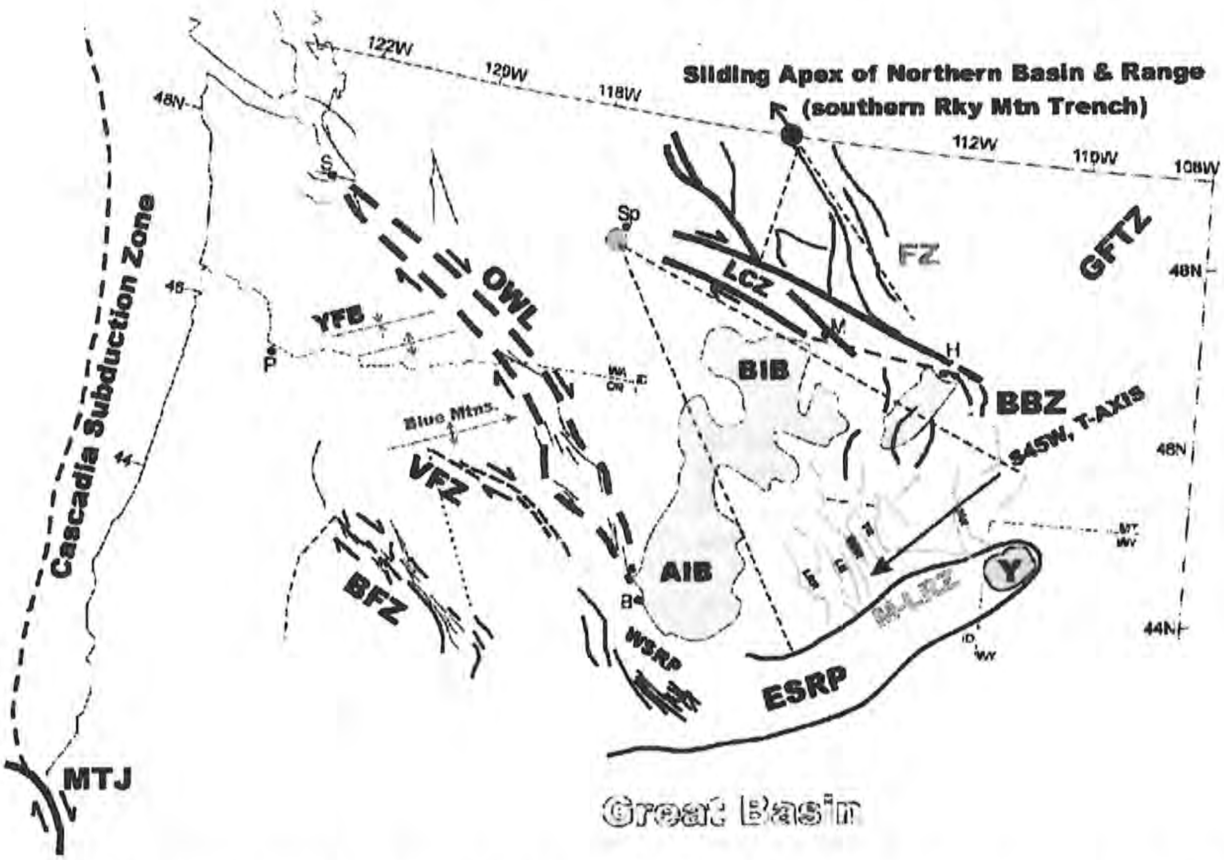

FIGURE 5: Cartoons showing the intrusion of the Paradise pluton and relationship to the Bitterroot mylonite. **(a)** Around 55-54 Ma, large volumes of main-phase peraluminous plutons intrude what is now the Bitterroot footwall, as thick sheets at mid-crustal depths (~20 km). The major pluton in the central Bitterroot metamorphic core complex is the Bear Creek intrusion (Toth, 1987; Foster and Fanning, 1997). At this time, metasedimentary Belt Supergroup country rocks were undergoing upper amphibolite facies metamorphism and partial melting in the northeast border zone, and presumably above the batholith (Hyndman, 1980; Foster et al., in press). **(b)** At 53 Ma the metaluminous Paradise pluton, the youngest of the mid-crustal plutons, intruded the Bear Creek pluton but while the older pluton was still partially molten (Toth, 1987; Foster et al., in press; this study). Extension and collapse of the thickened crust began with movement accommodated by an eastward propagating extensional shear zone (Foster and Raza, in press). The partially crystallized Paradise pluton and Bear Creek pluton were deformed during movement along the mylonite zone, by shearing the Paradise pluton roof zone and forming the eastward projecting sheet phase (Toth, 1983; Toth, 1987). **(c)** By 50 Ma unroofing of the core complex was well under way (Foster and Fanning, 1997). Thermochronologic data indicate that the western part of the core complex had cooled below greenschist facies conditions by 48 Ma while the eastern portion is still at amphibolite facies conditions (Foster and Raza, in press). Exhumation of the shear zone resulted in retrogression of the exhumed granitic rocks as they cooled from amphibolite and greenschist facies conditions, to sub-greenschist facies conditions when chloritic breccias and brittle faults formed at shallower depths (Hyndman and Myers, 1988; Foster, 2000). **(d)** By 35 Ma ductile deformation and most exhumation of the core complex and granitic magmatism had effectively ceased (Foster and Fanning, 1997; Foster and Raza, in press).

DISPERSAL OF METALS IN SURFACE ENVIRONMENTS IN AND DOWNSTREAM OF THE COEUR D'ALENE MINING DISTRICT, IDAHO

Steven E. Box, Arthur A Bookstrom, Laurie S. Balistrieri, and Keith R. Long - U.S. Geological Survey, 904 W. Riverside Ave., Spokane, WA 99201 **sbox@usgs.gov**

ABSTRACT

Riverine disposal of about 56 million metric tons of mill tailings into the South Fork of the Coeur d'Alene (CdA) River and its tributaries within the CdA mining district has resulted in wide dispersal of the ore metals in the drainage basin. Early milling practices of coarse crushing produced a range of coarse to fine grain sizes in tailings. The coarse fraction overwhelmed the carrying capacity of the streams, leading to aggradation of the streambed and adjacent floodplain in the mining district with very high metal sediment (2-6% Pb, 1-4% Zn). The fine fraction was transported downstream and deposited in the lake back-flooded channel and floodplain of the lower CdA valley and into CdA Lake (2-3% Pb, 1-2% Zn). Milling practices evolved to fine-grinding (-0.15mm) and flotation in the 1920's, resulting in entrenchment of the district streams and stranding the aggraded floodplain along the South Fork above flood level. Essentially all of the flotation tailings (<0.5%Pb, 0.5%Zn) were transported to the lower valley and CdA Lake, with the finest fraction spilling over into the Spokane River and on to its junction with the Columbia River nearly 200 miles downstream. The oversupply of fine sediments exceeded the annual carrying capacity of the lower CdA River channel, leading to aggradation of the bed (3-6 m) and banks and increased sedimentation rates across the floodplain. Riverine disposal of tailings ended in 1968 and impoundments were constructed near each mill. However, reworking of the bed and banks of the impacted streams continues to transport sediment bearing 0.3-0.5% each of Pb and Zn from the mining district to the channel and floodplain of the lower valley and to CdA Lake and beyond. Of the Pb released to the river, we estimate that 22% remains in the South Fork valley, 28% in the valley of the lower CdA River, and 35% on the bottom of CdA Lake.

Weathering of the ore sulfides (PbS-galena) ZnS-sphalerite) begins with exposure to the oxidizing surface environment in the mine walls and the remaining tailings; sphalerite is more resistant to oxidation than galena. The relative abundance of gangue and wallrock carbonates and sparseness of pyrite in the ore bodies leads to mostly near-neutral pH in waters draining mines and tailings. The relative insolubility and high affinity of Pb for oxide surfaces at near-neutral pH promotes retention of Pb in secondary minerals (Pb sulfate, Pb carbonate, or Pb in solid solution with an sorbed on Fe and Mn oxides) at the site of galena breakdown. In contrast, the relatively high solubility of Zn and its lower affinity for oxide surfaces allows most Zn released during sphalerite oxidation to stay in solution and drain away from the weathering site, leading to declining Zn/Pb in oxidizing soils. Zn can cycle between the dissolved and solid states by several processes controlled by water chemistry, solution pH and redox state, resulting in complex dissolved metal loading pathways within groundwater aquifers and lake bottom sediments. Pb cycles between secondary solid phases by similar processes, and Pb bioavailability is controlled by the solubility of these phases in the digestive tract. Waters draining mine adits, tailings piles and metal-enriched sediments and soils are typically high in Zn (but low in Pb), leading to excedances of water quality guidelines for Zn in surface water downstream nearly to the Columbia River.

EMPLACEMENT CHRONOLOGY OF THE PARADISE PLUTON: IMPLICATIONS FOR THE DEVELOPMENT OF THE BITTERROOT METAMORPHIC CORE COMPLEX, MONTANA/IDAHO

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ABSTRACT

The Paradise pluton is a mid-crustal, main-phase intrusion of the east-central Idaho-Bitterroot batholith and part of the footwall of the Bitterroot metamorphic core complex. Structural evidence from the Paradise pluton shows that it was still partially molten during the initial stages of movement on the Bitterroot mylonite. Intrusion into the shear zone produced a thin sheet (~1450 m thick) phase that projects eastward from the main body of the pluton. Mineral lineations and deformation in the sheet match those in the mylonite zone outside the Paradise pluton. This indicates the emplacement of the Paradise pluton was synchronous with the development of the mylonite shear zone. High precision U-Pb zircon data from the Paradise pluton gives a crystallization age of 53.2 ± 0.7 Ma, which also approximates the initiation age of the shear zone. This evidence, along with previously reported U-Pb zircon and thermochronologic data, further constrain and define, the timing and role of magmatism in the tectonic evolution of the Bitterroot metamorphic core complex.

INTRODUCTION

The evolution of metamorphic core complexes, comprising high-grade mid-crustal rocks juxtaposed with relatively low-grade shallow-level rocks by extensive mylonite shear zones, has been debated for more then 20 years (e.g. Coney, 1980; Crittenden et al., 1980 and references therein). Thermochronologic data (see review by Foster and John, 1999) and structural relations (see reviews by Wernicke, 1992; 1995) indicate that core complexes are unroofed and exhumed from mid-crustal depths during extension, with movement accommodated on shallow-angle normal faults in the upper crust, and mylonitic shear zones at deeper depths. In addition, considerable debate has centered on the role of magmatism in the origin of core complexes and the initiation of extension.

Some workers proposed that magmatism was necessary for the occurrence of ductile, extensional deformation in the middle to upper crust and the domed appearance of the core complexes (Coney, 1980; Hyndman, 1980; Rehrig and Reynolds, 1980; Keith et al., 1980; Lister and Baldwin, 1993). However, some highly extended areas in the Basin and Range Province are devoid of significant synkinematic plutons (e.g., Wernicke et al., 1985) and in many cases it is not clear whether magmatism promoted or was the product of extension (e.g., Axen et al., 1993).

The Bitterroot metamorphic core complex of southwestern Montana and eastern Idaho, is one of a series of Eocene core complexes in the northern Cordillera (Figure 1a). Most of the Bitterroot complex footwall is composed of Cretaceous to Eocene granitic plutons of the east-central Idaho-Bitterroot batholith (Figure 1b) (Hyndman, 1980; Toth, 1987; Foster, 2000). Movement associated with unroofing and exhumation was accommodated on a 500 to 1,500 m thick mylonitic shear zone, which defines the eastern boundary of the complex (Hyndman, 1980; Garmezy, 1983; Hyndman and Myers, 1988; Foster, 2000). The exposure of deformed granitic plutons within the mylonite zone makes the Bitterroot core complex an ideal area to investigate the timing relationships between magmatism, the onset of extension and exhumation (Bickford et al., 1981; Chase et al., 1983; Garmezy, 1983; Foster and Fanning, 1997; Foster et al., in press; Foster and Raza, in press).

BITTERROOT METAMORPHIC CORE COMPLEX

Rocks exposed in the footwall of the Bitterroot metamorphic core complex are primarily mid-crustal, main-phase plutonics of the east-central Idaho-Bitterroot batholith, with a smaller area of Proterozoic Belt Supergroup metasediments on the northern edge (Figure 1b) (e.g. Hyndman, 1980; Lewis et al., 1992, Lewis, 1997; Foster, 2000; Foster et al., in press). In the eastern Bitterroot complex, metamorphism and pluton emplacement occurred at depths of ~15-25 km (Hyndman, 1981; House et al., 1997; Foster et al, in press).

An extensive north-south trending mylonite zone defines the eastern edge of the footwall (Hyndman, 1980). Mylonite, ranging from 500 to 1,500 m thick, overprints plutonic rocks and Belt metasediments of the footwall, with lineations and kinematic indicators showing top-to-the-east (~110^{o}) movement (Garmezy, 1983; Hyndman and Myers, 1988; Foster, 2000). Most deformation in the mylonite zone occurred under amphibolite facies conditions, with later retrogression from exhumation resulting in overprinting greenschist facies deformation and the formation of chloritic breccia localized near the top of the shear zone (Hyndman and Myers, 1988; Foster, 2000; Foster and Raza, in press).

The northern, southern and western sides of the Bitterroot complex footwall are more poorly defined, but are broadly constrained by a semi-circle of Eocene, shallow-level, hypersolvus alkali-feldspar granite plutons and felsic volcanics (Hyndman, 1980; Foster and Fanning, 1997). Part of the western border is also defined by a north-trending segment of the upper Selway River (Wiswall and Hyndman, 1987; Foster and Coyner, 1999) with the possible "breakaway zone" indicated by major brittle faults in the same area (Foster and Coyner, 1999; Foster, 2000).

Ar-Ar thermochronology, along with metamorphic P-T-t data, record rapid exhumation of the core complex in Eocene time (Garmezy, 1983; Foster and Fanning, 1997; House et al., 1997; Foster, 2000; Foster et al., in press). This is indicated by thermochronologic contours in the footwall that decrease in age from west to east (Foster, 2000; Foster et al., in press; Foster and Raza, in press). These data indicate that deformation within the shear zone at temperatures >500^{o}C to <300^{o}C took place between ca. 53 and 35 Ma in an extensional setting.

East of the footwall mylonite, the Sapphire block forms the present day Sapphire Mountains and hanging wall of the core complex (Hyndman, 1980). Most of the Sapphire block is composed of tilted and rotated blocks of Proterozoic Belt sediments and metasediments, intruded by smaller granitic stocks and unmylonitized plutons (i.e. Burnt Ridge pluton) similar in composition to the main phase of the Idaho-Bitterroot batholith (Wallace et al., 1989; Foster, 2000). These relationships suggest they are from the structurally higher roof zone of the batholith (Hyndman, 1980; Garmezy, 1983; Foster, 2000; Foster et al, in press). Apatite fission-track dates of ~40-57 Ma from the Sapphire block indicate that most rocks within the hanging wall had cooled below 110^{o}C before most of the Bitterroot footwall experienced significant cooling and exhumation. This suggests that the rocks in most of the Sapphire block resided in the upper ~5-7 km of the crust by middle Eocene time (Foster and Raza, in press).

PARADISE PLUTON-INTRUSIVE RELATIONSHIPS

The large, peraluminous, two-mica granite Bear Creek pluton comprises most of the plutonic rocks exposed in the central Bitterroot core complex footwall (Toth, 1987; Foster et al., in press). Recent U/Pb zircon data from two areas of the Bear Creek pluton indicate crystallization dates of 54.6 ± 0.8 and 54.3 ± 0.7 Ma (Foster and Fanning, 1997).

The main-phase Paradise pluton, the focus of this study, intrudes the southeastern part of the Bear Creek pluton (Figure 1b). Unlike the peraluminous granites of the Bear Creek pluton, rocks from the Paradise are metaluminous with a molecular ratio of $Al_2O_3/CaO+K_2O+Na_2O$ < 1.1 and <1% normative corundum (Toth, 1987).

In plane view, the western "main body" of the Paradise pluton forms an elliptical-shaped mass with several arm-like extensions projecting toward the east and south (Figure 2). Another separate, smaller body of the pluton is located ~5 km southeast of the main body, near El Capitan Peak. The Paradise pluton is exposed over an area of ~105 km^2 (Toth, 1983).

The main body of the Paradise pluton forms a thick plug, intruding the Bear Creek pluton, with vertical walls on the northern and western sides (Toth, 1987). Towards the east and south it grades into a thinner "sheet phase" ~1450m thick, with a shallow dipping top and bottom (Figure 3). The lower contact of the sheet and Bear Creek pluton is sharp and continuous over large distances (Toth, 1983). The upper contact of the sheet contains roof zone material with numerous xenoliths of the Bear Creek pluton and Proterozoic Belt metasediments (Toth, 1983).

Foliation is moderate to very strong throughout the Paradise pluton, with magmatic foliation in the main body, suggesting emplacement during deformation (Toth, 1987). Measured flow foliations, shown in Figure 3, indicate the main body is a broad antiformal structure (Toth, 1983). The structure of the sheet phase of the pluton is remarkably regular with foliations consistently trending 040, 25N (Toth, 1983). Magmatic foliations in the sheet phase are strongly overprinted by crystal-plastic deformation fabrics forming strong foliations and lineations. Our measurements of lineation direction are identical to the regional lineation in the Bitterroot mylonite. Amphibolite facies fabrics dominate the base of the sheet phase and grade vertically upwards to greenschist mylonite and ultramylonite near the top. These relationships suggest that intrusion of the Paradise pluton was synchronous with the development of the mylonite.

Local magma mingling between the Paradise and Bear Creek plutons suggests that the Paradise pluton was intruded during the last stage of crystallization of the Bear Creek pluton (Toth, 1983). Prior to this study, the best available date for the Paradise pluton was a hornblende Ar-Ar cooling age of 51.4 ± 0.5 Ma for a sample from the western part of the pluton's main body (Garmezy, 1983). This hornblende age represents when the pluton cooled below about 500-530^{o}C and is probably slightly younger than the crystallization age (Foster et al, in press). This study seeks to obtain a precise date of crystallization of the Paradise pluton, utilizing the U/Pb system on magmatic zircons.

SAMPLING AND SHRIMP-II ANALYSES

One sample, SC99-12, was obtained from the sheet phase of the Paradise pluton near El Capitan Peak (Figures 1b and 2). The sample is a medium grained, well-foliated mylonitic granodiorite, containing medium to large (1-2 cm) K-feldspar augen porphyroclasts, hornblende and visible sphene.

Zircon was separated from the sample using conventional heavy liquid and magnetic methods. Zircon grains were mounted in epoxy together with the reference zircon, AS-3, sectioned approximately in half, and polished. The zircon mounts were analyzed using the SHRIMP-II facility at the Research School of Earth Sciences, Australian National University. A summary of the methods used to date relatively young zircons using SHRIMP-II are discussed at length by Compston et al. (1992) and Williams (1998). For zircon of Eocene age, correction for common Pb was made using the measured $^{207}Pb/^{206}Pb$ and $^{238}U/^{206}$ ratios following Tera and Wasserburg (1972), as described by Compston et al. (1992). Correction for common Pb for the Archean zircon area was made using the measured $^{207}Pb/^{206}Pb$ ratios in the normal manner (Compston et al., 1992). Errors quoted for the crystallization ages are at the two sigma level.

RESULTS

Eighteen areas in fifteen zircon grains from sample SC99-12 were analyzed with SHRIMP-II (Figure 4). One analysis gave a concordant Archean $^{207}Pb/^{206}Pb$ age of 2,562.9 ± 48.4 Ma and was not included in crystallization age calculations. The remaining seventeen analyses give a weighted mean age of 52.3 ± 0.9 Ma with a MSWD of 4.7, indicating excess scatter beyond analytical. Five analyses with ages ranging from ~48.6 to ~50.6 Ma, had high ^{204}Pb and low Th/U ratios, suggesting radiogenic Pb loss. Three of these analyses with apparent Pb loss came from rims that are structureless and unzoned in cathodluminescence. The narrow range of ages and structureless rims of the grains suggests the Pb loss occurred during metamorphism, most likely as the pluton was mylonitized.

If we eliminate these five spot analyses, the remaining twelve concordant analyses record similar $^{206}Pb/^{238}U$ ages with a weighted mean of 53.2 ± 0.7 Ma and a MSWD of 1.7. All of these areas are from euhedral zircon with magmatic zoning patterns. We interpreted the 3.2 ± 0.7 Ma to record the magmatic crystallization age of the Paradise Pluton.

DISCUSSION AND CONCLUSIONS

U-Pb zircon data provide a chronological framework for much of the plutonism in the Bitterroot metamorphic core complex. The oldest Cretaceous plutons tend to be quartz diorite and tonalite in composition and give ages between ~95 and 75 Ma (Bickford et al., 1981; Toth and Stacey, 1992; Foster and Fanning, 1997; Foster et al, in press). These plutons are variably deformed and possess weak to strong, high temperature fabrics, suggesting they were synkinematic with thrusting. The main-phase peraluminous to mildly metaluminous plutons (Hyndman, 1983) give dates ranging from about 65 to 53 Ma, with a significant proportion of the granitic plutons, such as the Bear Creek pluton, having been intruded at ~54-53 Ma (Figure 5a) (Foster and Fanning, 1997; Foster et al., in press). Many of these plutons form thick (3-10 km) sills (Wiswall and Hyndman, 1987) and intrude the upper part of the middle crust (~0.6 GPa), perhaps by spreading out at the brittle-ductile transition, the mid-crustal strength maximum. The youngest of the main phase plutons is the Paradise pluton, discussed in this paper. The Paradise pluton intruded at a shallower level than the Bear Creek pluton, but while parts of the older pluton were still partially molten (Toth, 1987). The U-Pb zircon data from the Paradise pluton indicates crystallization at 53 ± 1 Ma, and because intrusion was synchronous with mylonitization, this marks the initiation of extension in the complex (Figure 5b).

Therefore, extension in the Bitterroot complex began at about 53 Ma when the extensional shear zone propagated eastward through middle crustal depths where magma was still being emplaced in the form of the Paradise pluton, pegmatites, and partial melting occurring in the northern border zone (Foster et al., in press; this study). Thermochronologic data indicate that extension after 53 Ma was relatively rapid. Contours of Ar-Ar, K-Ar and fission-track cooling ages from in the footwall decrease from west to east in the direction of tectonic transport of the hanging wall, and from relatively shallow to relatively deep structural levels (Foster, 2000; Foster et al., in press; Foster and Raza, in press). This indicates that the dominant cause of cooling was tectonic exhumation (e.g., Foster and John, 1999). The exhumation process occurred relatively rapidly between 52 and 40 Ma (Figures 5c and 5d), causing the cooling of the western part of the footwall below ~110°C by ~45 Ma and the eastern part of the footwall below 250-300°C by 43 to 40 Ma. The eastern-most part of the mylonite zone cooled below ~200°C by ~ 39-35 Ma, based on the K-feldspar minimum ages (Foster et al., in press; Foster and Raza, in press). This interpretation is also consistent with decompression metamorphism in the eastern part of the northeast border zone between 50 and 48 Ma (House et al., 1997).

Emplacement of major volumes of magma into the Bitterroot metamorphic core complex from about 54 to 53 Ma (Bear Creek and Paradise plutons) probably led to significant weakening of the crust, because of elevated temperatures at mid-crustal levels and the high melt fraction. The magma emplacement and partial melting in the middle crust of the Bitterroot complex 54-53 Ma followed the end of thrusting and contraction in the Montana foreland by only 1-3 million years based on a minimum age for thrusting of about 56-54 Ma (e.g., Harlan et al., 1988). It is therefore possible that extensional deformation and collapse of the thickened crust was focused in the Bitterroot metamorphic core complex, because of the strength contrasts with areas to the east and west where magmatism was either older (west) and/or concentrated in the upper crust (east of the complex).

ACKNOWLEDGMENTS

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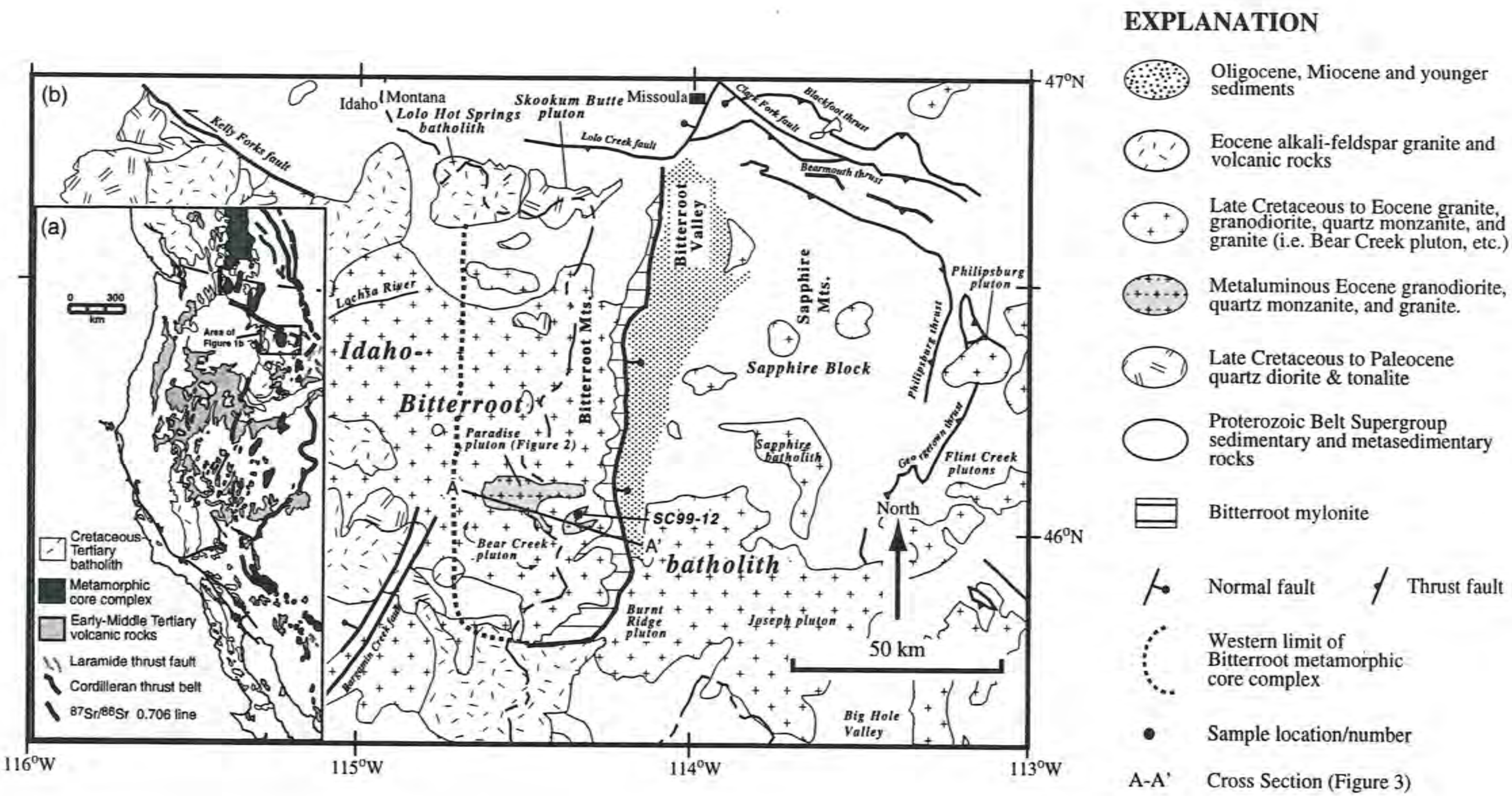

FIGURE 1: **(a)** Inset: Map of western North America showing the location of the Bitterroot metamorphic core complex in relation to major Mesozoic and Cenozoic tectonic features (after Coney, 1980). **(b)** Geological map of the northern Idaho batholith (Idaho-Bitterroot batholith) region showing sample location and the location of the Paradise pluton in relation to other Bitterroot core complex features (after Toth, 1987; Foster, 2000). Geologic cross section is shown in Figure 3.

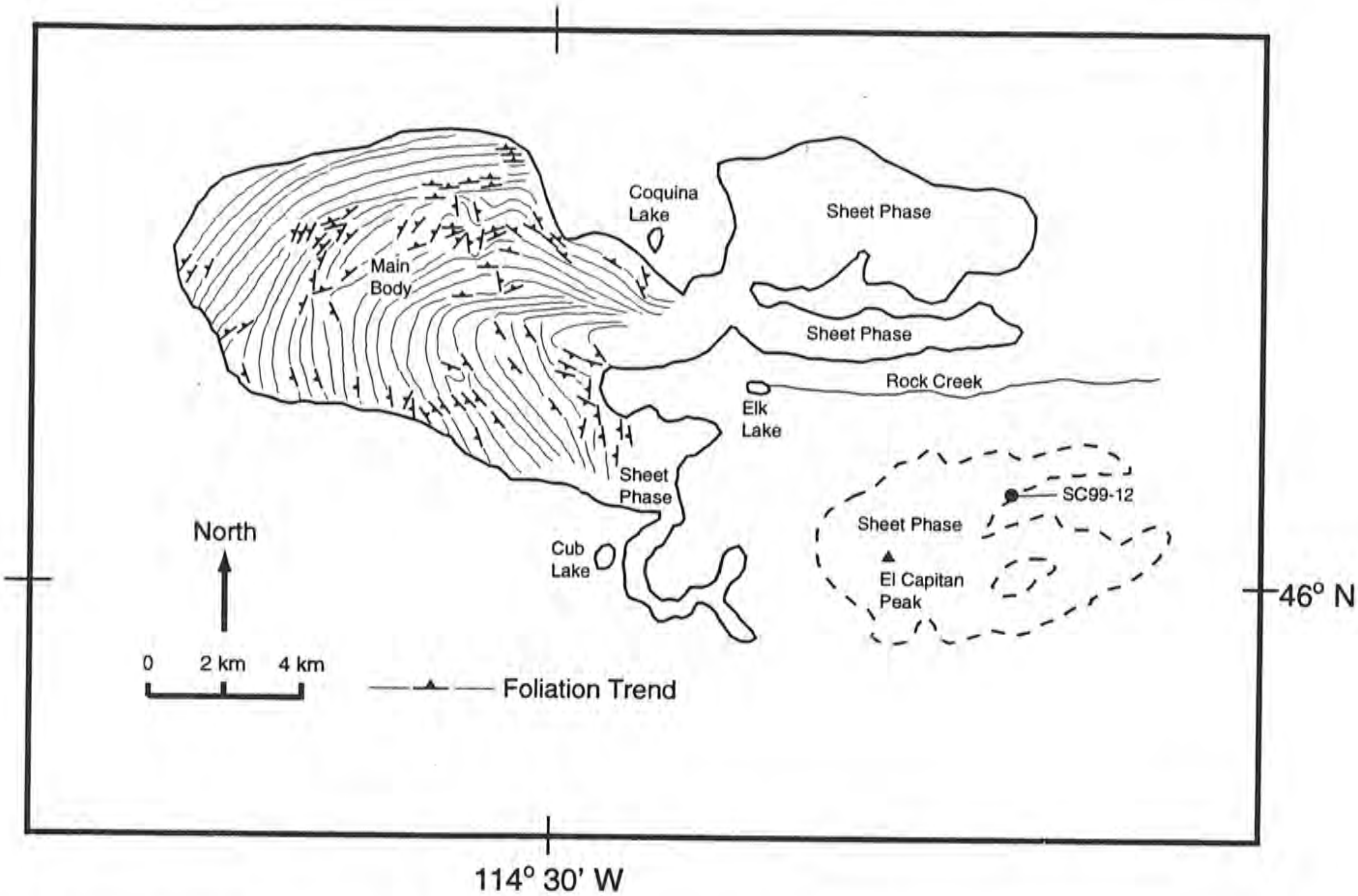

FIGURE 2: Expanded map of the Paradise pluton showing main body of the pluton with foliation trends, the sheet phase and sample location. (after Toth, 1983).

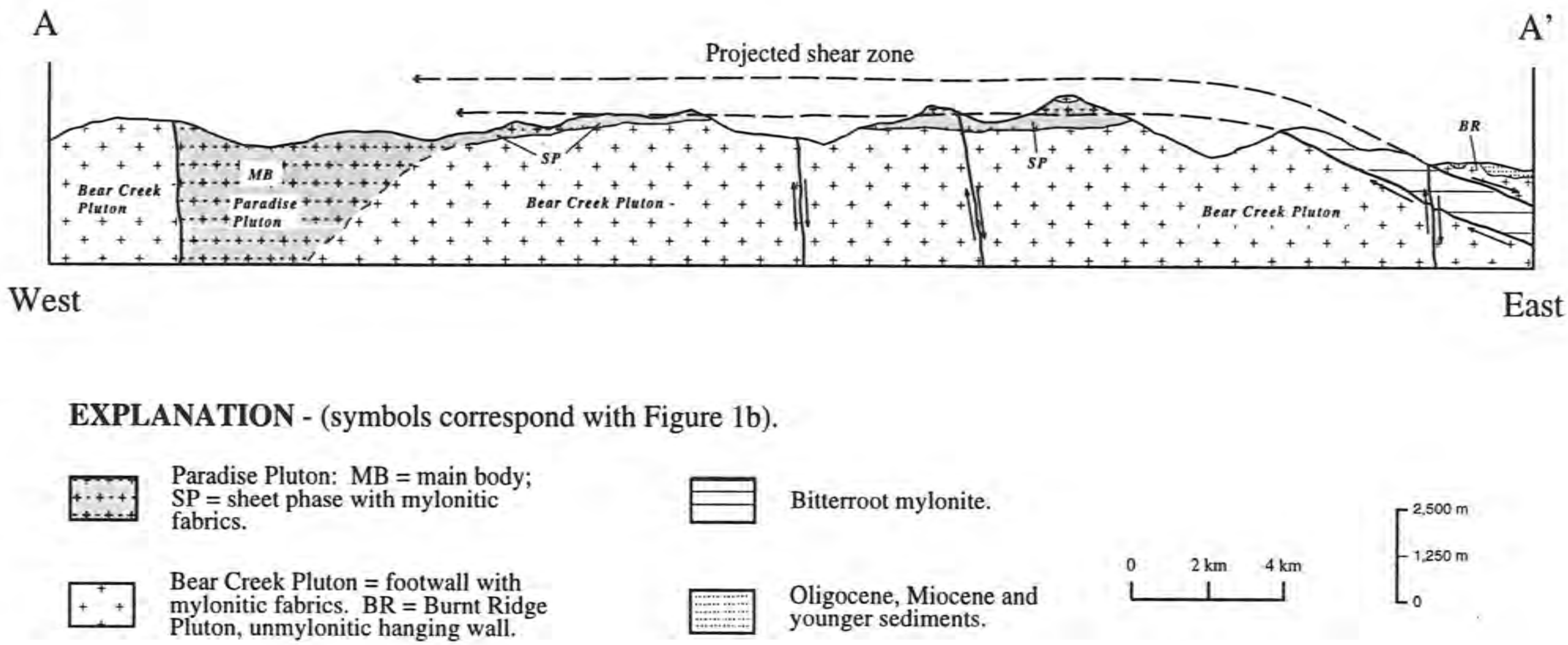

FIGURE 3. Geologic cross-section for the line noted on Figure 1 (modified from Toth, 1983). The mylonitic rock fabrics in the shear zone grade structurally downward to protomylonite and foliated granites. Below the projection of the top of the shear zone the Bear Creek and Paradise plutons show protomylonitic fabrics.

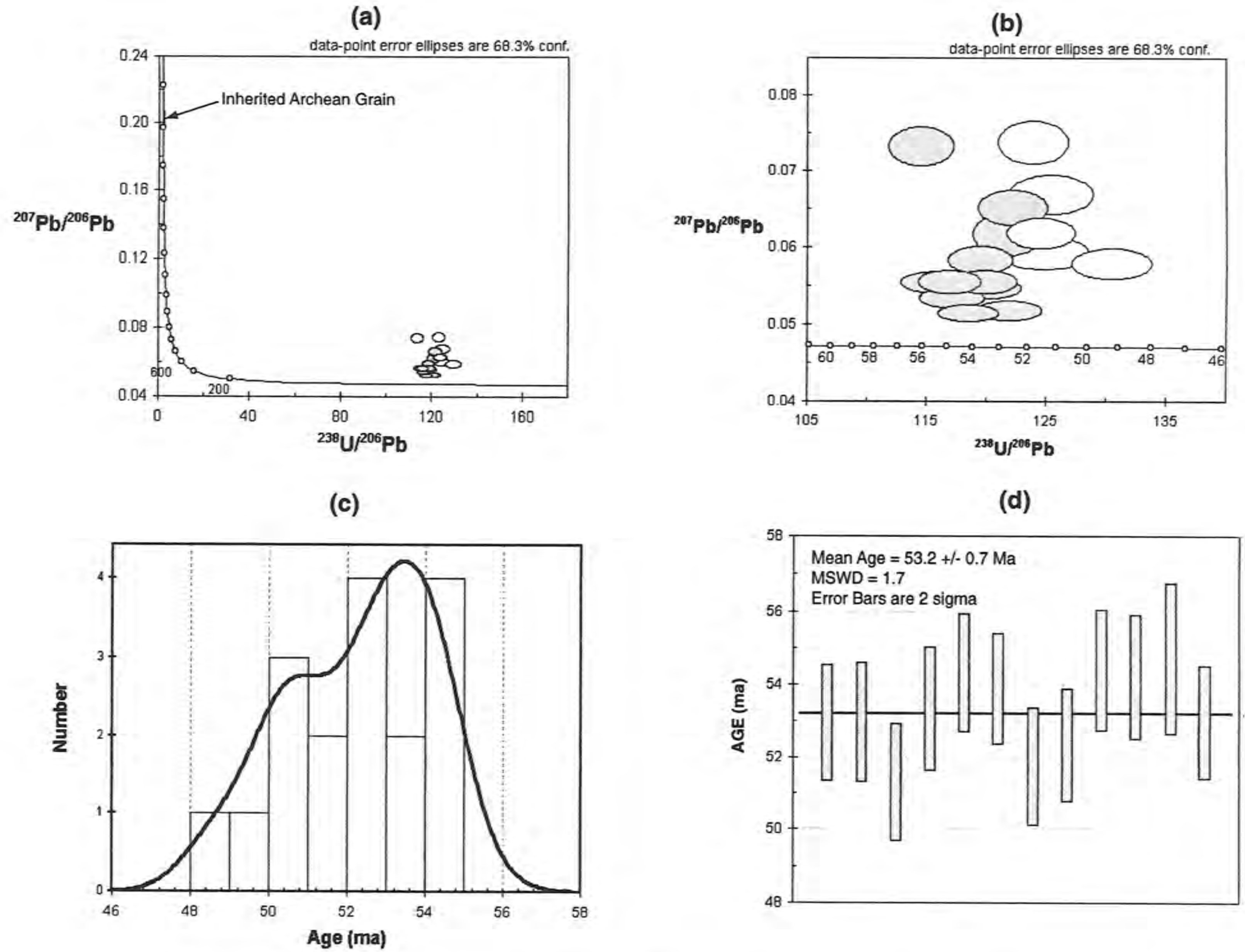

FIGURE 4: **(a)** Tera-Wasserberg concordia plot with all 18 U/Pb spot analyses of zircon. Filled data points are analyses used for crystallization age calculation. Open data points are analyses with apparent Pb loss. Concordant Archean data point as indicated. **(b)** Expanded Tera-Wasserburg concordia plot from Figure 4a, with filled/open data points same as previous. (c) Gaussian total distribution plot of the 17 Eocene-age analyses. **(d)** Crystallization age calculation plot for the 12 concordant analyses.

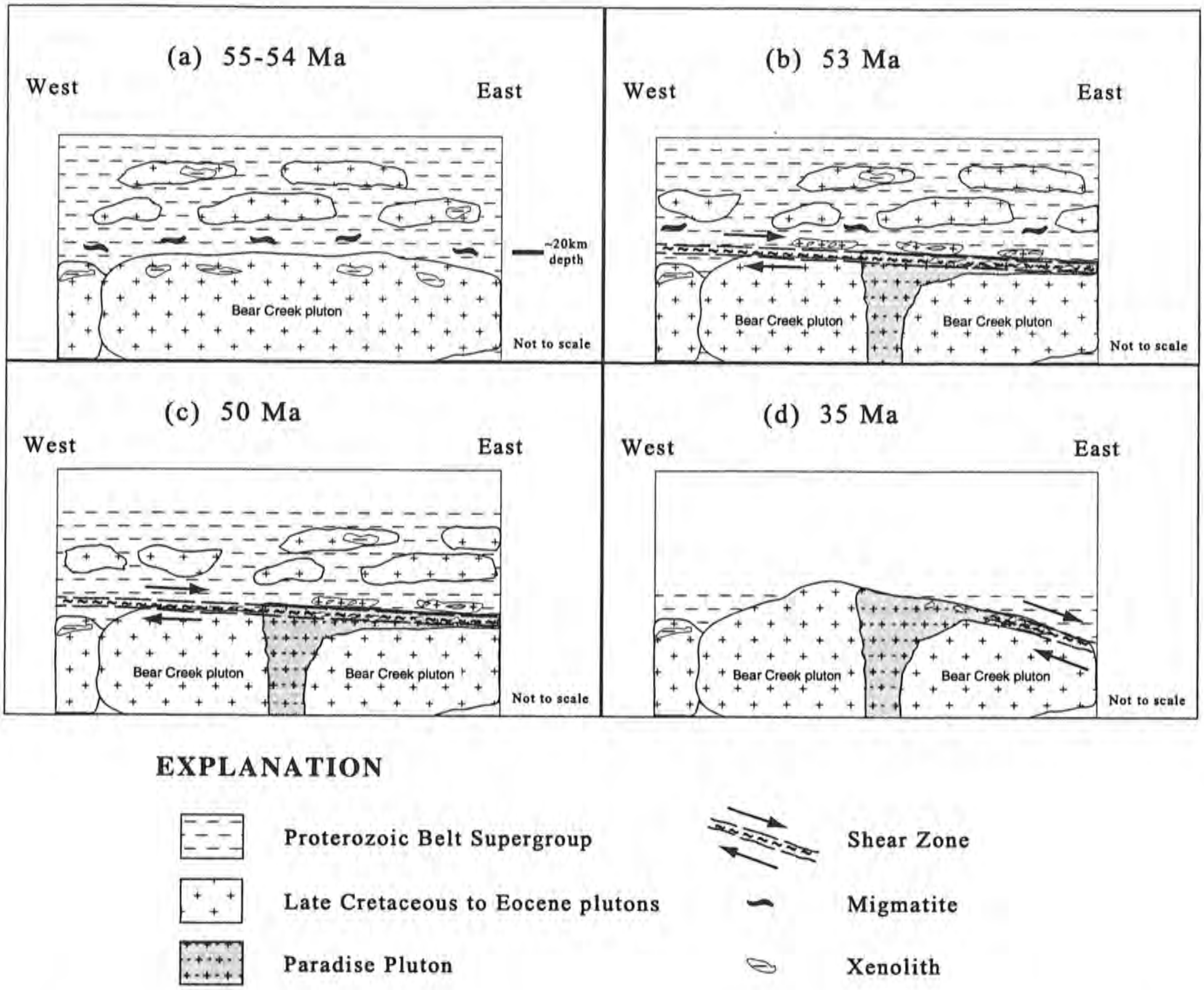

FIGURE 5: Cartoons showing the intrusion of the Paradise pluton and relationship to the Bitterroot mylonite. **(a)** Around 55-54 Ma, large volumes of main-phase peraluminous plutons intrude what is now the Bitterroot footwall, as thick sheets at mid-crustal depths (~20 km). The major pluton in the central Bitterroot metamorphic core complex is the Bear Creek intrusion (Toth, 1987; Foster and Fanning, 1997). At this time, metasedimentary Belt Supergroup country rocks were undergoing upper amphibolite facies metamorphism and partial melting in the northeast border zone, and presumably above the batholith (Hyndman, 1980; Foster et al., in press). **(b)** At 53 Ma the metaluminous Paradise pluton, the youngest of the mid-crustal plutons, intruded the Bear Creek pluton but while the older pluton was still partially molten (Toth, 1987; Foster et al., in press; this study). Extension and collapse of the thickened crust began with movement accommodated by an eastward propagating extensional shear zone (Foster and Raza, in press). The partially crystallized Paradise pluton and Bear Creek pluton were deformed during movement along the mylonite zone, by shearing the Paradise pluton roof zone and forming the eastward projecting sheet phase (Toth, 1983; Toth, 1987). **(c)** By 50 Ma unroofing of the core complex was well under way (Foster and Fanning, 1997). Thermochronologic data indicate that the western part of the core complex had cooled below greenschist facies conditions by 48 Ma while the eastern portion is still at amphibolite facies conditions (Foster and Raza, in press). Exhumation of the shear zone resulted in retrogression of the exhumed granitic rocks as they cooled from amphibolite and greenschist facies conditions, to sub-greenschist facies conditions when chloritic breccias and brittle faults formed at shallower depths (Hyndman and Myers, 1988; Foster, 2000). **(d)** By 35 Ma ductile deformation and most exhumation of the core complex and granitic magmatism had effectively ceased (Foster and Fanning, 1997; Foster and Raza, in press).

PETROGRAPHY AND MINERALOGICAL INVESTIGATIONS OF THE PICKET PIN PGE DEPOSIT STILLWATER COMPLEX, MONTANA: PRELIMINARY RESULTS

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ABSTRACT

The Picket Pin deposit is located near the top of Anorthosite II, an approximately 570 m thick anorthosite at the top of the Middle Banded series within the Stillwater Complex, Montana (Boudreau and McCallum, 1985). Primary field investigations of Anorthosite II (AN II) proximal to sulfide mineralization reveals intricately varying compositions on a scale of centimeters to tens of meters. A single 10 m x 25 m outcrop was chosen for a detailed study of the PGE-bearing sulfide distribution within AN II. The study area was divided by intercumulate pyroxene percentage into four groups: 0-5%, 5-10%, 10-15%, and 15-20%. The pyroxene divisions reveal an alteration trend from unaltered clinopyroxenes and orthopyroxenes (15-20%) distal to mineralization to relict pyroxenes altered to chlorite and clinozoisite (0-5% relict pyroxene) within the mineralized zone. This trend may suggest that hydrothermal ore-bearing fluids were the cause of the alteration halo. Plagioclase shows a similar trend. The ratio of large (0.5-2 cm) 'framework' plagioclase to small (<0.5 cm) intercumulate plagioclase increases near to sulfide mineralization. Plagioclase also shows a textural trend from small embayments in the 15-20% pyroxene group, to highly eroded with unusual grain to grain contacts near sulfide mineralization. The sulfides occur as intercumulate grains within the 0-5% pyroxene group. Original exsolution textures of Ni within pyrrhotite suggest that the sulfide grains may not have been remobilized as suggested for the J-M Reef (McCallum, 1999). The sulfides are compositionally zoned with pyrrhotite-pentlandite-chalcopyrite-braggite (PGE-bearing sulfides) in the most altered zone, to oxides ilmenite and magnetite distal to the sulfides. This compositional zoning may suggest a fluid change in Eh/pH from reducing to a more oxidizing condition for precipitation of PGE-bearing sulfides. Anhedral intercumulate clinozoisite and epidote enclose the sulfides and oxides and appear to be contemporaneous with sulfide precipitation. If the clinozoisite is contemporaneous, then the temperature of precipitation would range from 500 to 550°C using the quartz-clinozoisite system.

INTRODUCTION

The processes of transport and deposition of 'reef-type' platinum-group-element (PGE) deposits remains enigmatic although numerous models have been proposed (Boudreau, Naldrett, Zientek and others). The Stillwater Complex contains reef-type, PGE enriched, sulfide-bearing intervals including the J-M Reef and the Picket Pin deposit. The J-M Reef is located approximately 500 m above the contact of the Ultramafic series and the Banded series, and occurs within the Troctolite-Anorthosite zone I (TAZ I), a complex lithologic unit which contains numerous subdivisions. The Picket Pin deposit, located approximately 3 km above the J-M Reef, is hosted within a thick anorthosite (AN II) of the Middle Banded series. The lack of lithologic complexities within the Picket Pin deposit provides an excellent opportunity to investigate the PGE-ore formational processes.

GEOLOGIC SETTING OF THE STILLWATER COMPLEX

The Stillwater Complex, a 2.7 Ga layered mafic complex, is situated in a fault-bound block in the northern Beartooth Mountains of south-central Montana (fig.1). The complex is exposed along strike (N 60° W) for approximately 45 km and attains an exposed thickness of 6.5 km. The

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complex intruded into middle Archean metasediments and forms a wide contact aureole up to pyroxene-hornfels grade. The well-exposed basal contact aureole extends approximately 8 km perpendicular to strike. Presure-temerature conditions inferred from the aureole are 3 ± 0.5 kbar with a temperature of 850°C (Vaniman et al., 1980). Evidence from the P-T conditions may suggest that the complex represents a subvolcanic chamber in which the volcanic carapace has been lost to erosion (Helz, 1995). Isotopic evidence suggests the Stillwater magma was either contaminated with crustal material or derived from an upper mantle enriched in Rb, U, Th, and light rare-earth elements (LREE) (Lambert et al., 1985). Isotopic evidence also suggests numerous metamorphic events have effected the complex. A 1,555-m continuously cored, vertical drillhole collared in the Stillwater River canyon indicates 1,990 m of northward overthrusting during the Laramide orogeny (Geraghty, 1999). Since middle Eocene time, the Stillwater Complex has been subjected to erosion, uplift, glaciation, and minor faulting (Page, 1977).

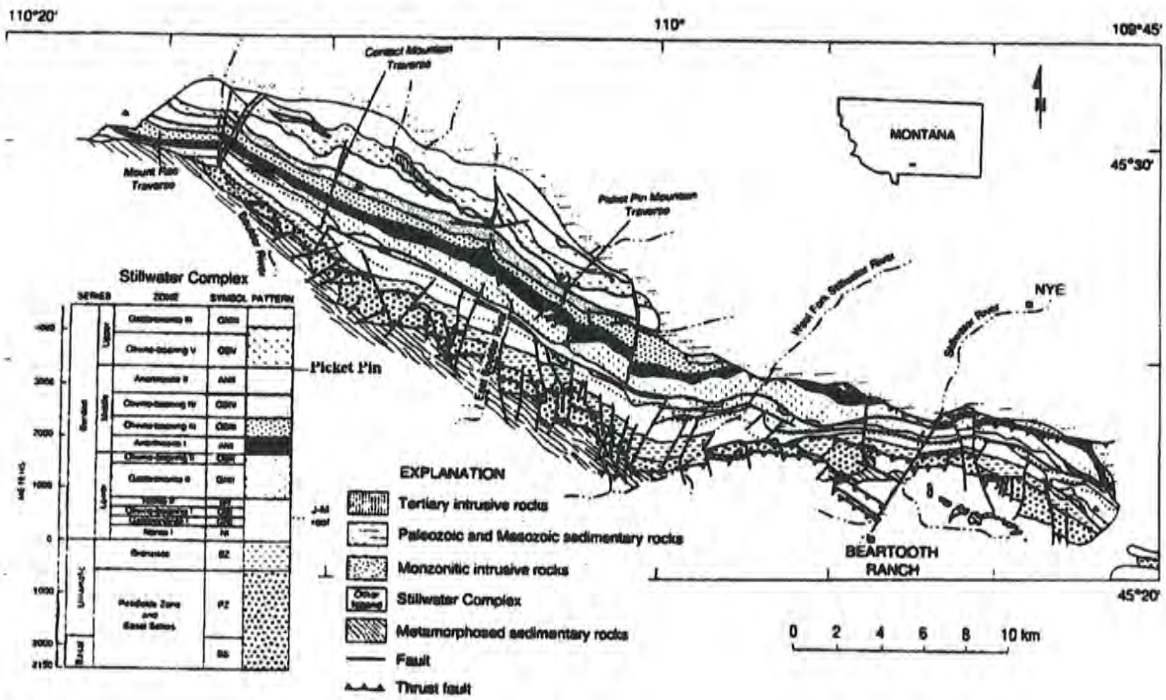

FIGURE 1
Geologic map of the Stillwater Complex and nomenclature, from Czamanske and Loferski (1996), modified after Zientek (1993).

Geology

Applying the nomenclature of McCallum et al. (1980), the Stillwater Complex has been divided into three main units: the Basal, Ultramafic, and Banded series (fig.1). The Basal series is laterally continuous and variable in thickness and locally up to more than 100 m thick. The unit is dominantly comprised of orthopyroxenites with subordinant underlying norites. Massive accumulations of base-metal sulfides, locally PGE-rich, occur throughout the Basal series. Sulfide occurrence increases downsection toward the basal contact, but locally. interrupted by reversals and discontinuities (Zientek et al., 1985). The Basal series is bound above by a sharp contact with the lowermost olivine cumulates of the Ultramafic series.

The Ultramafic series has been divided into two subunits: the lower Peridotite zone and the overlying Bronzitite zone. The lower Peridotite zone consists of cyclic poikilitic harzburgite (olivine cumulate) with locally PGE-enriched chromite, granular harzburgite (olivine-bronzite cumulate), that is overlain by bronzitite (bronzite cumulate). The number of cyclic units varies with strike length. Between 8 and 21 cyclic units have been recognized throughout the Peridotite zone (Zientek et al., 1985). The disappearance of cumulate olivine marks the sharp contact between the Peridotite and Bronzite zones. The Bronzitite zone consists of size-graded and laminar-bronzite cumulates. Local cumulus olivine and chromite occur in thin layers within the Bronzitite zone (Raedeke and McCallum, 1984).

The contact between the Ultramafic and Banded series is marked by the first occurrence of cumulate plagioclase. The plagioclase-rich cumulates of the Banded series are up to 4.5 km thick, and make up more than three fourths of the Stillwater Complex. The Banded series is divided into the Lower, Middle, and Upper Banded subseries and are further subdivided into twelve zones by cumulate mineralogy (fig. 1) (McCallum et al., 1980). The Lower Banded series is approximately 1,590 m thick and contains norites and gabbronorites with minor occurrences of anorthosite, pyroxenite, and troctolite. The An content of the plagioclases decreases upsection from An 82 to An 75, which may suggest fractional crystallization from a basaltic magma (Raedeke and McCallum, 1980). The Lower Banded series is host to the laterally continuous, PGE-rich JM Reef with a grade of 20-25 ppm Pd+Pt (Leroy, 1985). The upper boundary is located at the contact of the first thick anorthosite unit (AN I).

The Middle Banded series is approximately 1,750 m thick and contains the two thick anorthosite units, AN-I (350 m thick) and AN-II (570 m thick). AN-II is further divided into a basal coarse-grained anorthosite (~560 m thick) and overlain by a medium-grained anorthosite (~10 m thick) (Boudreau and McCallum, 1985). Situated between AN-I and AN-II are two olivine-bearing zones, OB-III (400 m) and OB-IV (430 m thick). The typical rock types found within the olivine-bearing units are troctolites, gabbros, and gabbronorites, with the exception of a 90-m anorthosite in OB-IV. Two major petrographic deviations occur within the Middle Banded series; 1.) The remainder of the complex is enriched in plagioclase (82 volume percent) over 60 volume percent expected from fractional crystallization, and 2.) The average An content remains consistent throughout the two thick anorthosite units at An 76, with the exception of the base of AN-I where it is An 80 (Raedeke and McCallum, 1980). Mineralogy of the two anorthosite units, AN-I and AN-II, consists of approximately 90 volume-percent plagioclase, intercumulate olivine, intercumulate augite and inverted pigeonite, with local intercumulate sulfides and oxides. Intercumulus sulfide and oxide mineralogy consists of magnetite, ilmenite, pyrrhotite, pentlandite, chalcopyrite, minor pyrite, and PGE's. Detailed petrography and mineralogy of AN-II is discussed below. The upper boundary of the Middle Banded series is marked by the reappearance of olivine, and is placed at the upper contact of AN-II with the overlying troctolite of the olivine-bearing zone V (OB-V).

The Upper Banded series is approximately 1,130 m thick and divided into two zones, the lower olivine-bearing zone (OB-V), and upper gabbronorite zone (Gabbronorite III). The lower OB-V (~95 m thick) is characterized by variable sequences of troctolites, anorthosites, norites, and gabbronorites. Gabbronorite III, approximately 1,035 m thick, is a uniform gabbronorite with cotectic proportions of plagioclase, augite, and low-Ca pyroxene. The An contents for the plagioclase in the Upper Banded series from bottom to top are from An 73 to An 62, which is consistent with the fractional crystallization model (Raedeke and McCallum, 1980). An unknown amount of the top of the Upper Banded series has been lost to erosion (Helz, 1995). Paleozoic sedimentary rocks unconformably overlie the upper contact.

Geologic setting of the Picket Pin PGE deposit

Howland and Peoples were the first to find PGE-bearing sulfides in the Banded series (Howland et al., 1936). They found two distinct sulfide-bearing horizons in the upper portion of the complex. The uppermost, containing anomalous PGE's, appears to describe the Picket Pin deposit (Boudreau and McCallum, 1985). The Picket Pin PGE deposit is approximately located at the contact between the coarse-grained and medium-grained anorthosites of AN-II (fig.2).

The Picket Pin deposit is a laterally continuous zone of PGE-bearing sulfide mineralization along the entire 22 km of exposed strike of the deposit. The deposit is located at the contact between the coarse-grained and medium-grained anorthosites of AN II within the Middle Banded series (fig.2). The sulfide distribution typically occurs as intermittent stratabound, podiform and lenticular concentrations of 1 to 5 percent sulfides occupying intercumulate grain boundaries of plagioclase within the upper 10 to 20 m of AN II. Mineralized pods range in diameter from centimeters to meters; the lenses attain a maximum thickness of approximately 1.5 meters, with a lateral extent of tens of meters (Boudreau and McCallum, 1985). Troctolites and anorthosites of OB V within the Upper Banded series overlie the Picket Pin deposit.

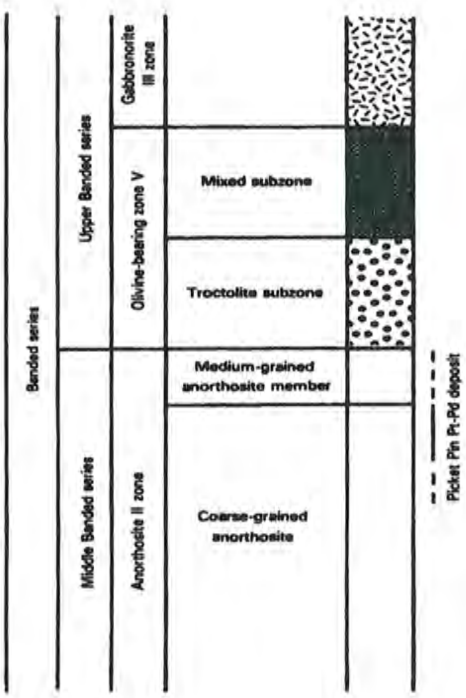

FIGURE 2. Picket Pin PGE deposit (from Boudreau and McCallum, 1985).

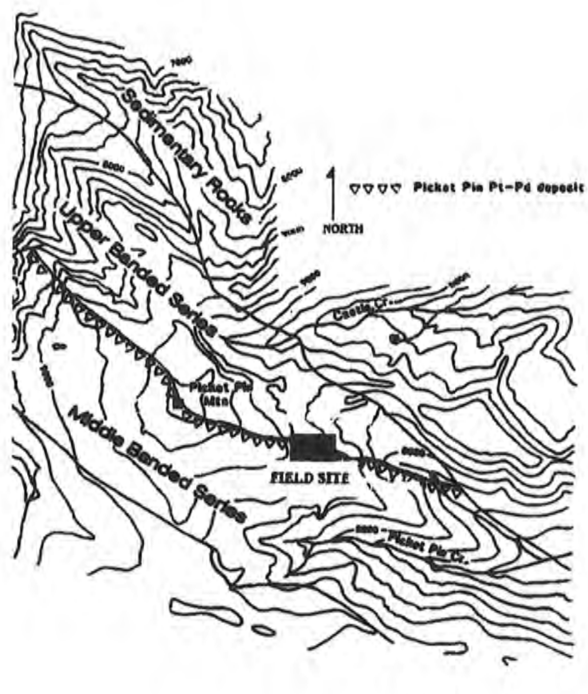

FIGURE 3 Location of study area from Boudreau and McCallum (1985).

STUDY AREA

The study area is accessed by traveling west from Limestone, Montana on U.S. Forest Service Road 140 (Picket Pin-Iron Mountain road). The Picket Pin deposit is crossed as the road levels off just south of the Picket Pin cirque. The contact between AN II and OB V (the Picket Pin deposit) strikes east down the drainage from this plateau. The study area is down the drainage and approximately 300 m due east from the plateau (fig 3).

Primary field investigations of AN II proximal to sulfide mineralization revealed intricately varying compositions on a scale of centimeters to tens of meters. A single outcrop with dimensions of 10 m by 25 m was selected for detailed petrographic and mineralogical analysis (fig. 4). Sample sites were located on a three-meter square grid to prevent bias. Initial field and petrographic analyses involved 35 representative samples of this outcrop. Polished thin sections were made from each sample.

Petrographic microscopy on all samples determined modal abundance of minerals and sulfide-oxide relationships. Prelimanary An content was determined using Energy Dispersive X-ray Spectroscopy (EDS). Modal analysis is divided by intercumulate mineralogy. Major mineralogy is discussed below and mapped in figure 6. Scanning Electron Microscopy (SEM), Backscattered Electron Imaging (BEI), and Energy Dispersive X-ray Spectroscopy (EDS) was

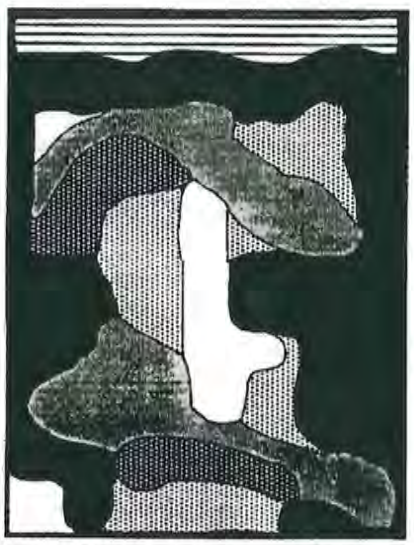

FIGURE 4. Compositional map of study area in plan view. Width of figure approximately 15 m.

- Troctolite of Upper Banded series
- 0-5% pyroxene
- 5-10% pyroxene
- 10-15% pyroxene
- 15-20% pyroxene
- Covered

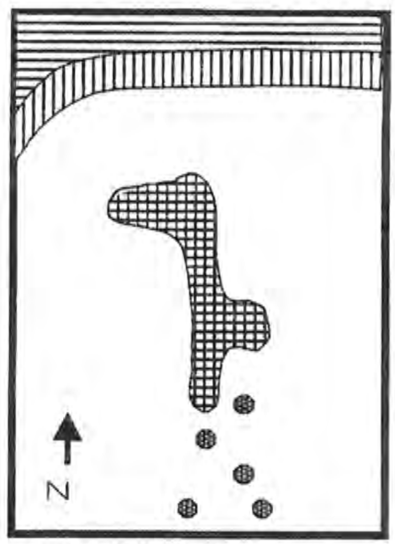

FIGURE 4b. Plan view of study area. Width of figure approximately 15 m.

- Troctolite of Upper Banded series
- Medium-grained anorthosite
- Coarse-grained anorthosite
- Sulfides
- Clinozoisite and epidote patches

performed at the Image and Chemical Analysis Laboratory (ICAL) at Montana State University, Bozeman. Rontgenanalysen-Technik (Rontec) software was used for spectral and elemental analysis, density imaging, and elemental mapping.

Anorthosite II

The division between the coarse-grained and medium-grained anorthosites of AN II is well-documented (Boudreau and McCallum, 1985). The pyroxene mode was not uniform within the basal coarse-grained anorthosite, and has recently been divided into ranges that fell within 0-5% relict pyroxene, 5-10%, 10-15%, and 15-20% (Haskin and Salpas, 1992). These further divisions are important in delineating the sulfide-bearing horizons, which occur in the 0-5% range. The modal divisions are also important in understanding the formational dynamics of AN II. Point counts were used to determine percentages. Below are the petrographic analyses of these divisions within the study area.

0-5% pyroxene:
This division consists of a framework of large (0.5-2 cm), lath-shaped plagioclase with an average of An 75. These large plagioclases are highly altered to clinozoisite and make up 60% of this rock type. Small (<0.5 cm), blocky plagioclase, also altered, makes up 20% of this group. The large to small plagioclase ratio is 1:2. Clinozoisite (15%) occurs as a replacement within the plagioclase and as an alteration zone surrounding the sulfides. The sulfides (5%) fill the intercumulate spaces. Relict pyroxene altered to chlorite occurs distal to the sulfides.

5-10% pyroxene:
Large plagioclase (0.5-2 cm) is slightly altered, and makes up 55% of this rock type. The small plagioclase (<0.5 cm) forms 30% of this group. The large to small plagioclase ratio is 1: 4. The pyroxene (5-10%) is highly altered and shows very little of its original composition. The pyroxene is completely replaced by chlorite, clinozoisite, and an unknown mineral. Clinozoisite (5%) replaces the plagioclase and forms at grain junctions. Minimal sulfides, and trace oxides are found within this group.

10-15% pyroxene:
Large plagioclases (50%) within this group are fresh with minor local alteration. The small plagioclases (35%) are likewise fresh with minor local alteration. The large to small plagioclase ratio is 1: 5.4. The pyroxene (inverted pigeonite, and augite) is altered to amphibole, with only trace amounts of relict pyroxene. Clinozoisite is a minor constituent (<1%) and occurs locally replacing the plagioclase or at grain boundaries. No sulfides are present within this group. Interstitial oxides, magnetite and ilmenite, occur locally and may be present up to 2%. Epidote is the common alteration surrounding the oxides.

15-20% pyroxene:
The large (50%) and small (30%) plagioclases are fresh and unaltered. Numerous grains show complex, diffuse zonation. The ratio of large to small plagioclases is 1:6.3. Pyroxenes in this group are a combination of both clinopyroxene and orthopyroxene with inclusions of olivine. The pyroxenes (inverted pigeonite and augite) are only locally altered to amphibole. No clinozoisite or sulfide mineralization is visible in thin section. Oxides, magnetite and ilmenite, are present in trace amounts.

Sulfides

Most of the sulfide mineralization of the Picket Pin deposit occurs within the uppermost 20 m of AN II. Major accumulations of sulfides are found at and below the contact of the coarse-grained and medium-grained anorthosites of AN II (Boudreau and McCallum, 1985). Mineralization occurs as podiform and lenticular concentrations of 1 to 5% sulfides, occupying the intercumulate space between plagioclase grains. Mineralization in the study area is podiform and pipelike within the coarse-grained anorthosite of AN II. The podiform mineralization is transgressive in nature, with an approximate length of 20 m and width ranging from 1 to 1.5 m. The sulfide mineralogy consists of pyrrhotite ($Fe_{1-x}S$), chalcopyrite ($CuFeS_2$), pentlandite ($(Fe, Ni)_9S_8$), braggite ($(Pt, Pd)S$), and minor pyrite (FeS) in decreasing order of abundance. One grain of sperrylite (PtAs) was identified.

Clinozoisite, quartz, epidote, and apatite, in decreasing order of abundance, accompany the sulfide mineralization. Abundant clinozoisite with minor epidote enclose all sulfide grains. In the field, clinozoisite and epidote form 0.5 to 5 cm circular patches that lead from downsection upward to more abundant sulfide mineralization. Microscopic investigation of one such patch reveals a 1 mm central oxide grain surrounded by 0.5 mm envelope of epidote, which is further enclosed by 1 cm of clinozoisite. The structure of both plagioclase and pyroxene are obliterated. Only near the margin of the patch can relict plagioclase be inferred. The clinozoisite patches appear to be a good field indicator of high-grade sulfide mineralization. Interstitial quartz occurs locally and may form a halo surrounding the sulfides. Quartz may also be found as discrete anhedral secondary grains within the clinozoisite. The quartz appears to be more abundant proximal to the oxides. Minor apatite occurs in association with the quartz, and is likewise most abundant near the oxides.

The sulfides can be divided into two groups: Large (millimeter scale), blocky grains occupying most of the intercumulate space, and patches of numerous small (micron scale) grains. The large sulfide grains are mainly pyrrhotite with exsolution and zoning of pentlandite (figures 5 & 6). The patches of small sulfide grains are commonly chalcopyrite and braggite. Analysis with SEM and EDS has revealed segregation between pyrrhotite, pentlandite, chalcopyrite, and the PGE-bearing sulfides. Pentlandite occurs as blade-like inclusions within the pyrrhotite (fig. 5), or is segregated to the perimeter of the pyrrhotite (fig. 6). Chalcopyrite is commonly present as small (<0.25 mm) isolated grains and is segregated to the perimeter of both pyrrhotite and pentlandite. Discrete PGE-bearing sulfides occur as isolated 25-micron grains (fig. 7), and occur close to chalcopyrite. The PGE-bearing sulfides appear to overlap the chalcopyrite stability field and extend further towards an oxidizing condition. Trace amounts of PGE's also appear throughout pyrrhotite and pentlandite grains.

Oxides

Intercumulate ilmenite and magnetite occur distal to sulfide mineralization, within the 5-10% pyroxene zones of AN II. Manganese and vanadium are commonly associated with ilmenite (fig. 8). As mentioned above, quartz and apatite are more abundant close to the oxides. Epidote with trace clinozoisite encloses all oxide grains. The importance of epidote versus clinozoisite and oxides versus PGE-bearing sulfides is the higher oxidation state of epidote. This oxidation state may suggest that PGE-bearing sulfides require lower oxidation than the oxides to precipitate. No PGE-bearing sulfides are present near the oxides.

Plagioclase

The plagioclase can be divided into two groups: 1) Large (0.5-2 cm), lath-shaped grains, and 2) Small (<0.5 cm), blocky grains (fig.9). The large grains have been referred to as 'framework' plagioclase (Haskin and Salpas, 1992). These large framework grains are interpreted to be original cumulate minerals. The small plagioclase grains occupy the space between the large grains, and are interpreted as intercumulate plagioclase (Haskin and Salpas, 1992). The ratio of large to small plagioclase increases towards mineralization, and is highest in the mineralized samples. Thus, mineralization is concentrated in the coarser-grained plagioclase. Odd erosional textures are apparent within the small plagioclase. These erosional textures appear to be either more abundant or more prominent proximal to mineralization. Both large and small plagioclase exhibits diffuse zoning. Zoning patterns are difficult to identify microscopically, but appear to be either oscillatory or reverse. This zoning appears to be randomly distributed from sample to sample.

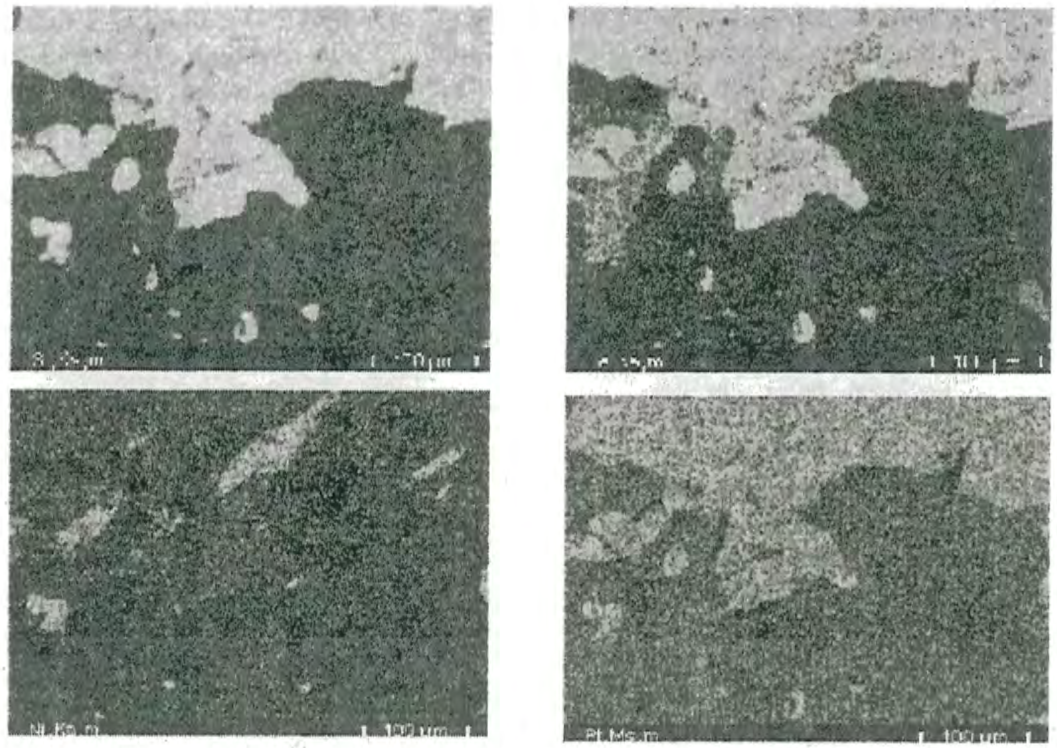

Figure 5. Elemental photomicrographs of a typical large sulfide grain. The lower left photograph shows blade-like inclusions of pentlandite within pyrrhotite suggestive of original exsolution textures. Note trace amounts of Pt within the sulfide grain.

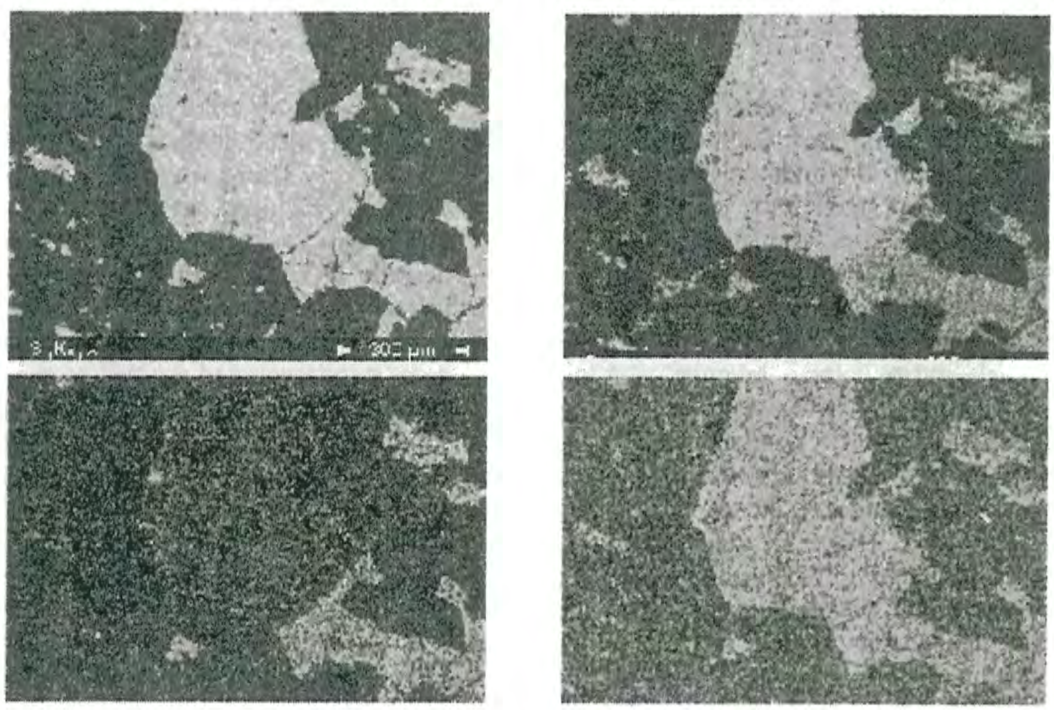

Figure 6. Elemental photomicrographs of a typical large sulfide grain showing compositional zoning of pyrrhotite ($Fe_{1-x}S$) and pentlandite ($(Fe, Ni)_9S_8$). Note the isolated Pt grain (right side center) on the lower right photograph. This Pt grain is typical of the Picket Pin deposit. The surrounding material is mostly clinozoisite with minor epidote.

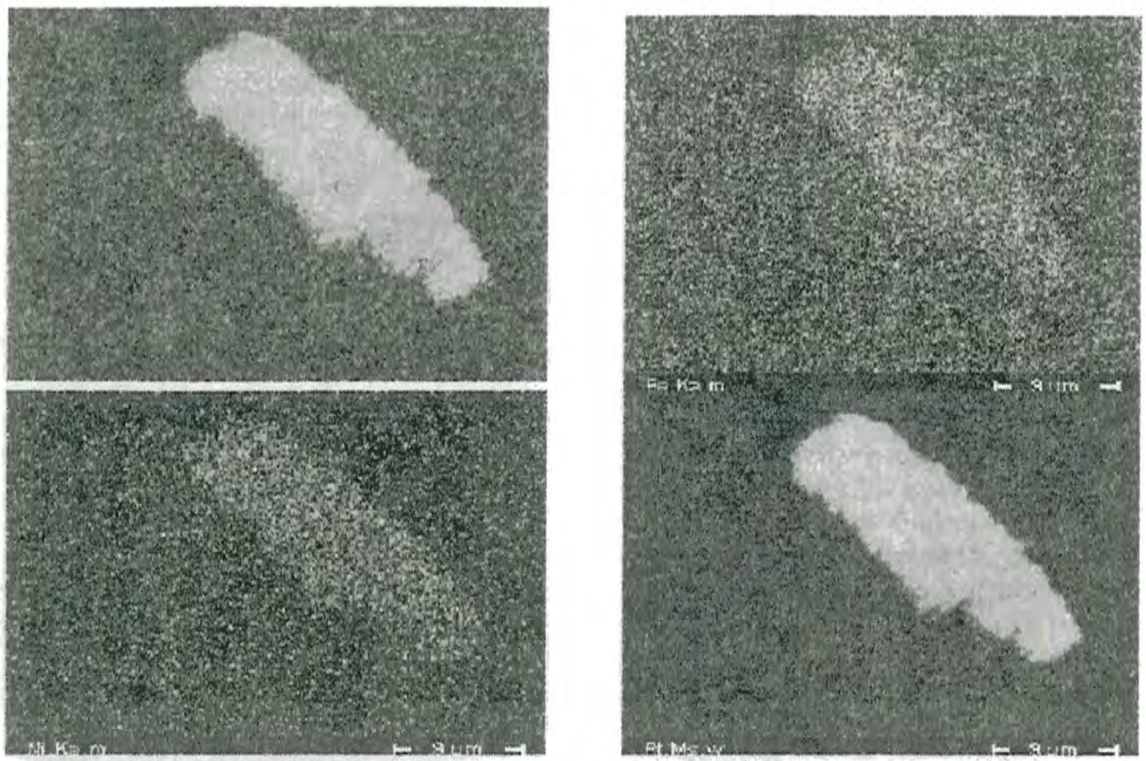

Figure 7. Elemental photomicrographs of and isolated bragite ((Pt, Pd)S) grain typical of the Picket Pin deposit. The Surrounding material is mostly clinozoisite with minor quartz.

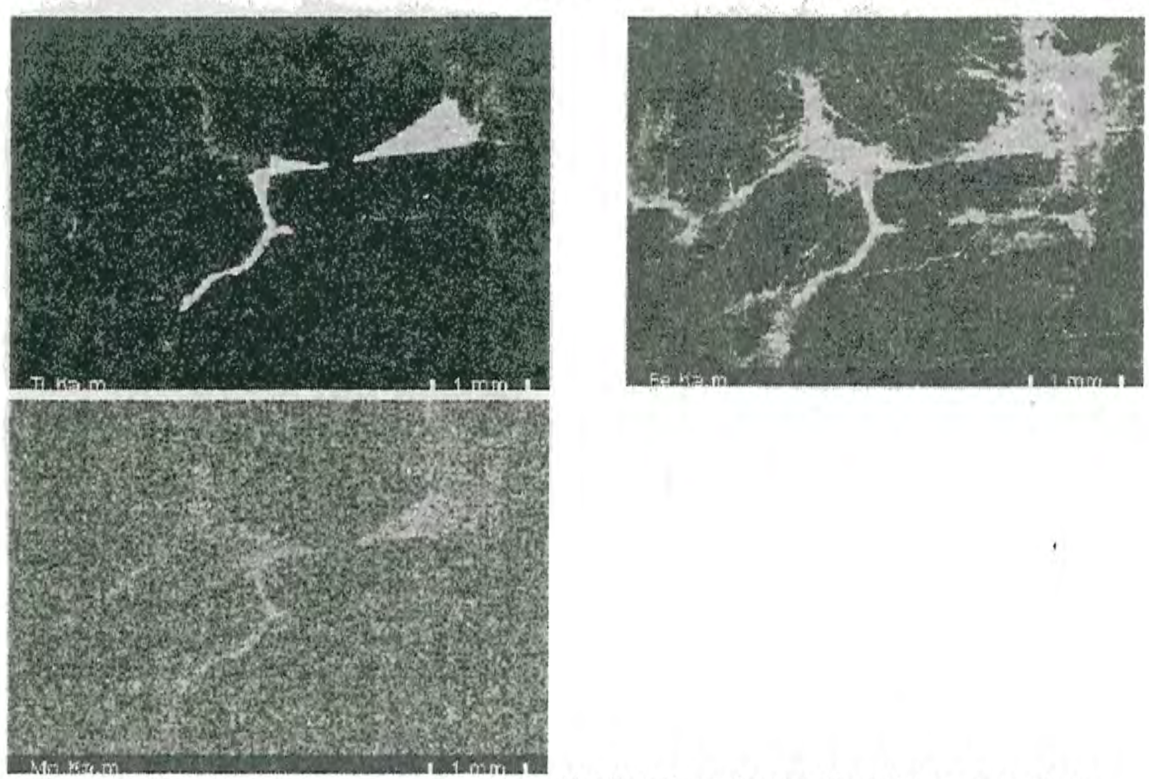

Figure 8. Elemental photomicrographs of the oxides ilmenite and magnetite with trace amounts os manganese.

Pyroxene

The pyroxenes of the 15-20% group are discrete intercumulate augite grains and orthopyroxene formed by the inversion from pigeonite (inverted pigeonite, Hess, 1960). The augite is enclosed in orthopyroxene, and the orthopyroxene contain exsolution lamellae of augite typical of Stillwater-type orthopyroxenes. The pyroxene of the 10-15% group has been altered to amphibole and only relict orthopyroxenes remain. Plagioclases within this group show more erosional textures. No augite is apparent within the 10-15% group. The alteration continues in the 5-10% group where amphibole is altered to chlorite. Only relict textures of the original pyroxenes remain in the strongly altered minerals. The original pyroxenes are completely replaced by chlorite in the sulfide bearing, 0-5% group.

Discussion

Assuming the sulfides have not been remobilized, interpretations of the ore-forming conditions and timing of mineralization can be made for the deposit. Sulfide mineralization was post-magmatic as suggested by the pyroxene alteration halo. Mineralization preferentially occurred where the pyroxene content was below 5 modal percent and where the large-plagioclase ratio was greatest, hence more coarsely grained. This may be attributed to more numerous grain-to-grain contacts creating greater surface area for alteration-fluid contact. Sulfide mineralization is also accompanied by clinozoisite and epidote, which can be used to constrain the temperature and oxidation state of the ore-bearing fluid. The intimate relationship between clinozoisite and the sulfides, if contemporaneous, may suggest a precipitation temperature for the sulfides between 500-550°C. The relationship between clinozoisite and the sulfides, and epidote with the oxides, suggests precipitation of the PGE-sulfides require a neutral to slightly reduced environment. This is further supported by the close relationship between PGE-sulfides and chalcopyrite.

Continuing Work

To test the above preliminary interpretations, a separate outcrop of similar dimensions will be studied during the 2001 field season. It should be noted that both outcrops are statistically insignificant when compared to the approximately 11 km^2 of AN II. This study should be used in the framework of previous work.

ACKNOWLEDGMENTS

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Field Trips

DISPERSAL OF METALS IN SURFACE ENVIRONMENTS WITHIN AND DOWNSTREAM FROM THE COEUR D'ALENE MINING DISTRICT, IDAHO: A FIELD TRIP GUIDE

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INTRODUCTION

The Coeur d'Alene mining district has produced over 130 million (metric) tons of ore from which about 34,000 tons of silver, 7.3 million tons of lead, and 2.9 million tons of zinc have been recovered since 1886 (Long, 1998). The district is the world's largest producer of silver, and one of the nation's largest producers of lead and zinc. The ore was produced from many steeply dipping vein deposits scattered over a 40 x 15 km area, primarily in the drainage of the South Fork of the Coeur d'Alene River (figure 1).

Prior to 1968, approximately 56 million tons of mill tailings, generated at ore-concentration mills, were discarded to the adjacent streams. Stream runoff and flooding resulted in wide dispersal of the ore metals within and down-valley from the mining district. Reworking of this metal-enriched sediment continues today. Weathering of the primary ore minerals in the oxidizing surface environment has resulted in a complex distribution of derivative metallic materials in the drainage basin. High concentrations of dissolved zinc and cadmium in surface waters have serious impact on the aquatic biota in parts of the drainage basin. High concentrations of relatively extractable lead in derivative stream sediments and floodplain soils present a hazard to animals (including humans) exposed to these materials, which they may ingest or inhale.

This field trip begins at the uppermost mill site on Canyon Creek, a major tributary to the South Fork of the Coeur d'Alene River, and proceeds to six additional field stops downstream along Canyon Creek, the South Fork and the main stem of the Coeur d'Alene River for about 70 km along the path of the dispersed metals.

ROAD LOG

The field trip begins at the bottom of the eastern Wallace off-ramp from Interstate Highway 90. Proceed north up Canyon Creek Road (Idaho State Highway 4) 8.0 miles to the junction of Gorge Gulch and Canyon Creek, at the east end of the town of Burke, Idaho. This is Stop 1 and the trip mileage begins here at 0.0.

Mile 0.0 ----- Stop 1. The former mining/milling town of Burke, Idaho:

We are looking downstream (west) along Canyon Creek from the confluence of Gorge Gulch (entering from the north) across the mostly abandoned town-site of Burke. We are very near the site of the 3 original claims filed in May of 1884 in what was to become the Coeur d'Alene mining district: the Tiger (on the north side of the valley), the Poorman (on the south side of the valley), and the Ore-or-no-go (later the Hecla, its headframe visible downstream on south side) claims. The Hercules claim, up Gorge Gulch, was staked in 1900, and was the last major outcropping deposit discovered in the district. The cribbing west of the mouth of Gorge Gulch holds up a mine waste platform in front of the main haulage portal to the Hercules mine. These are the furthest upstream major mining developments on Canyon Creek, and this juncture separates the relatively un-impacted channel of Canyon Creek upstream from major physical and chemical impacts to Canyon Creek downstream. The history of milling and tailings disposal at Burke reflects their general history throughout the district, and discussion of some of their details is relevant to the dispersal of metals in and downstream of the Coeur d'Alene mining district.

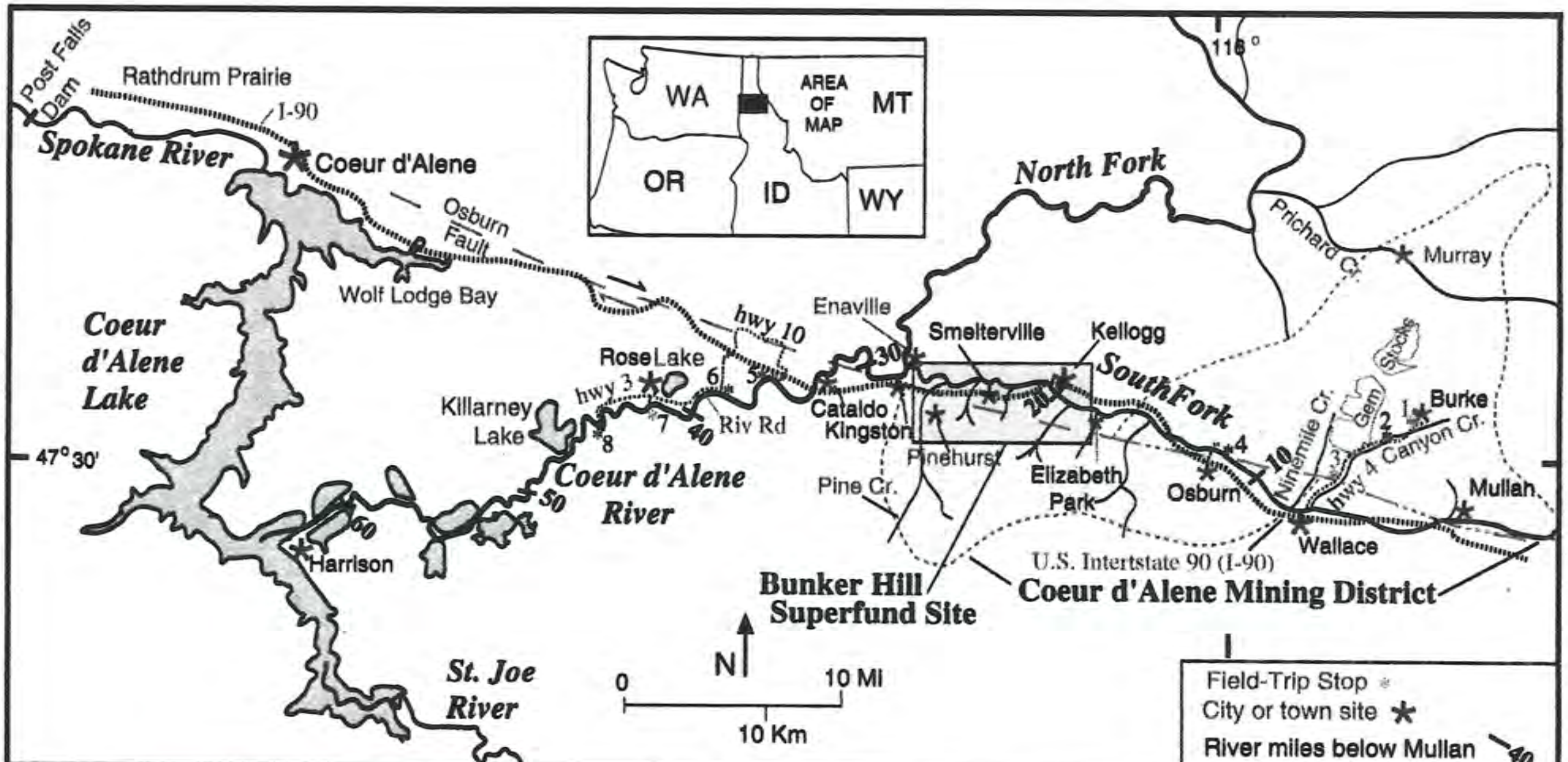

Figure 1. Index and location maps, showing selected features of the Coeur d'Alene (CdA) mining district, the Bunker Hill Superfund Site, the South and North Forks, the CdA River and its lateral lakes, the lower St. Joe River, CdA Lake, and the upper Spokane River.

In the relatively narrow valley just downstream, the Tiger and Poorman ore concentration mills were constructed by 1888, processing a total of 400 tons of ore per day. In the "jig" mill, ore was coarsely crushed to less than one inch diameter, sorted into several size fractions, and passed through a variety of devices (jigs, shaker tables, vanners and buddles) to concentrate the particles with higher specific gravity. Recovery of metal values from the ore by gravity concentration was relatively inefficient, varying from 50-90% throughout the district. Concentration ratios in mills also varied, with a typical range from 5:1 to 10:1 (that is, for every 5 tons of ore, 1 ton of concentrate and 4 tons of tailings were produced by the mill). Concentrates were shipped by rail to the smelter, leaving a large mass of "jig" tailings. The lack of nearby flat land on which to dispose the tailings led to the general practice of disposal of tailings into or adjacent to the nearest stream. In the case of the Tiger and Poorman mills in 1888, about 320 tons of tailings, generally containing several percent each of Pb and Zn, were discarded into the creek daily. During low-flow periods the coarse fraction of the tailings would accumulate in the stream channel near the mill, to be flushed downstream during the next high-flow episode. In some cases the coarser tailings fraction was given or sold to the rail companies for use in construction of railroad beds and roadbeds throughout the district. Tailings disposal was a limiting issue for mill location, and many mines (including the Hercules and the Hecla mines here) opted for constructing their mills further downstream where the streams had sufficient year-round flow to remove tailings from in front of the mill.

The Tiger and Poorman mills consolidated into one larger mill in 1896, which continued to operate until the Tiger and Poorman ore bodies were exhausted in 1908. The Hercules mill was erected up Gorge Gulch in 1906, but it burned in 1909. Hercules ore was processed at the former Tiger-Poorman mill from 1909 to 1911, when the Hercules mill at Wallace was completed (Mile 8.2). By the time of the dismantling of the Tiger-Poorman mill in 1912, over one million tons of jig tailings had been flumed into Canyon Creek at this location.

No mill operated at Burke from 1911 to 1937, when the Star flotation mill (the tall concrete structure at the west end of Burke) was constructed. The flotation process, which gradually replaced gravity concentration in mills of the district between 1915 and 1925, required fine grinding of the ores (to fine sand size and finer) to allow concentration of the metallic sulfide minerals in froth atop agitated slurry of ground ore. Pb and Zn concentrations in flotation tailings were generally less than 0.5% each. From 1937 to 1968, the Star mill disposed of over 4 million tons of fine tailings (less than 0.2 mm in grain size) into Canyon Creek from within the tall concrete mill building. Beginning in 1959 the coarser sand fraction of the tailings (roughly 50% by weight) was separated from the tailings stream and returned to the mine as sand fill. Beginning in 1968, Federal law prohibited riverine disposal of tailings, thus requiring all active mines in the district to impound their tailings. From 1968 to closure in 1982, 2.8 million tons of tailings from the Star mill were piped 4 miles down-valley into unlined tailings ponds in a wide valley flat at Woodland Park (stop 3 on figure 1).

Metal enrichments in sediments, soils, ground- and surface waters result from mining and milling activities around Burke. Stream sediments two miles upstream from this point yielded background values of 32 ppm Pb and 48 ppm Zn (Box and others, 2001). Stream sediments 0.7 miles downstream show metal-enriched values of 2930 ppm Pb and 4000 ppm Zn. Concentrations of Pb and Zn in surface soil samples around Burke range up to 1 percent each, and concentrations of Pb and Zn 12 feet below ground surface near the Star mill range up to several percent each (EPA, 2001). Elevated dissolved Zn values (2-8 mg/L) are noted in groundwater wells around the Star mill (EPA, 2001). Adit drainage from the Hercules mine (Balistrieri and others, 1998; MFG, 1991) varies seasonally from 0.1 to 6.5 mg/L Zn during fall and spring sampling, respectively. Available data for the Star mine drainage (piped 4 miles down-valley to the Star #5 tailings pile) indicates dissolved Zn ranges from 1.1 to 1.4 mg/L in fall and spring sampling, respectively (MFG, 1991). Synoptic low-flow surface water sampling in the Fall of 1997 (EPA, 2001) showed an increase in dissolved Zn concentration from 39 to 119 micrograms per liter as the stream passes beneath the Star mill building, exceeding the chronic-illness water quality criteria for fish in that reach. Stream cobbles are visibly iron-stained below the Star mill building but not above. Fish surveys indicate viable fish populations in Canyon Creek upstream from Burke, but no live fish were observed downstream, except at the mouth of Canyon Creek, where it enters the South Fork (Stratus Consulting, Inc., 1999).

Return to cars and proceed downstream about 1 mile to gravel parking area on left side of road adjacent to milepost 7 in Canyon Creek.

Mile 1.0 ---- Stop 2. Stream bank stratigraphy near Milepost 7 in Canyon Creek: - From the gravel parking area, cross over the old railroad embankment and walk about 100 feet downstream to the edge of Canyon Creek. A low bench with scattered bricks and foundations held some of the mineworker houses in the town of Mace. Low cut-banks on the riverward face of the bench reveal a 60 cm red-stained silty gravel with downstream dipping foresets overlying a 4 cm black organic-rich clay that overlies a gray silty sand and unconsolidated cobble gravels. This stratigraphy is typical of the jig-tailings aggraded floodplain in the Coeur d'Alene mining district. The black clay represents forest litter deposits that capped the narrow floodplain prior to the onset of milling at the Tiger-Poorman complex. The red gravels were probably deposited during spring high-flow conditions during or soon after the period of active operation of the Tiger/Poorman mills (1888-1911). The large foresets and photos of a significant high-flow event in late May of 1912 suggest a possible depositional date. Although no samples have been analyzed at this location, Pb and Zn concentrations of similar jig-tailings-bearing sediment in Canyon Creek are typically several percent each.

This small remnant of tailings-bearing sediment accounts for only a tiny fraction of the more than 1 million tons of tailings released by the Tiger-Poorman mills (which would equate to perhaps half a million cubic yards of tailings volume). The narrow confined creek bed and its relatively steep gradient would allow transport of the mostly less-than-one-inch sized tailings during spring flows. As mentioned earlier, some of the coarsest fractions of the early tailings were transported away by the railroad to be used to shore up existing railroad or road embankments or to construct new ones either in or near the mining district.

The concrete dam just upstream provided water to a flume that carried water downstream along the south bank to other ore concentration mills, where the water was used to generate electricity for the mills, to slurry the ore through the crushing and concentration circuits in the mill, and finally to slurry the tailings to the adjacent stream.

Return to vehicles and continue downstream.

Mile 1.5 ---- The main portal of the Standard-Mammoth mine was located on the north side of the canyon here. The log cribbing of the mine portal area was removed in the mid-1990s, the adit closed, and the waste rock at the portal contoured and seeded with grass. The mine operated from 1890 to 1912, and the ore was shipped by rail from this portal down-valley to a mill-site on Canyon Creek just above its confluence with the South Fork (field-trip Mile 6.9). About 4.5 million tons of ore were mined from this ore body, the seventh largest in the Coeur d'Alene district.

Mile 2.1 ------ The main portal of the Tamarack-Custer mine is located just north of the highway bridge that crosses to the south side of Canyon Creek here. The Tamarack-Custer produced over 2.6 million tons of ore over an extended life from 1890 to 1959. From 1890 to 1916 the ore was concentrated at a gravity mill along Ninemile Creek, on the west side of the ridge. From 1917 to 1928 ore was trammed down-valley to the old Frisco mill, which was gradually converted to an all-flotation mill. From 1928 to 1940 ore was shipped by rail to the former Hercules flotation mill on the South Fork at Wallace. From 1940 to 1959 ore was processed at the Dorn flotation mill, constructed adjacent to the bridge we just crossed. During all this time tailings were primarily discarded into the creek or river that was adjacent to the concentration mill. Waste rock was piled into this huge pile near the mine portal, where it served as a platform for a number of company buildings that serviced the mine and mill.

In the last few years the state of Idaho has excavated a significant volume of tailings-bearing sediment from the stream channel and banks just downstream of the Tamarack mine area and between the former railroad embankment on the north side and the roadbed on the south side of the creek. This material was trucked a few miles down-valley to an unlined repository in Woodland Park, which we will see. A pool and drop structure has been engineered into the reconstructed channel. This remedial excavation area continues for next 0.8 miles along Canyon Creek.

Mile 2.7 ----- At the road bridge which crosses back to the north side of Canyon Creek, two mill sites are visible: the Black Bear gravity mill, against the hillside to the left, and the Frisco mill, on the hill-slope ahead of us on the south side of the stream. The Black Bear gravity mill had a relatively short early history (1888-1893) but later was rehabilitated as a flotation mill as part of Frisco mill operation.

The Frisco gravity mill began operation in 1890 and is perhaps most famous for having been destroyed by "giant powder" (dynamite) in July of 1892 by union miners frustrated by their inability to gain higher wages from the mine owners. The mill was immediately rebuilt as an 800 ton-per-day gravity mill, and operated through 1916. The mill was bought in 1917 to become the main Tamarack mill. It produced a mixture of jig and flotation tailings until its closure in 1928.

Mile 3.3 ------ The building to the left labeled "Hecla Assay Office" was part of the Hecla mill at Gem, which operated from 1889 to 1948. The Hecla mine at Burke shipped its ores 3 miles by rail from the mine portal at Burke to this mill. The Hecla ore bodies were the fourth largest in the district, producing over 7 million tons of ore. The mill operated primarily as a gravity concentration mill until about 1915, when flotation cells were added to treat the fine fraction of the ore. In 1925 the building mentioned above was constructed over the creek to house flotation cells, which treated the reground tailings from coarse jig concentration circuits, and the flotation tailings were released into the creek out the bottom of the building. In the last few years of its life, this mill was used to process jig-tailings-bearing sediment deposited in the channel and floodplain of the South Fork downstream near Osburn, and the fine flotation tailings from this operation were poured back into the river.

The history of this mill reflects the general trend in the mills in the district. Flotation methods were first introduced to treat the fine fraction of the crushed ores between 1913 and 1917. Grinding circuits were gradually added into the early 1920's to re-grind middlings from the gravity concentration circuits to be processed by flotation. Then re-grinding of all the coarse tailings from gravity circuits was added in order to process those tailings by flotation. Finally, in the 1930s, the practice of gravity concentration was abandoned altogether, and all the ore was finely ground and run through flotation circuits. This resulted in a gradually increasing proportion of finer tailings in the river system between 1915 and 1930.

Mile 3.9 ------ The valley floor begins to widen here into Woodland Park and the stream gradient gradually decreases. Before 1930, the coarser tailings discarded into the channel of Canyon Creek from all the mills upstream would be flushed downstream to here during high-flow runoff. As the gradient decreases and the stream channel widens here, current velocities would decrease, and some of the tailings would settle to form bars of metal-enriched sediment. Aggradation and shallowing of the stream channel resulted in increasingly common over-bank flooding, and deposition of tailings-laden sediment across the floodplain. Ransome and Calkins (1908) describe the surface of Woodland Park in 1904 as "a barren waste of gray shingle (jig tailings) through which project the dead stumps of trees." The state of Idaho completed an extensive excavation of the tailings-contaminated floodplain materials here in 1996, transporting the material to the Woodland Park repository, which we will observe at the next stop.

Mile 4.4 ------Flotation tailings piles piped from the Star mill at Burke begin along the left side of the road here and continue for the next 1.1 miles. These piles were constructed between 1968 and 1982, and contain approximately 2.7 million tons of tailings in unlined impoundments. In the summer of 2001 the upstream most impoundment pond (Pond #1) is being capped with an impermeable cover to serve as a base for a small wetland treatment cell. The waters draining from the Gem portal will be piped to the artificial wetland to promote anoxic conditions in which metal sulfide precipitation should occur, reducing the dissolved metal content of the water to within water quality standards.

Mile 5.1 ------Turn left on Gray's Bridge Rd., continue 0.15 miles, and park along road just west of bridge.

Mile 5.25 --- **Stop 3. Overview of Woodland Park:** We are entering the widest part of Woodland Park. The 30-foot embankments to the west of us are the post-1968 Star tailings impoundments; the road carried us between cells #4 and #5. Water draining from the Star mine portal is piped 4 miles down-valley from Burke to the top of cell #6, where it is gradually lost to infiltration through the tailings pile. Looking up and down river, the effects of removal of the jig-tailings-contaminated floodplain soil and of the 10-foot high railroad embankment are evident. Over 300,000 cubic yards of metal-enriched soil (average metal content: Pb = 27,000 ppm; Zn = 7,000 ppm) was removed in 1995 and 1996 from the historic floodplain of Woodland Park by the State of Idaho, in cooperation with landowners Hecla Mining Co and the Bureau of Land Management. Most of the exposed metal-enriched floodplain soils were removed by this action, except for that material buried beneath the tailings impoundment structures between 1968 and 1981. An unlined repository was constructed (with a base of rounded river cobbles built up above the 100 year floodplain) to hold the excavated materials and is visible on the east side of Canyon Creek just downstream. An additional 100,000 cubic yards were added to the repository from the upstream excavations near the Frisco mill-site. Final closure of the repository is in progress.

One of the major goals of this remedial action was to reduce the loading of dissolved metals (particularly Zn) from this historic tailings depositional area into the creek. Two- to three-hundred pounds of Zn per day were loaded to Canyon Creek in Woodland Park during low water in December 1997 (EPA, 2001), accounting for 10-15% of the total dissolved metal load in the South Fork at its mouth. This surface water loading in the Woodland Park reach results primarily from transfer of metal-enriched groundwater to the stream as the valley narrows. Loading of dissolved zinc into the groundwater is thought ultimately to be driven by oxidation of the ore mineral sphalerite (ZnS) in the sandy tailings-contaminated soils, and transfer of the released Zn ions by downward percolation of precipitation and snowmelt to the underlying cobbly groundwater aquifer. High dissolved Zn concentrations in the groundwater prior to the excavations (10-100 mg/L) have not significantly decreased in the five years since completion of the excavation, nor has metal loading to Canyon Creek from Woodland Park significantly decreased. We infer that a significant mass of Zn has been precipitated or sorbed along the interstitial spaces within the aquifer matrix, and that fluctuating chemical conditions (redox, acid-base) within the aquifer continue to re-mobilize Zn ions from those precipitation/sorption sites within the aquifer matrix and are maintaining the Zn loading to the groundwater. Paulson and others (1996) showed that rainwater can leach a significant amount of Zn from aquifer gravels of Woodland Park. However some portion of the loading may be still be caused by downward leaching of Zn from remaining remnants of jig-tailings-contaminated soils in the excavated areas. Another remaining groundwater loading source may be driven by impounded water on the Star tailings ponds, where piped-in Star mine drainage is allowed to pond on and percolate through the impoundments and their underlying

jig-tailings-contaminated soil.
Return to junction of Gray's Bridge Rd. and Highway 4 (odometer now reads 5.4).

Mile 6.2 ------ Road from community of Woodland Park joins on right. To the left (east) of the road, groundwater springs emerge onto the floodplain surface as the valley aquifer narrows. In 1907 a low tailings dam was constructed across the valley here between the roadbed and the east valley wall to pool the creek and contain coarse tailings. Operators of mines upstream constructed the tailings dam after complaints that the stream-borne tailings were aggrading the South Fork channel, causing increasing flood heights at the town of Wallace. The impoundment quickly filled with coarse tailings. In 1917 a flood washed out the dam, and it was not repaired.

Mile 6.9 ------ Site of Standard and Mammoth gravity mills (1895-1917) east of Canyon Creek. These mills processed about 4.5 million tons of ore from the two mines, and all the jig tailings were either flumed to the creek or loaded into railcars for use in road or railroad bed construction.

Mile 7.2 –Turn right onto westbound on-ramp of Interstate 90 (labeled "Coeur d'Alene").

Mile 7.7 ------Ninemile Creek enters the South Fork valley from the right. Several Pb-Zn mines and mills (Black Cloud, Dayrock, Success, Tamarack-Custer, Rex, Interstate-Callahan) operated in the drainage beginning in the 1890's up to 1974, producing a few million tons of tailings, either impounded into repositories or flumed to the creek. Some of the highest dissolved zinc concentrations in stream waters in the district are found in the East Fork of Ninemile Creek.

Mile 8.2 ------ Foundations of Hercules mill-site (1911-1942). Trains carried Pb-Zn ore from the Hercules mine portal at Mile 0.0 of field trip to the Hercules mill-site. The mill began as a gravity "jig" mill and gradually converted to all flotation processing by the late 1920's. Over 2 million tons of mostly fine tailings went into river here.

Mile 9.3 ------ Lake Creek enters South Fork valley from south (left). The presently operating Galena mine and mill are located a few miles up the creek. The Galena mine and mill have operated intermittently since 1926. Although the early operation mined a galena-rich vein, the main ore body proved to be dominated by silver-rich tetrahedrite, with very minor lead and zinc. These silver-rich ore bodies, poor in Pb and Zn, are distinct from the typical Pb-Zn-Ag ore bodies of the district and are characteristic of the geographically restricted "Silver Belt", which runs along the south side of the South Fork valley between here and the Sunshine mine on Big Creek, 6 miles to the west. The Galena mill released its tailings into Lake Creek until about 1965, at which time tailings impoundments were constructed along Lake Creek. In the early 1970's the mill began its present practice of piping its tailings to the large impoundment in the South Fork valley north of Osburn.

Mile 10.6 ------ Osburn city limit. Across the river to the north is the presently active tailings pile for the Galena mill tailings. The pile was initially constructed on its east end in 1972. It was expanded to roughly its present footprint in 1979, at which time the river channel was moved to its present rip-rapped alignment.

Mile 11.0 ------ Coeur mine portal area and its large waste-rock pile are visible to the south of highway one-half up Shields Gulch.

Mile 11.9 ----- Turn off on Exit 57 ("Osburn");

Mile 12.2 ---- Junction of highway off-ramp and Twomile Rd. Turn right, cross bridge over South Fork and turn right onto Nuckols Gulch Road. At 0.2 miles from off-ramp the road skirts a rocky outcrop that served as the northern anchor of a post-and-plank tailings dam that extended to the southeast. Pull off road into open area on left at 0.5 mile from hwy off-ramp.

Figure 2. Oblique aerial view looking west down the South Fork Valley at Osburn at 10 AM on December 23, 1933 during the peak flow of a major flood event. A remnant of the 1901 tailings dam across the South Fork is visible in the upper central part of the photo (just above "A"). The abandoned 1901 channel ("B") on the lower left side of the photo is carrying some water during this flood. The presence of roads cut across the network of anastamosing floodplain channels (above "C") indicates that this former floodplain surface was not inundated during the 1933 flood.

Mile 12.7 ---- Stop 4. Osburn Flats historic tailings deposition area: This wide valley area is Osburn Flats, and its 100-year history gives some indication of the complexity of the dispersal of metal-rich materials within the populated areas of the mining district. The town of Osburn is mostly built on a low glacial outwash terrace slightly above active floodplain level. In the 1890's, as more and more tailings debris was dumped into the South Fork and its tributaries upstream, sand and gravel tailings bars began to clog the South Fork, such that even moderate spring runoff would cause the river to overtop its banks and spread over the floodplain. Floodplain deposition of tailings killed the riparian vegetation, creating a gray, bleak landscape along the river. Complaints and lawsuits by communities within the district and by farmers downstream of the district led the mining companies in 1904 to build a low tailings dam (about 6 feet above bank level) across the river just downstream from here to try to keep the coarse tailings from continuing downstream. At this time the river channel was south of the large gravel pile visible south of the freeway. The tailings reservoir quickly filled with fine to coarse tailings, and then a major flood in 1917 tore the wooden dam away. The river re-established its course on the north side of the valley near its present course. The reddish brown material at our feet is representative of floodplain tailings deposited behind the dam. The gradual elimination of coarse tailings dumping by area mills between about 1912 and 1930 allowed the river to erode downward, and become increasingly incised below its aggraded base level, leaving behind floodplain terraces with several feet of aggraded tailings-contaminated materials that remained above active flood level. An oblique air photo taken looking down-valley over Osburn during a 100-year flood in December 1933 (figure 2) shows the river remaining in a wide braided channel without overtopping its banks. Essentially all of the early floodplains in the mining district from Wallace to the confluence with Pine Creek also experienced aggradation prior to the 1920's, and were left high and dry as the river re-incised itself after the mills quit sluicing coarse tailings to the river. The jig-tailings-bearing sediment still exposed at the surface of these early floodplains (as it is at this stop) can have Pb concentrations in the 1-5 percent range, whereas Zn concentrations typically are below one percent. Oxidation has weathered away most of original sulfide carriers of the Pb and Zn. Most of the Pb remains in place in secondary minerals (primarily in association with Fe- and Mn- oxy-hydroxides). Much of the Zn leaches into groundwater, but some also remains sorbed onto Fe- and Mn- oxy-hydroxides.

The large gravel pile south of the freeway is the remains of major streamside tailings reprocessing plant that operated at that site in the 1940's, reprocessing about 4 million tons of material to extract zinc and other metals from the early tailings trapped in the channel and on the floodplains behind the tailings dam. The fine fraction was sieved from the cobble fraction, leaving the large cobble fraction behind. The fine fraction was processed through a "sink-and-float" plant to float out woody debris and lighter secondary oxide minerals. The remaining heavy fraction was shipped to the Galena, Gem or Polaris mills for flotation processing. The flotation concentration process was only effective on metal sulfides, and surficial weathering caused oxidation of the sulfides. Therefore, the favored material for re-processing was relatively un-oxidized stream sediment, which had been maintained in a reducing environment at or below the water table since deposition.

In the 1960's Interstate Highway I-90 was constructed through the South Fork valley. The freeway embankment (visible across the river) buried parts of the jig-aggraded floodplain with a variety of fill materials, including tailings excavated from the Bunker Hill tailings pile. In the early 1970's the Coeur and Galena mines constructed the large tailings repository (visible upstream), which they expanded in the late 1970's and still use today. In 1997 and 1998, the state of Idaho excavated tailings metal-enriched floodplain sediment from the south side of Nuckols Gulch road here, placing the excavated materials atop the south end of the Coeur-Galena tailings pile.

Despite the long history of excavation of tailings-bearing floodplain sediment in Osburn Flats, significant dissolved metal loading still occurs through the Osburn Flats reach (200 to300 lbs. of Zn per day during low water in December, 1997: EPA, 2001). This accounts for 10-15% of the dissolved metal load to the South Fork at its mouth.

Return to cars and return to westbound onramp (odometer reads 13.3) and proceed west on I-90.

Mile 14.3 ---- The Polaris mill-site (later the ConSil mill-site) is visible on the left at the foot of the hill on the south side of the valley. The adjacent mine accesses a number of major silver-rich deposits in the Silver Belt. The mill processed ore from those deposits from about 1936 to 1969. The mill also was used in the 1940's to process floodplain jig tailings excavated at Osburn.

Mile 16.0 ---- Big Creek enters the South Fork valley from the south. The recently closed Sunshine mine, which was(the largest silver-producing mine in the world, is located about 1 mile upstream. The mine operated from the 1920's until early 2001, when chronically low silver prices finally led to closure of the deep mine. The front of two large tailings piles, used to impound tailings since 1968, are visible from the freeway. Prior to 1968, tailings were flumed to Big Creek and the South Fork.

Mile 18.0 ---- Entering the east end of the 7-mile long, 3-mile wide Bunker Hill Superfund site, established in 1986.

Mile 19.5 ---- Milo Creek enters the South Fork valley from the south. The discovery outcrop and original workings of the Bunker Hill mine, the largest mine in the Coeur d'Alene district, are located a few miles upstream.

Mile 20.2 ---- The portal of the Kellogg Tunnel of the Bunker Hill mine is on the south side of the valley, near the metal-sided buildings at the base of the red-brown stained hillside. The two-mile long tunnel, completed around 1900, was driven to access the Bunker Hill workings from below, and provides haulage to the mill-site, which is in front of the portal. Unlike most of the mines in the district, drainage from the Kellogg tunnel is very acidic (<3.0) and extremely metal-enriched. A water treatment plant, constructed in 1974, has operated since then to significantly decrease loading of dissolved metals, especially Zn, to the South Fork and the main stem of the Coeur d'Alene River.

Mile 20.8 ---- The terrace along the south (left) side of the freeway for the next 1.3 miles is the tailings impoundment for the Bunker Hill mill (1926-1981). From the 1890s to 1926 coarse jig tailings were flumed to unconfined piles in this part of the floodplain. In 1926 the jig tailings were re-graded to form dikes around settling ponds for flotation tailings. The 100-yr flood of December 1933 severely eroded the Bunker Hill tailings impoundment, which was repaired, and continued to receive substantial quantities of tailings into the 1970s. The Bunker Hill tailings are now (in the summer of 2001) being re-graded and capped with a 3-layer cap, consisting of 1 foot of sandy smelter slag, an impermeable fabric, and a 1- to 2-foot top layer of uncontaminated soil. These remedial actions are intended to reduce seepage of surface precipitation through the pile and loading of leached metals into the underlying groundwater and ultimately to the adjacent South Fork.

Mile 21.7 ---- The dip in the guardrail on north side of highway marks the general location of major metal-charged springs emanating from the base of the tailings pile and under the highway embankment, causing repeated settling of the embankment here. These springs are a major source of metal loading to the river (several hundred pounds of Zn per day at low water). It is hoped that capping of the tailings pile will reduce the flow of these springs and their resultant metal loading to the river.

Mile 22.1 ---- The re-contoured hillside across the open area to the south is the former site of the Bunker Hill smelter (1917-1981), which was demolished over the last 6 years. The flat area between the hillside and the freeway was the site of a large pile of black, sandy slag, the glassy non-economic remains of the melting of the ore concentrates in the smelter. The granular character of the material and the low extractability of its contained metals made it a favorable material for smoothing the top of both the tailings pile to the east and the smelter footprint to the south, which were then overlain by impermeable plastic liners.

Mile 23.7 ---- The low terrace to the south here is the former tailings pond (1927-1969) of the Page mine and mill, located about one mile to the south. The top of the unlined tailings pile now supports sewage treatment ponds for the town of Kellogg. A large area on both sides of the freeway from the Smelterville exit to the Pinehurst exit ("Smelterville Flats") was the site of a major floodplain tailings excavation by the EPA in 1998. Over 2 million cubic yards of tailings-contaminated floodplain soil (averaging 2-4 feet thick, with several percent of Pb and less than one percent of Zn) were excavated and transported onto the top of the Bunker Hill tailings pile. A layer of clean soil from the Rathdrum Prairie near Coeur d'Alene was spread over the excavated surface. As in the Woodland Park floodplain soil removal, little change in groundwater metal concentrations around the excavated area is evident as of 2001

(USEPA, 2001). About one-half of the total dissolved Zn load to the South Fork (about 1000 lbs of Zn per day at low water) is contributed in the Kellogg-Smelterville Flats area.

Mile 24.8 ---- A short remnant of the low tailings dam constructed in 1902 at west end of Smelterville Flats (and breached by flooding in 1917) is preserved on the north bank of the river here.

Mile 25.2 ---- Pine Creek enters the South Fork from the south. Several major mines operated in the Pine Creek drainage from about 1920 to the 1960's. Although many of the flotation mills constructed small impoundments for their generated tailings, most of these piles were heavily eroded in subsequent floods. Since the major floods of 1996, a number of small tailings piles were removed (and transported to the Bunker Hill tailings pile) or were consolidated on more-protected sites, and capped. Pine Creek contributes relatively minor loads of dissolved metals to the South Fork, along with sediment that is relatively low in Pb and Zn.

Mile 27.8 ---- I-90 passes the village of Kingston on the main stem Coeur d'Alene River, below the confluence of the South Fork with the 3- to 4-times larger North Fork. Kingston was flooded by high water bearing metal-enriched sediment in 1974 and again in 1996.

Mile 30.6 ---- I-90 crosses a bridge over the Coeur d'Alene River below the village of Cataldo, which was flooded in 1974 and 1996 despite an artificial levee built after the 1933 flood. The river gradient decreases sharply to nearly zero about one-half mile downstream, the upstream extent of the summer backwaters of Lake Coeur d'Alene.

Mile 31.5 ---- At the Cataldo mission exit (#39), diverge to the right, then turn left, cross the I-90 overpass, turn right, and follow an access road 0.9 miles past Cataldo Mission (yellow building on hill) to Cataldo boat launch. Gather around picnic tables near the boat launch.

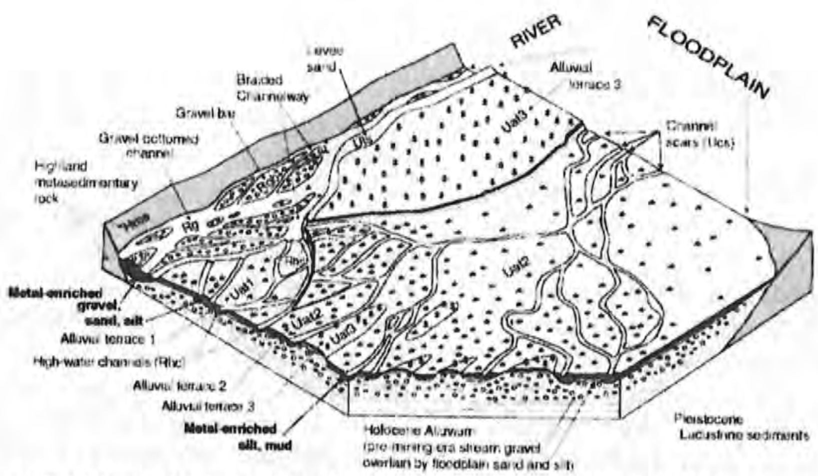

Figure 3. Schematic block diagram, showing features typical of the braided, gravel-bottomed CdA River and alluvial terraces of its floodplain, between the confluence and Cataldo Landing (modified from Williams and Rust, 1969). The alluvial terraces are in the active floodplain, and are blanketed by metal-enriched sediment. On steep faces, thickness of the layer of metal-enriched sediment is represented in dark gray. For full explanation of map symbols, see Bookstrom and others (1999).

Mile 32.4 ---- Stop 5. Cataldo Landing: Upstream from Cataldo Landing, the Upper Perennial Subsystem of the Coeur d'Alene (CdA) River is characterized by relatively steep gradients, swift currents, a cobble-gravel bottom, relatively non-cohesive banks, and a braided channel. Mining-derived metals are preferentially concentrated in relatively fine-grained particles, so concentrations of river gravel are relatively low, compared to metal concentrations of fine-grained fractions of gravel, and sandy to muddy floodplain sediments. The braided gravel channel-way is bounded by remnants of up to four progressively higher and older alluvial benches, all of which lie within the 100-year floodplain. Overflow channels and channel scars braid across some alluvial terraces, leading to marshes and oxbow ponds, which drain back to the river. Metal-enriched sand and mud are present on most benches, but are thickest on the lower benches, especially near the river and in partly filled overflow channels. The floodplain is relatively narrow where the river is incised into Precambrian bedrock, but the floodplain is much wider where it follows an older valley that contains remnants of Miocene alluvial and lacustrine deposits (as at Kingston, and Cataldo Flats).

At Cataldo Landing the river gradient flattens, channel-bottom gravel gives way to metal-enriched sand, and the braided channel-way narrows to a single channel that meanders between pre-mining-era levees of cohesive silty clay, overlain by red-brown bank-wedge and back-levee deposits of oxidizing metal-enriched sand and silt (figure 4). Ranges of metal concentration and thickness of metal-enriched sediment generally decrease with increasing distance from the river (figure 5). Zn/Pb ratios of metal-enriched riverbank and levee sediment generally are less than 1, because Zn is leached relative to Pb in oxidizing environments with mildly acidic pH. By contrast Zn/Pb ratios of metal-enriched riverbed sediment generally are greater than 1, because Zn is concentrated relative to Pb in transitional to reducing environments with nearly neutral pH.

At Cataldo Landing, nearly vertical banks of red, iron-stained sediment are retreating by a combination of undercutting, collapse, and erosion. Large, undercut slabs and blocks of red-brown sediment commonly collapse after flooding. Wave attack erodes these slabs and blocks, and flood-stage river currents erode both the riverbanks and collapsed slabs and blocks, especially during major, erosive winter floods, and especially along the outside margins of meander bends, where currents are swiftest and strongest.

Nevertheless, bank erosion is a relatively minor source of suspended sediment transported during floods. Suspended sediment from spring runoff floods generally have Zn/Pb ratios greater than 1, indicating predominantly riverbed source material. Fine sediment can be winnowed from a large area of riverbed sediment, whereas only a small area of riverbank sediment is exposed to lateral erosion during relatively prolonged and passive spring floods. Suspended sediment from the major winter flood of 1996 had Zn/Pb < 1, indicating that sediment from oxidizing environments was predominant. Since levee areas are much larger than riverbed or riverbank surfaces, it is likely that fines were not only scoured from the channel, and eroded from the riverbanks, but also were winnowed from levee sediment, by rapidly flowing waters within and near the river channel during the 1996 winter flood.

A floating suction dredge operated in the river channel near Cataldo Landing from 1932 to1967. The dredge pumped a slurry of metal-enriched sediment and water from the river bottom through a moveable pipeline to Cataldo Flats, where the slurry was discharged onto the floodplain to form overlapping dredge-spoil fans on Cataldo Flats and Mission Flats, north and west of the river. Although the dredge formerly removed sand from this site, most suspended metal-enriched sediment was carried past the dredge, and deposited farther down-valley. As the extent and thickness of dredge-spoil deposits increased, dikes were built to contain them, and prevent slurry from flowing back to the river. Dredge spoils vary mostly between 4 ± 4 m, and generally thin exponentially with increasing distance from the outfall zone. Surface samples

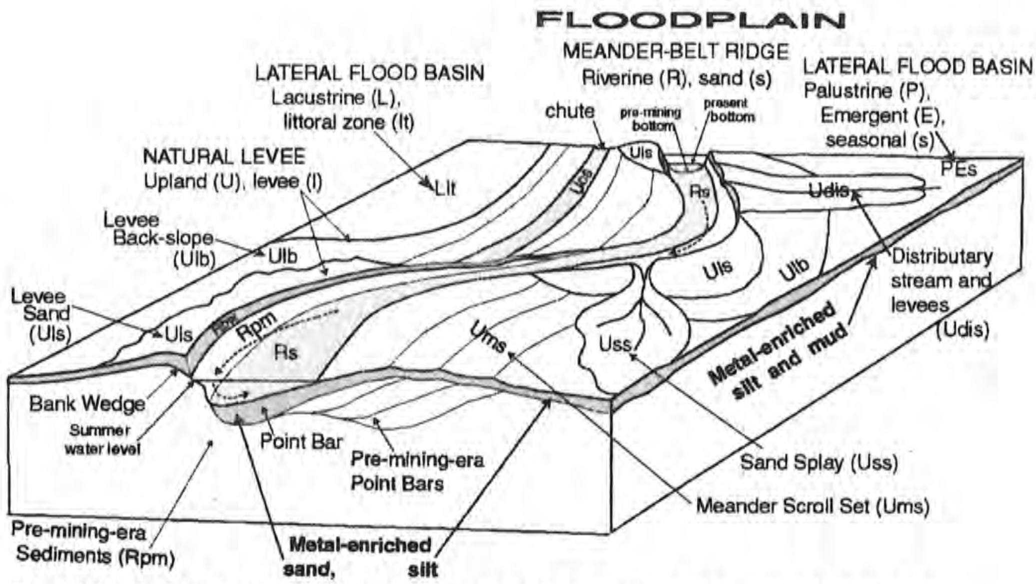

Figure 4. Schematic block diagram, showing features typical of the meandering, sand-bottomed CdA River and its floodplain, between Cataldo Landing and Harrison (modified from Reineck and Singh, 1980; Collison, 1978; and Leopold, 1997). Dotted arrows represent flow paths. On steep faces, thickness of the layer of metal-enriched sediment is represented in dark gray. For full explanation of letter symbols, see Bookstrom and others (1999).

of dredge spoils commonly contain about 2,000 to 5,000 ppm of Pb. Groundwater returns metals leached from weathering dredge spoils to riverside seeps, red with metalliferous bio-slime.

A very wide, shallow bar of metal-enriched sand fills the central part of the river channel, where the dredge once operated. Thickness of metal-enriched sediment (containing at least 1,000 ppm of Pb) varies from 2.5 to 4.3 m near channel margins to more than 6.7 m (> 22 ft) in the middle of the central sand bar. This sand bar formed after dredging ceased in 1967, but is visible in 1975 aerial photographs. It is a dynamically stable feature that consists of sediment deposited since 1967.

Stop 5 to Stop 6: From Cataldo Landing, return to the Cataldo Mission exit, cross I-90, and parallel the highway eastward to a road that runs 1.1 miles to the northern margin of the floodplain. At a T-junction, turn west (left) onto old US Highway 10. After crossing Cataldo Slough look for road-cut exposures of Miocene sedimentary strata. Proceed 2.3 miles, and turn southward (left) across an I-90 overpass, then turn sharply east (right), and follow a gravel road down and around a southward curve (left). Continue 1.9 miles southward along the eastern margin of Canyon Marsh, to the CdA River. Park there for stop 6.

Mile 39.3 ----- Stop 6. Coeur d'Alene River channel transect near Dudley: A line of five vibro-core drill holes was drilled across CdA River channel about 300 m east of stop 6 (near Dudley). This transect is at the downstream end of a long straight stretch of the river channel, where sonar depth profiles indicate that the channel has relatively steep side-slopes of clayey pre-mining-era sediment, and a relatively flat bottom of metal-enriched sand, with dune

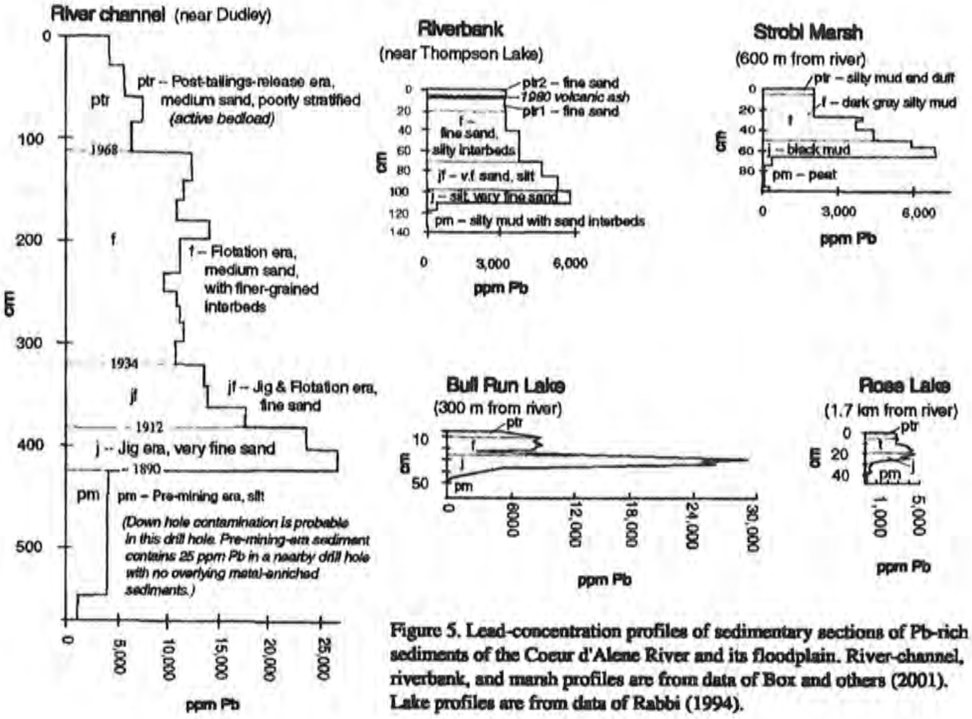

Figure 5. Lead-concentration profiles of sedimentary sections of Pb-rich sediments of the Coeur d'Alene River and its floodplain. River-channel, riverbank, and marsh profiles are from data of Box and others (2001). Lake profiles are from data of Rabbi (1994).

forms up to 1 m in amplitude. Patterns of bank erosion indicate that incipient meanders are beginning to form along this straight stretch, anomalously directing the maximum current against the inside (south) riverbank, as the channel curves from northwest to west.

From north to south along the drilled transect, the river bottom slopes gently southward to a maximum water depth of about 6 m (20 ft) near the south bank. The northern 80 percent of the pre-mining-era channel bottom is covered by 3 to 5 m (10 to 16 ft) of metal-enriched sands. A core taken 21 m from the north bank penetrated 4.23 m of metal-enriched sand, containing 3,000 and 6,000 ppm of Pb in medium-grained sand near the top, to between 23,000 and 27,000 ppm of Pb in very fine-grained sand at the bottom of the section of metal-enriched sediment (figure 5, River channel core). Pre-mining-era sediment exposed near the south bank, and sampled in a drill hole, contains 21 to 28 ppm of Pb. A Ground Penetrating Radar transect detected a maximum thickness of 8.34 m (27.4 ft) of mining-era sediment in the river channel opposite stop 6 (USEPA, 1998).

After the winter flood of 1996, a large log, which had previously been covered by well-stratified metal-enriched sediment, was uncovered by channel scour, so that it protruded about 1.5 m (5 ft) from the scoured northern margin of the channel bottom at the Dudley drill transect. We also observed other scoured exposures of stratified metal-enriched sediment between Cataldo Flats and Rose Lake after the 1996 flood, indicating that along this river reach, metal-enriched sediment that has been stored on the riverbed for some time, was locally scoured and remobilized during the 1996 flood.

Stop 6 to Stop 7: From stop 6, drive down-river (west) on River Road, toward the town of Rose Lake. Canyon Marsh floods annually due to runoff from Fourth of July Creek, and is drained by pumps housed in buildings north of the road. During major floods, river water overflows River Road, carrying metal-enriched sediment into Canyon Marsh. Recently, riprap has been placed along the base of the riverbank in an effort to reduce bank erosion. Between 1.2 and 2.4 mi from stop 6, Orling Slough, is a shallow lateral pond with a long, narrow back-levee marsh. Lead concentrations in surface sediment decrease laterally from the river, from 5,000 - 7,000 ppm on the levee, to 450 - 1,000 ppm in the deepest part of the pond (about 1.5 m). At Rose Lake village, turn left onto Idaho State Highway 3, and stop by the Rose-Lake Bridge.

Mile 42.3 ----- Stop 7. Rose-Lake Bridge: At the Rose Lake village, the river emerges from a long, narrow, straight valley segment, incised into Precambrian strata. It enters a wider part of the valley bottom, which is at the convergence of several tributary valleys, containing eroded remnants of Miocene sedimentary valley-fill. This indicates that the river re-enters the wide Miocene valley, which it left below Cataldo Flats.

At the bridge site, the river scours to about 15 m (50 ft), where the channel bends sharply from northwest to southwest (against a bedrock buttress) and then curves back to the northwest. Metal-enriched surface sediment, containing > 5,000 ppm of Pb is widely distributed across and into the mouths of Porter Slough, and Rose Creek, north and west of the sharp river bend, and into Bull Run Lake and Blackrock Slough, south of the river. Patterns of Pb distribution indicate that overflow, tangential to the outer margins of meander bends, carries metal-enriched sediment into these areas. Rose Lake village is built on the natural levee of a major distributary stream that diverges from the river into the mouth of Rose Creek. The highway embankment now blocks that distributary, but a ditch west of town connects the Rose-Lake wetland to the river, and levees of Pb-rich sediment have formed by deposition of over-bank sediment around it. Red metalliferous bio-slime forms where return flow from the ditch enters the river, and it flocculates along the riversides, as water levels recede in the autumn.

A dusty riverbank east of the bridge is a popular camping spot, and a sandy point-bar beach on the south side of the bridge is a popular children's playground. West of the bridge, a sandy terrace between highway 3 and the river also is a popular recreational area. Sandy to dusty sediment in these areas generally contains well above the 2,000-ppm threshold of Pb concentration, considered by EPA to require rapid remedial action in common-use areas (USEPA, 1999). Every flood that inundates these areas re-supplies them with metal-enriched sediment.

Stop 7 to Stop 8: Drive down-valley (west) about 3 mi, cross the river on the Highway 3 bridge, and park on broad right shoulder of the road about 0.3 miles beyond the bridge for an overview of the floodplain (stop 8).

Mile 45.5----- Stop 8. Lane Segment, Middle CdA River Valley: The floodplain of the Lane segment of the CdA River valley is about 1 to 2 km (0.6 to 1.2 mi) wide. In summer, the water-surface gradient approaches 0 from Cataldo Landing to CdA Lake, and flow is slow to negligible. The meandering river channel contains thick deposits of metal-enriched sand (figures 4 and 5). Along straight stretches the river is bounded by steep banks, cut in bank-wedge deposits of red, metal-enriched sand and silt, underlain by pre-mining-era levees of gray silty mud. Bank-wedge deposits of metal-enriched sediment thin toward levee tops, and only thin deposits of metal-enriched sediment are present along the outside margins of some meanders, where the river has laterally eroded nearly to the crest of the pre-mining-era levee. Point-bar deposits of metal-enriched sediment are present along the lower inside margins of meanders, and pre-mining-era meander-scroll sets are blanketed by metal-enriched sediment. Deposits of metal-enriched levee sand extend relatively far down-valley from the lower outside margins of meanders. Sand splays extend through low passes in levees, and fan out onto the floodplain. Distributary streams and man-made canals transport metal-enriched sediment across the floodplain, onto their levees, and into back-levee marshes and lateral lakes. Ranges of thickness, grain size, and concentration of Pb in metal-enriched sediment tend to decrease with increasing lateral distance from the river, as shown on a set of digital maps of surficial geology and wetlands by Bookstrom and others (1999), and a map of Pb distribution in surface sediment by John Kern and others (unpublished data, 2000).

Sediment in Lane Marsh south of the railroad embankment has much lower Pb concentration than sediment between the river and the railroad embankment, which serves as an imperfect barrier to the transport of Pb-rich sediment into the south part of the marsh, except at its southwest end, where a bridge allows free flow between the north and south parts of Lane Marsh.

Volcanic ash from the May 1980 eruption of Mt. St. Helens was deposited throughout the CdA River valley to form a nearly white layer of microscopic volcanic-glass fragments. This layer is about 0.5 to 3 mm thick, and has been preserved in riverbank and levee environments, but is much less commonly preserved in palustrine and lacustrine environments. Where it is present, it provides a time-marker, against which rates of sedimentation post-1980 deposition of metal-enriched sediment can be measured.

Based on available data, average annual rates of deposition of metal-enriched sediment since 1980 were 8 mm/y on riverbank-wedge deposits, 3.8 mm/y in lateral lakes, 3.1 mm/y on levees, and 2.4 mm/y in back-levee marshes (Bookstrom and Box, 1999, unpublished data). The average Pb concentration in sediments deposited in the 13 years after 1980 is 2,570 ppm of Pb. That is about 4 percent less than that of sediment deposited in the previous 12 years, between 1968 and 1980 (assuming that samples taken above and below the 1980 marker bed and within the 0 to 5 cm depth interval, represent sub-equal thickness intervals and sub-equal time intervals). This indicates that Pb concentrations of sediment deposited on the floodplain of the CdA River since 1968 have not decreased significantly since the cessation of direct disposal of tailings into tributary streams.

Detrital metallic sulfides and carbonates are present in sediment stored in the transitional redox environment of the river-bottom, and in tan-colored sediment recently deposited on riverbanks and levees, above the 1980 Mt. St. Helens volcanic ash layer (Robert Hooper and Brian Mahoney, unpublished data, 2001). However, detrital metallic sulfides and carbonates are rare in older, redder, more oxidized sediment on the natural levee, where Pb resides mostly in non-stoichiometric and nano-crystalline ferro-manganese/oxy-hydroxides. Zinc is depleted relative to lead in oxidized sediment, where it is strongly partitioned into siliceous ferri-hydrite, and is a minor component of more complex manganese oxy-hydrides (Thornburg and Hooper, 2001).

In samples of black, organic-rich sediment from back-levee marshes and lateral lakes, where redox conditions are transitional to reducing, authigenic sulfides predominate over minor detrital sulfides and surficial oxy-hydroxides. SEM and TEM studies show that Pb resides mostly in compositionally variable bio-coatings of amorphous to nano-crystalline Pb-Zn-Cu sulfide, and Zn resides mostly in authigenic zinc sulfide (Thornburg and Hooper, 2001). Microscopic spheroidal and stick-shaped forms suggest precipitation by bacterial sulfate reduction. Because of their amorphous to nano-crystalline forms, and enormous surface free energy, these authigenic sulfides are much more soluble and bio-available than detrital galena or sphalerite, as indicated by sequential extractions from samples collected and stored under reducing conditions.

END OF FIELD TRIP

Return to cars and turn left (north) onto Highway 3, and proceed 8.3 miles to its junction with Interstate Highway 90. Enter I-90 eastbound and return to Wallace (about 25 miles).

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A GEOLOGICAL AND ECONOMIC OVERVIEW OF THE GOLD HUNTER MINE

Jon Carlson - Geologist at the Lucky Friday Unit of the Hecla Mining Company, Mullan, Idaho

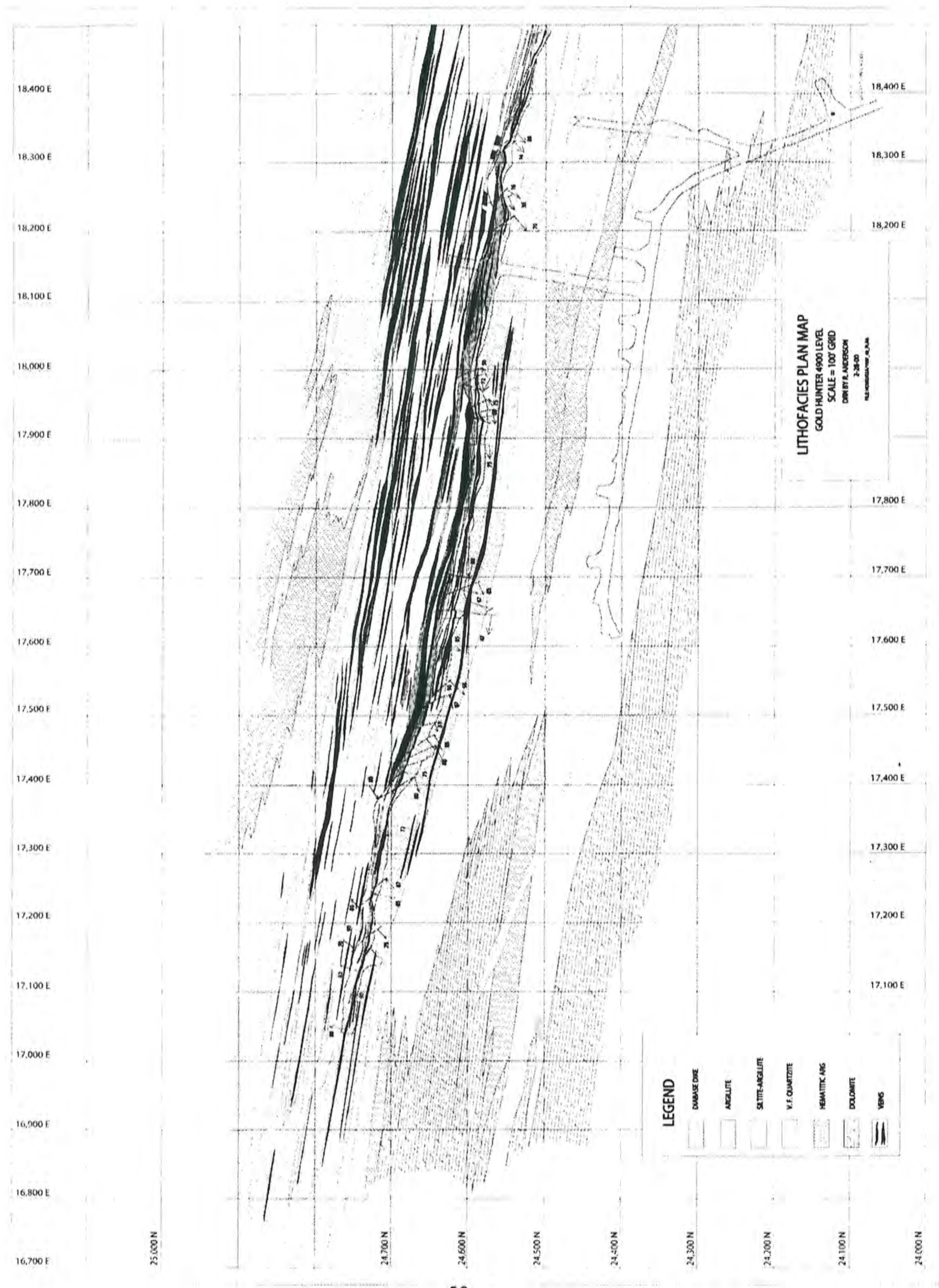
Located in northeastern Idaho, the Gold Hunter Mine discovery in 1884 was one of the original claims staked in the Coeur d'Alene mining district. Since then, the district has produced over 1 billion ounces of silver, 8 million tons of lead, and three million tons of zinc. The Proterozoic Belt Basin, consisting of muds, silts, sands and carbonates hosts the district. The Gold Hunter mine is believed to be in the lower to middle Wallace formation of the Belt Supergroup. Typical host rock includes argillite, silty argillite, fine-grained quartzite and minor dolomite. Major gangue minerals are siderite, quartz, pyrite, and rare barite, calcite and boulangerite ($Pb_5Sb_4S_{11}$). Vein mineralogy includes galena, sphalerite, tetrahedrite (freibergite), pyrite, with rare chalcopyrite and pyragyrite. Horizontal and vertical mineral zoning exists within the system. High silver, very low lead, very low zinc veins exist in the northern and southern zones. Lower silver, moderate lead and high zinc veins characterize the mid-zone. The mechanisms controlling the mineral zoning are unknown. Controversy exists regarding the age of the Coeur d'Alene district veins. Estimates of the age of vein emplacement cluster in two groups; Proterozoic and Cretaceous, inferring two periods of vein development or alternatively a Cretaceous age remobilization of veining initially formed in the Proterzoic, perhaps contemporaneous with basin development.

The Gold Hunter veins generally dip to the south within 10 degrees of vertical, and strike about N280. Up-section is thought to be toward the south. The economic strike length is currently 1500 feet (457 m). Although individual sulfide veins are rarely greater than two feet (0.6 m) in width, the mineralized, but sub-economic zone varies from 80 to 150 feet wide (24 m to 46 m). This system extends from the surface, to minimally 6750 feet (2057 m) below, while raking westward at 80 degrees.

Current mining is concentrated along the high silver, moderate lead, low zinc veins near the southern edge of the deposit, collectively known as the 30 vein. Production on the 30 vein began on the 4900 level and has reached to the 4670 and 5130 levels. Each of four, double-sided stopes are about 750 feet (229 m) long and typically between seven and ten feet wide (2 m to 3 m). Since January 1997, the Gold Hunter deposit has mined 844,000 tons at 16.7 ounces of silver per ton, 9.3 % lead and 1.4 % zinc, producing 14.1 million ounces of silver, 78 thousand tons of lead and 12 thousand tons of zinc.

Recent core drilling indicates the deposit persisting at depth, below the economically accessible limits of the 4900 level. To access these reserves a second 4500 foot long crosscut must be constructed. The planned drift will originate from the Silver Shaft at the 5500 level and will intercept the 30 vein at the 5700 elevation. This, and a future planned crosscut from the 5900 level will extend the mine's life to, minimally, the year 2012, with known reserves.

Northwest Geology, v. 30, p. 49-50, 2001


LITHOFACIES PLAN MAP
GOLD HUNTER 4900 LEVEL
SCALE = 100' GRID
DRN BY R. ANDERSON
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LEGEND
DIABASE DIKE
ARGILLITE
SILTITE-ARGILLITE
V.F. QUARTZITE
HEMATITIC ARG
DOLOMITE
VEINS
18,400 E
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18,200 E
18,100 E
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FLOATER'S GUIDE TO THE BELT ROCKS OF ALBERTON GORGE, WESTERN MONTANA

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INTRODUCTION

Near Huson the Clark Fork River veers from its leisurely northwestward course in the Missoula-Ninemile Valley to slice west through the mountains and obliquely across the structural grain of the Lewis and Clark Line. Between Cyr and Tarkio it cuts a narrow inner gorge in the flat valley floor and reveals the underlying bedrock geology. Here, in Alberton Gorge (see Figure 1), also known as Cyr Canyon, the Clark Fork has polished beautiful examples of Belt Supergroup sedimentary features and exposed complex faults and folds characteristic of the Lewis and Clark Line. On this trip, we will float 10 miles through Class II and III rapids to view these fantastic examples of Belt geology.

Although whitewater boaters do not consider Alberton Gorge to be a difficult run, it should not be attempted by those without whitewater experience or suitable whitewater craft. Several fatalities have occurred along this stretch. Spring runoff should be avoided. This trip is scheduled for early August, when water temperatures average about 70° F with flows of 1500 to 4000 cubic feet per second (cfs).

The geology of the area has been studied by Campbell (1960), Hall (1969), Wells (1974), Lonn (1984), Harrison and others (1986), Winston and Lonn (1988), and Lewis (1998b). Despite this attention, structure and stratigraphy of the area remain unresolved, and Montana Bureau of Mines and Geology is currently re-mapping the region at the 1:100,000 scale. Completion of the Plains 30' x 60' quadrangle in 2003 will fill the gap between the already completed Wallace (Lonn and McFaddan, 1999; Lewis and others,1999) and Missoula West (Lewis, 1998b) quadrangles. This paper incorporates new findings from that ongoing work.

REGIONAL GEOLOGY

Middle Proterozoic Belt Supergroup and Cambrian rocks are complexly folded and faulted in this segment of the western thrust belt (Winston, 1986a). Cretaceous to Paleocene compression produced asymmetric to overturned folds, penetrative cleavage, and thrust and reverse faults (see Figure 4). Most structural features have northwest or west-northwest strikes. The compressive structures were subsequently cut by Tertiary normal and strike-slip faults. In some places the extensional faults appear to have reactivated the thrust planes. Most younger faults also strike northwest.
This trip crosses part of the Lewis and Clark Line. The Lewis and Clark Line has had different shapes and different meanings to different geologists, but in this paper it is regarded as a wide, indistinct belt of folds and faults that have anomalous, for northwestern Montana, northwest to west-nothwest trends (see Figure 1). It extends from the Coeur d'Alene mining district southeastward to Missoula and

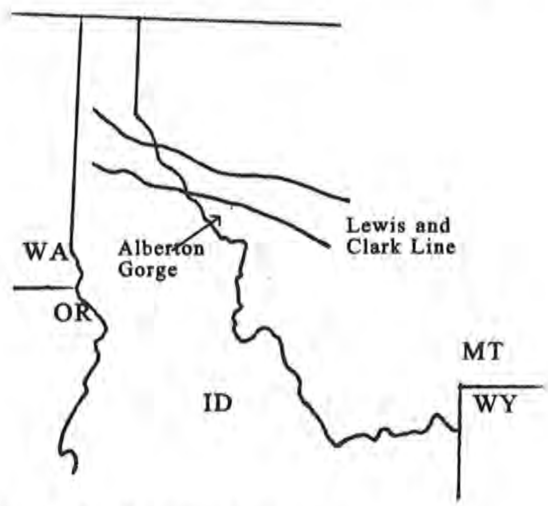


Figure 1.– Location map.

on to north of Helena. Despite speculation on Precambrian origins for the line (Hobbs and others, 1965; Harrison and others, 1974; Reynolds, 1977; Leech and others, 1988), the structures that actually define the line in the Superior to Alberton area are those described in the preceeding paragraph. All are Cretaceous or younger, with no evidence for Precambrian tectonism. In fact, Winston (2000) has equated this part of the Lewis and Clark Line as originally defined by Billingsley and Locke (1941) with the Cretaceous/Paleocene western fold and thrust belt. Participants on the trip will view the structures of the Lewis and Clark Line and reach their own conclusions. The trip also provides participants an opportunity to see the Belt section from Wallace to Mount Shields Formation (Figure 2) and view river-polished examples of Belt sedimentary types (Winston, 1986b). Because most Belt rocks are mixtures of siliciclastic fine-grained arenite, siltstone, and claystone, and color is affected by diagenesis and metamorphism, conventional descriptions based on color, grain size, and composition are inadequate. Winston (1986b) has tried to address the problem by devising a system of sediment types that do successfully delineate Belt units (Figure 3). The trip provides participants with the opportunity to observe many examples of diagnostic sediment types and to discuss what the sedimentary features indicate about the environments of deposition.

RIVER ACCESS

To reach the take-out from Wallace, Idaho, take Interstate 90 east 69 miles to the Tarkio exit, exit the interstate, turn right and follow the signs 1 mile to the Tarkio Fishing Access.

To reach the put in, continue east on I-90 from Tarkio for 5 miles to the Fish Creek exit. Get off, turn left and proceed 0.3 miles across a railroad crossing to a stop sign. Turn right and

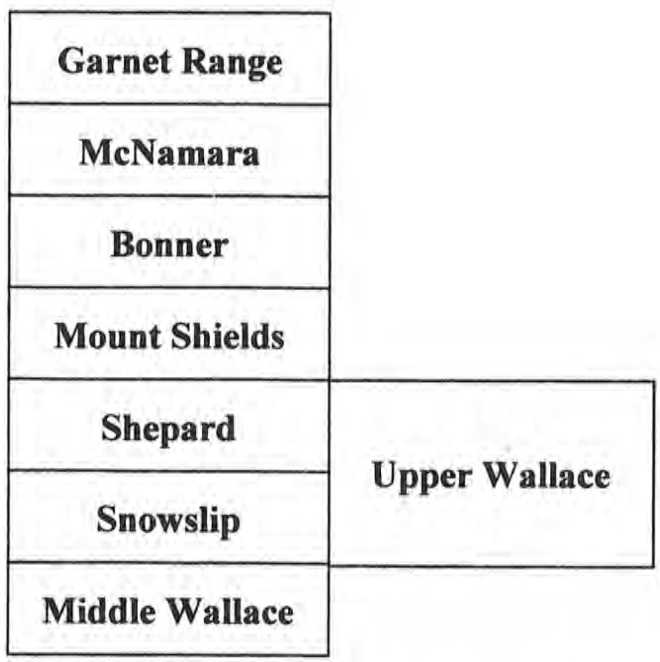


Figure 2. Middle Proterozoic Belt stratigraphic units in the Alberton Gorge area.

travel 3.3 miles to a road junction just before a bridge across the Clark Fork. Turn right, into the Cyr River Access.

To reach the put-in from Missoula, Montana, drive 35 miles west on I-90 and exit at that Cyr exit. Continue 0.2 miles across the bridge and turn left into the Cyr River Access.

To reach the take out from the put in, turn left on the old highway and drive 3.3 miles to the Fish Creek Road. Turn left and proceed 0.3 miles to the junction with I-90. Get on I-90 westbound, exit in 5 miles at the Tarkio exit. Turn left and follow the signs to the Tarkio Fishing Access

RIVER LOG

Begin the trip at the Cyr River Access. We will put in here, but first walk up the gentle, grassy slope at west end of the parking lot for an overview of the geology. The wide valley surrounding you is developed along the Boyd Mountain Fault, a major northwest-striking normal fault that cuts obliquely across the river canyon. We will cross its trace downriver. To the southeast, the massive mountain topped by a lookout is Plateau Point, underlain by southwest dipping, overturned Missoula Group and Wallace Formation beds in the lower, east limb of the Reservoir Creek anticline. The rocks were first folded in response to Cretaceous/Paleocene compression, and then broke in a forelimb thrust, the Reservoir Creek thrust, exposed on the east side of Plateau Point (see Figure 4). This style of deformation is common in the western fold and thrust belt, particularly in the Superior-St.Regis-Mullan area. Thrusts are steeply dipping and often break from huge overturned folds.

Beyond Plateau Point and out of sight, just above the town of Alberton, is another northeast directed thrust, the Lothrop thrust (see Figure 4). The Lothrop thrust exemplifies another common structural style of this area. The thrust brings Proterozoic Shepard Formation up over Cambrian Hasmark Formation. Behind (southwest of) and closely paralleling the thrust is a southwest-dipping normal fault that probably merges with the Lothrop thrust at depth, and suggests reactivation along this thrust plane. Lewis (1998b,1998c) found this structural style, that is, normal faults developed behind and parallel to thrust faults (see Figure 5), to be common in the area. Although data are preliminary, the Lothrop fault system appears to pass northwest into the Osburn Fault near Superior as mapped by Campbell (1960). Near Superior, the coincidence of the Osburn Fault with a zone of closely spaced thrusts (Lonn, mapping in progress) suggests that there, too, reverse faults may have been reactivated by Tertiary extension, with resultant backsliding.

The flat surface on which you are standing is littered with huge sub-angular boulders deposited by floodwaters during the drainings of Glacial Lake Missoula.

Walk across the road to the unloading area, where the Montana Department of Fish, Wildlife, and Parks has thoughtfully placed boulders (although some are upside down!) that provide great examples of Belt sedimentary structures and sediment types. We will spend some time discussing them.

Walk down the boat ramp and launch. This is River Mile (RM) 0.0. Across the river and under the bridge are Pleistocene flood deposits deposited during the drainings of Glacial Lake Missoula. Note the poor sorting of clasts.

Below is a large, calm pool with a bedrock outcrop at its lower end on river right at RM 0.2. Boaters use the terms "right" and "left" in reference to downstream views, so this outcrop is on river right. The outcrop is the informal middle member of the Wallace Formation, striking downriver (northwest) with a near vertical dip. Stratigraphic "up" is to the northeast (river right), and the rocks are on the forelimb of the Reservoir Creek anticline, whose axis parallels the river for the next couple of miles. Notice the small scale folds, common in the Wallace Formation. Here they appear to be tectonic in origin, but the middle Wallace also commonly exhibits soft sediment deformation.

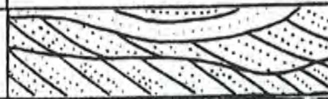
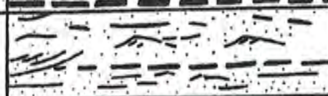
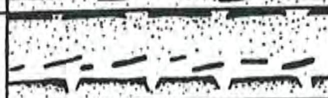
SEDIMENT TYPE	SEDIMENTARY STRUCTURES	DESCRIPTION	DEPOSITIONAL PROCESSES
CROSSBEDDED SAND		Coarse- to fine-grained, crossbedded, feldspathic sand, beds 10 to 150 cm thick.	Channeled flood and sheetflood transport and deposition.
FLAT-LAMINATED SAND		Medium- to fine-grained flat-laminated sand, climbing ripples, mudchips, beds 10 to 150 cm thick.	Sheetflood transport and deposition.
DISCONTINUOUS LAYER		Fine sand to silt lenses in mud layers, occasional mudchip concentrations.	Waning flood and intermittent flow transport and deposition.
MUDCRACKED EVEN COUPLE		Even, mudcracked, graded fine sand and silt-to-mud layers 3 to 10 cm thick.	Sheetflood transport and deposition.
MUDCRACKED EVEN COUPLET		Even, mudcracked, graded, fine sand and silt-to-mud layers 0.3 to 3 cm thick.	Sheetflood flow across exposed mudflats followed by deceleration, suspension settleout and desiccation.
MUDCRACKED LENTICULAR COUPLET		Oscillation-rippled fine sand and silt lenses, capped by clay laminae, cut by mudcracks.	Wave transport of fine sand and silt, followed by clay settleout and desiccation.
MUDCRACKED MUD		Mud layers up to 2 cm thick, cut by mud-filled mudcracks.	Suspended load transport across dried playa floors, followed by submergence and desiccation.
MICROLAMINA		Interlayered or graded silt and clay laminations less than 0.3 cm thick.	Alternating silt and clay suspension settleout.
COARSE SAND AND INTRACLAST		Coarse- to fine-grained, sand and flat clasts, crossbedded and imbrecated at various angles.	Transport of coarse sand grains and scoured clasts by breaking waves.
CARBONATE MUD		Micrite and dolomicrite without detectable siliciclastic laminations.	Aragonite or calcite precipitation, in places followed by dolomitization.
UNCRACKED LENTICULAR COUPLET		Oscillation-rippled fine sand and silt lenses, capped by clay laminae, cracked and uncracked.	Wave transport of fine sand and silt, followed by suspension settleout.
UNDULATING COUPLET		Graded to sharply bounded silt-to-clay couplets that thicken and thin across outcrops in a gently wavy or undulating manner.	Episodic deposition of silt by small storm waves, possibly limited in size by shallow depth, followed by suspension settleout.
PINCH-AND-SWELL COUPLET		Graded fine sand to dark mud layers with undulating scoured and loaded bases, 0.3 to 3 cm thick.	Episodic erosion by storm waves, deposition of hummocks, which loaded into underlying mud, followed by mud settleout.
PINCH-AND-SWELL COUPLE		Graded fine sand to dark mud layers with undulating scoured and loaded bases >3 cm thick.	Episodic erosion by storm waves, deposition of hummocks, which loaded into underlying mud, followed by mud settleout.
MUDDY GRADED SAND		Graded structureless or plane-laminated, dark muddy sand beds.	Turbidiy flow transport and deposition.
UNCRACKED EVEN COUPLET		Even, uncracked graded silt-to-clay couplets 0.3 to 3 cm thick.	Episodic suspension transport and settleout.
PLANE-LAMINATED SILT AND CLAY		Even, sharply bounded, silt and clay interlaminations.	Alternating silt and clay transport and settleout.

Figure 3. Belt Sediment types (from Winston, 2000).

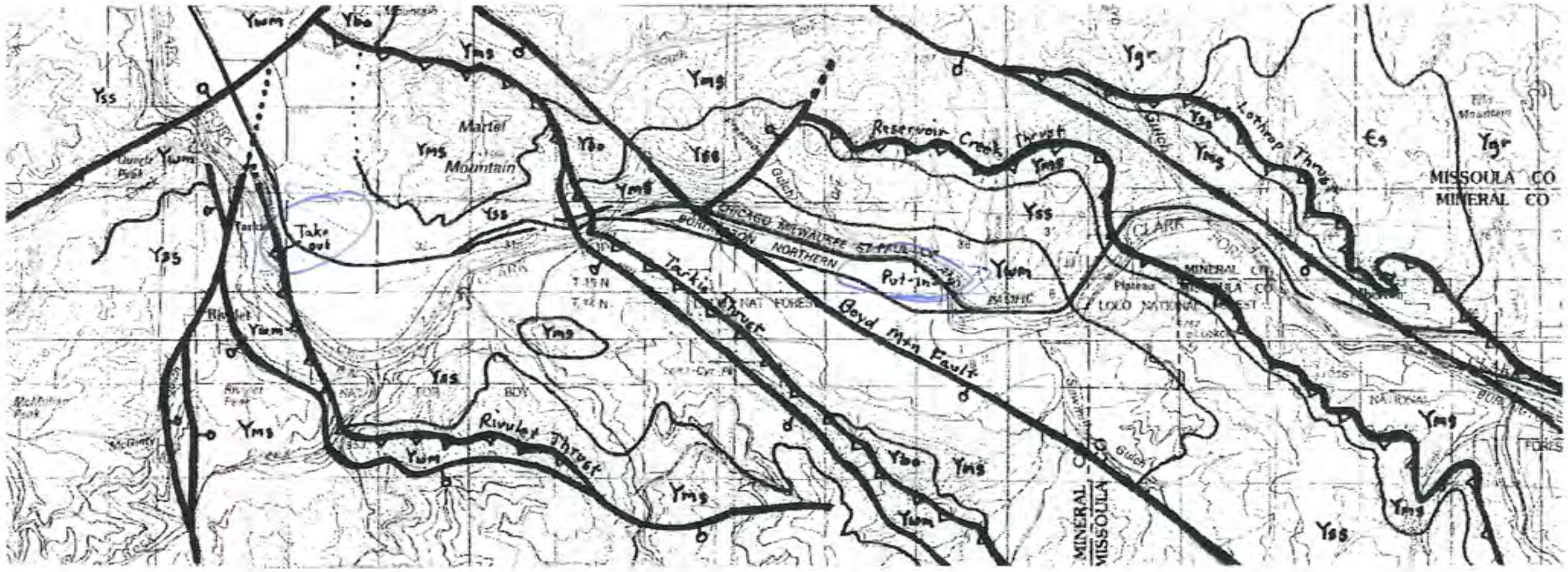


Figure 4. Bedrock geology of Alberton Gorge and the surrounding area. Ywm – Middle Wallace Fm; Yss – Snowslip and Shepard Fms; Yms – Mount Shields Fm; Ybo – Bonner Fm; Ygr – Garnet Range Fm; Cs – Cambrian sedimentary rocks. Surficial deposits not shown. Scale: 1 inch = 1.8 miles. Geology compiled from Winston and Lonn, 1988; Lewis, 1998b; and Lonn, unpublished mapping 2000-2001.

The Clark Fork turns abruptly left and passes through a riffle caused by ledges of Wallace. The river continues through a long calm section, then enters another riffle.

Stop 1 is at a small beach on river right near the top of this riffle (RM 1.2). The outcrop above the beach contains diagnostic undulating and pinch and swell couplets (see Figure 3) of the middle Wallace Formation. Tan-weathering, dolomitic, fine-grained quartzite and siltite beds commonly grade upward into black argillite. The sand beds thicken and thin across the outcrop, have sharp bases, and are loaded and sometimes cut into the underlying argillite. Note the prominent "gutter"of fine sand. Has it been compacted into the underlying black argillite or does it fill a scour channel? Look carefully for molar tooth structures (calcite) present in the carbonate mud sediment type, and for ptygmatic or "crinkle" cracks. These cracks formed subaqueously by wave action in soupy mud (Don Winston, personal communication, 2000). Unlike dessication cracks, they are discontinuous, do not intersect, and have a squiggly, contorted form in cross section.

Winston (1986b) interpreted the features of the middle Wallace to record relatively higher stands or deeper parts of the Belt Sea, but with water still shallow enough to allow storm waves to reach the bottom. Storm waves first reworked and deposited the sand beds, then the mud settled out of suspension.

The blocks of green mudcracked float probably rolled down from the stratigraphically and topographically higher Snowslip Formation, although dessication mudcracks do occur uncommonly in the middle Wallace.

Put in and run through the long riffle below. Just below the riffle a striking sequence of vertical beds comes into view. These are again outcrops of middle Wallace, but sedimentary features are somewhat obscured by bedding-parallel shears. As we proceed downstream, we are also going slightly downsection, and the cliffs flanking the Ledge and Cliffside I rapids on the right are also composed of middle Wallace.

Proceed through Cliffside I rapid (RM 2.1) to the top of its clone, Cliffside II (RM 2.6). The cliffs flanking Cliffside II are still middle Wallace, in structural continuity with that of the beginning of the trip. Here the rocks strike downriver and are overturned, still in the northeast limb of the Reservoir Creek anticline. However, downstream, directly on line with the strike of these beds, are gently dipping green and tan rocks that are clearly different.

Cliffside II rapid (RM 2.7). Below these rapids, rocks that are folded and broken, with gouge developed, suggest a northeast-striking fault that drops gently dipping Snowslip Formation down to the northwest (downstream). The fault truncates the overturned Reservoir Creek anticline and associated thrust. On river right, in the long calm section below the sharp left turn are nice exposures of tan and green dolomitic microlaminae characteristic of the lowermost Snowslip Formation.

The gougy, colorful, green and purple rocks that appear downstream represent more typical Snowslip Formation, but are crushed and brecciated along the Boyd Mountain fault. The purple cliffs at the downstream end of this straight, calm section of river are informal member 3 of the Mount Shields Formation on the other side of the Boyd Mountain fault.

Cross the trace of the Boyd Mountain Fault (RM 3.3). The Boyd Mountain fault is a major northwest-striking, down-to-the-southwest normal fault. Stratigraphic displacement here is at least 4000 feet (1219 m), but it varies greatly along the strike of the fault. Is this because there has been some strike-slip movement? The Boyd Mountain Fault can be followed for almost 10 miles (16 km) to the southeast and 40 miles (64 km) northwest, where it merges with the Osburn Fault. Tertiary(?) fluvial gravel in its hanging wall near St. Regis is tilted into the fault (Lonn and McFaddan, 1999), indicating listric movement. Around Superior, it is evident that rocks in the foot wall of the Boyd Mountain fault (northeast side) are much more intensely cleaved than are rocks in the hanging wall. This relationship extends to the Coeur d'Alene mining district, where the Osburn Fault bounds the different domains (Reid and others, 1993; Wallace and Hosterman, 1960; Campbell, 1960; Hobbs and others, 1965; Lonn and McFaddan, 1999). Perhaps the Boyd Mountain and Osburn faults are reactivated thrusts as suggested by Yin and others (1998), and their northeast sides represent significantly lower structural levels now exposed by extension.

RM 3.5-4.1. Pass beneath the purple cliffs, a spectacular exposure of Mount Shields member 3. Note the alternating green and red beds, and also that some of the green beds pass laterally into red beds, showing that color is not always a primary sedimentary feature and should not be used to differentiate Belt formations

Stop 2 is at the outcrop below the Sandy Beach river access (RM 3.9) on river left. The outcrop is located between the two beaches. If this popular spot is crowded, an alternate outcrop on the left at a small beach (RM 4.1) just above Triple Bridges should show the same features. This is Mount Shields member 3, characterized by even couplets and couples (refer to Figure 3), and also containing abundant lenticular couplets, flat laminated sand, discontinuous layer sediment type, microlaminae, both current and oscillation ripple marks, dessication cracks, and salt casts. Winston (1986b) interpreted much of the Mount Shields member 3 as recording sheetflood deposition across sandflats at the toes of alluvial aprons. Sand and silt were deposited first, and then clay settled out as the water ponded in a flat, playa lake environment. The lake then shrank to expose the mud, causing cracks to develop before the next flood arrived.

Continue downstream under the Triple Bridges (there are actually four bridges) and through Triple Bridges rapid (RM 4.25), where Mount Shields member 3 constricts the river. Hordes of kayakers normally play the waves here.

The next portion of the trip duplicates Stop 3 of Winston and Lonn (1988). On that trip, participants scrambled into the canyon from above, endangering themselves with slips, falls, and rolling boulders. Floating the river is a better way to travel, wouldn't you agree?

Pull into the eddy formed by the first isolated outcrop on the right downstream of Triple Bridges, and view the geology from the boat (RM 4.6). This is west-dipping Mount Shields member 3 capped by a thin layer of tan-weathering dolomitic rock, not unusual for the Mount Shields 3. Far to the northwest, in the Clark Fork Quadrangle, the Mount Shields member 3 passes into a lacustrine carbonate unit mapped by Harrison and Jobin (1963) as Striped Peak member 2. Further up on the outcrop the rocks are sheared and shattered; they in turn are topped by rocks that appear distinctly different, and indeed they are. The top of the outcrop is middle Wallace Formation, verified by viewing the distinctive black and tan lithology across the river downstream. The Wallace here has been thrust over Mount Shields 3 by the Tarkio thrust mid-way up the outcrop. Here the Tarkio thrust displays at least 6000 feet (1829 m) of stratigraphic offset. The thrust plane itself is well exposed a few hundred feet downstream.

Stop 3. Split Rock rapid (RM 4.7) and the giant mid-river boulder are formed along the sole of the Tarkio thrust. Land on the gravel bar below, river right. The best exposure of the fault is at the edge of the gravel bar. Boulder-sized fragments of Wallace Formation are set in a foliated matrix containing smaller, rounded quartzite and Wallace clasts, creating a mylonitic appearance. In thin section, the matrix is not foliated, but it does contain grains of strained, broken quartz with undulose extinction and twinned dolomite crystals. Deformation along the Tarkio thrust apparently involved both ductile and brittle processes.

Lewis (1998) was able to follow the Tarkio thrust for 10 miles (16 km) southeast and discovered the parallel normal fault that formed behind (southwest of) it (see Figure 5). A thin sliver of Wallace is caught between the two faults. This sliver can be found north of the river as well, but near the Martel Mountain ridge crest, the fault traces merge and Wallace Formation is no longer exposed (Figure 4). So, like the Lothrop thrust, the Tarkio thrust was

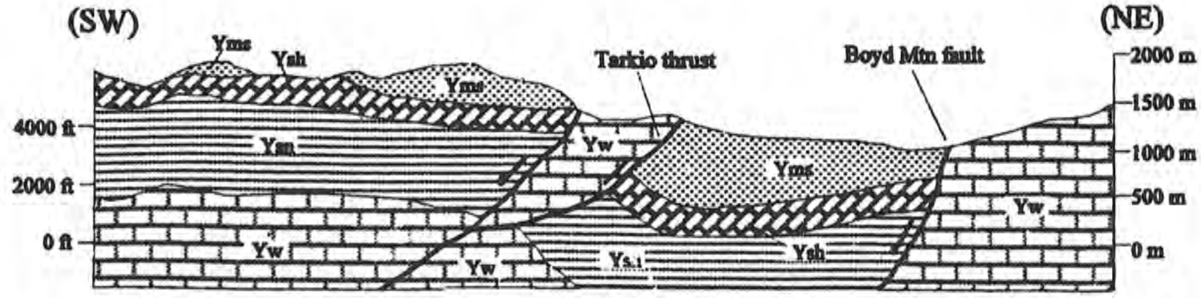


Figure 5. Cross section of the Tarkio thrust south of the river. Yw – Wallace Fm; Ysn- Snowslip Fm; Ysh – Shepard Fm; Yms – Mount Shields Fm. From Lewis, 1998c. The Lothrop and Rivulet thrusts have similar geometries.

probably reactivated by extension, and slid back. The trace of the normal fault probably crosses the river just downstream in the covered interval, for the next outcrops you see downriver are of Snowslip Formation.

Continue downriver through the narrow constriction that forms Tumbleweed rapid (RM 4.9), a strong Class III at most flows.

Smooth, sculpted gorge walls below Tumbleweed rapid are green- and tan-weathering, dolomitic, couplet-scale beds of the Snowslip Formation.

Stop 4 is on the right, below the glassy "Surfer Joe" waves (RM 5.1). Sediment types represented here are mostly dolomitic, uncracked varieties of even and lenticular couplets. Note the lenticular couplets near the water line that have been deformed by compaction. Walk up the inclined bedding surfaces for good exposures of even and lenticular couplets, best viewed by splashing a bucket of water on them. Dessication cracks and mud chips are uncommon, but straight-crested oscillation ripples are present. You may find some microlaminae. These rocks are mapped as lowermost Snowslip Formation, although some workers may place them in uppermost part of the middle Wallace Formation. Note that there is no upper Wallace Formation in this part of the Belt Basin. Upper Wallace is a term used in northern Idaho for the Snowslip and Shepard equivalents there, a problem that was addressed by the 2000 Belt Association Field Trip. It was proposed that the upper Wallace be given a new name. Upper Wallace sediments actually resemble those at this outcrop, while the type Snowslip Formation does not. More typical Snowslip is exposed in outcrops downstream.

Pull over to the stack on the right in the wide calm spot where the dip of the rocks flattens (RM 5.2). Splash water on these outcrops to see red even couplets and couples, flat laminated sand, and discontinuous layer sediment types. Downstream, and upsection, the rocks get coarser-grained and thicker bedded

Run through Boateater rapid (so named for the fearsome holes that develop during high flows) and look at the rocks on the left in the long calm section below (RM 5.4-5.6). We are now in an interval of thick quartzite beds mostly of the even couple and flat laminated sand sediment types. The Snowslip's type section in Glacier National Park contains few such beds, and is dominated by red and green mudcracked even and lenticular couplets. The interval here closely resembles the Mount Shields member 2, but a climb up the cliffs of Martel Mountain less than 0.5 miles (0.8 km) to the north reveals that these quartzite beds grade upward into unmistakable Shepard Formation and then into Mount Shields at the top of the mountain. Lewis (1998a,b) also described sandy intervals in the Snowslip at locations 12 miles (20 km) southeast of here and also in the Sapphire Mountains. These beds probably reflect deposition by sheetfloods on the middle and distal parts of alluvial aprons (Winston 1986b, 2000).

Exit the constricted gorge via Fang rapid (RM 5.6) with its large violent surfing wave and attendant gaggle of kayakers and run another rapid with an enormous boulder on the right (RM 5.9). Downriver are more Snowslip outcrops that appear to be internally deformed. A long section without bedrock outcrops follows and continues through a long riffle. Bedrock again appears just past the kayaker's take-out on the right (RM 6.4).

These north-, upstream-dipping outcrops above Fish Creek are mapped as Shepard Formation (Lewis, 1998b). Some deformation is apparent, including northeast-striking fault gouge and a possible west-northwest-trending fault with little apparent offset just above the mouth of the creek. Faults are ubiquitous in this part of the Belt Basin, but perhaps only those with documented significant offset should be mapped, at least at the 1:100,000 scale.

Two miles farther south a significant fault, the Rivulet thrust, has been mapped (Lewis, 1998b). Like the Tarkio thrust, this one has middle Wallace Formation in the hanging wall and is closely backed by a normal fault, so it is interpreted as another reactivated thrust. It roughly parallels the river on the left for the next 2 miles (3.2 km).

Land on the left just below the mouth of Fish Creek (RM 6.7) for Stop 5. Here, beautiful white sand ripples are exposed in lenticular couplets, and good examples of the microlamina sediment type are present. Most beds are dolomitic or calcareous. Green and tan-weathering, dolomitic microlaminae are characteristic of the Shepard Formation. Microlaminae in the Belt are enigmatic; their stratigraphic positions in cycles of the Helena and Wallace Formations indicate that they formed in very shallow water (Winston, 1993). Possibly they were deposited on wind set-up flats, where wind blew shallow water onto the mud flats surrounding the Belt sea, or maybe they represent wind-blown silt from nearby exposed playa flats (Winston, 1993 and personal communication, 2001).

The Shepard Formation's relative thinness (slightly less than 1000 feet [305 m]), its stratigraphic position between two coarser red-bed units, and its characteristic platy weathering make it one of the few marker beds of the Belt Supergroup. However, the Snowslip Formation also contains similar intervals, especially in its western facies equivalent, the upper Wallace, which we are approaching. This outcrop could be Snowslip that is structurally continuous with Snowslip upstream. Placing it in the Shepard Formation requires a fault, as yet unrecognized.

The Snowslip Formation to the west and north, near Superior and the railroad siding town of Quartz, lacks the red color, the mud cracks and chips, the sandy even couples, and the flat-laminated sands. It is instead a thick sequence (approximately 3000 feet [915 m]) of mostly green and tan, dolomitic uncracked couplets and microlaminae. In the area between Quartz and Superior, Harrison and others (1986) identified some rocks as western facies Snowslip, or upper Wallace, and some they mistakenly mapped as lower Wallace Formation, which resulted in some complicated structural interpretations. New mapping in progress is significantly simplifying the picture.

Continue downstream and downsection, through the rapids created by the huge mid-stream boulders (RM 6.8). By now, regardless of whether the Fish Creek outcrops we just passed are Shepard or Snowslip, lithologies here represent good Snowslip Formation. The railroad cut far above the river on the left indicates some structural complications, possibly related to the Rivulet thrust.

Stop 6 is at the last outcrop on the right just above Rock Creek (RM 7.5). The outcrop contains beautiful examples of "starved ripples" in lenticular couplets, and also some undulating couplets, both characteristic of the Snowslip Formation, especially its western facies.

Continue past the mouth of Rock Creek (RM 7.6), and its grove of small Western Redcedars. For the next mile the river has exposed mostly glaciofluvial deposits and a few ratty outcrops deemed Snowslip. On the right bank at about RM 8.6 are some iron-stained, brecciated outcrops that may mark the trace of the Rivulet thrust.

The rocky bluff that finally appears ahead on river left (RM 9.2) is composed of deformed middle Wallace Formation. Is the chaotic bedding the result of tectonic or soft sediment deformation, or both? Faulting is complex and unresolved here. The Rivulet thrust is nearby and may be dying into a east-verging, overturned fold. But the famous middle Wallace sedimentary breccia is present, and some of the folds appear to be sedimentary in origin. Both probably represent slump features formed during Proterozoic syndepositional faulting (Wallace and others,1976; Godlewski, 1980; Winston, 1986a) If we have time, we will pull over for a closer look, for no Belt field trip is complete without a heated debate on tectonic versus soft sediment deformation.

Continue around the corner through fast water to the Tarkio take-out on the right (RM 9.5). Outcrops across the river are beds of north-striking, near-vertical middle Wallace near its upper contact with the Snowslip to the east (right).

Drive up through glaciofluvial deposits to the interstate highway. The Quartz-Nemote Creek flats here are underlain by Glacial Lake Missoula silt beds, which are commonly preserved in wide sections of the valley above constrictions, where quieter water presumably prevailed during the drainings of Lake Missoula. The gravels in the high road cut along the interstate to the right were deposited on a great point bar (Harrison and others, 1986; Alt, 2000) during the Lake Missoula floods. During the floods, more than 200 million cfs (estimated from Pardee's 1942 calculations) passed this point. Now **that** would have been a river trip! For comparison, historic peak flow has been near 70,000 cfs, most recently in 1997.

End of trip.

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FIELD TRIP GUIDE: GLACIAL LAKE MISSOULA FLOOD DEPOSITS AND RELATED FEATURES OF THE RATHDRUM PRAIRIE, IDAHO

Roy M. Breckenridge and Kurt L. Othberg - Idaho Geological Survey

INTRODUCTION

During the last ice age, a lobe of the Cordilleran ice sheet advanced from Canada into the Idaho Panhandle, blocked the mouth of the Clark Fork River and created Lake Missoula. At maximum extent this glacial lake was up to 2,000 feet deep and covered 3,000 square miles of western Montana. Catastrophic failure of the Clark Fork ice dam released 500 cubic miles of water at a rate 10 times the combined flow of all the present-day rivers on earth. The torrent of water and ice thundered across the states of Montana, Idaho, Washington, and Oregon at speeds more than 65 miles per hour to the Pacific Ocean. The enormous energy of the flood water carved the land into canyons and cataracts, excavated more than 50 cubic miles of soil and rock, piled boulders in huge gravel bars, and drowned entire valleys in beds of mud. The continuous southward flow at the ice front repeatedly blocked the Clark Fork River and refilled Lake Missoula. This cycle was repeated until about 12,000 years ago at the end of the ice age. The latest episode of flood outbursts occurred from about 17,000 to 12,000 years ago.

In 1923, Professor J Harlen Bretz of the University of Chicago began publishing a series of papers explaining the origin of the Channeled Scabland in eastern Washington. He attributed this system of dry channels, coulees, and cataracts to an episode of flooding on a scale larger than geologists had ever recognized. His hypothesis was disputed by prominent geologists, and the resulting controversy is one of the most famous in geologic literature. Bretz's ideas for such large-scale flooding were viewed as a challenge to the uniformitarian principles then ruling the science of geology. After additional evidence by J.T. Pardee showed a source for the floods, Bretz's persistence resulted in his ideas becoming accepted.

OUTLINE OF GEOLOGIC FIELD TRIP OF RATHDRUM PRAIRIE

Today the effects of the ice age floods can be observed in an area covering 16,000 square miles in four states. The main flood route from Lake Missoula was from the south end of Lake Pend Oreille across the Rathdrum Prairie and the Spokane Valley. This field trip will explore some of the flood deposits and features in the Rathdrum Prairie and the "break out" from Lake Pend Oreille. The trip consists of 8 stops in the Rathdrum Prairie area in a loop north from I-90 in Coeur d'Alene that returns to I-90 near Post Falls. The field trip begins on the north shore of Coeur d'Alene Lake at Rutledge Point on Lake drive. The trip proceeds west on I-90 to U.S. 95 north to Athol and west through Farragut State Park and Lake Pend Oreille, then returns to U.S. 95 and Athol, west on Highway 54 to Highway 41 then south on Highway 41 through Rathdrum to I-90. Figure 1 is a map of the field trip route and location of Stops 1 through 8.

TRIP LOG

Mileage

0.0 Stop 1– *Rutledge Point- Centennial Trail*

Coeur d'Alene Lake is the second largest lake in Idaho and is dammed by Lake Missoula flood gravels here on the north. Due to its origin as drowned river system it has a numerous bays and an extensive shoreline. The lake is fed by the St. Joe and Coeur d'Alene river systems and is the source of the Spokane River, a tributary of the Columbia River. Glacial Lake Missoula floods inundated the area occupied by the present lake basin and drained west through

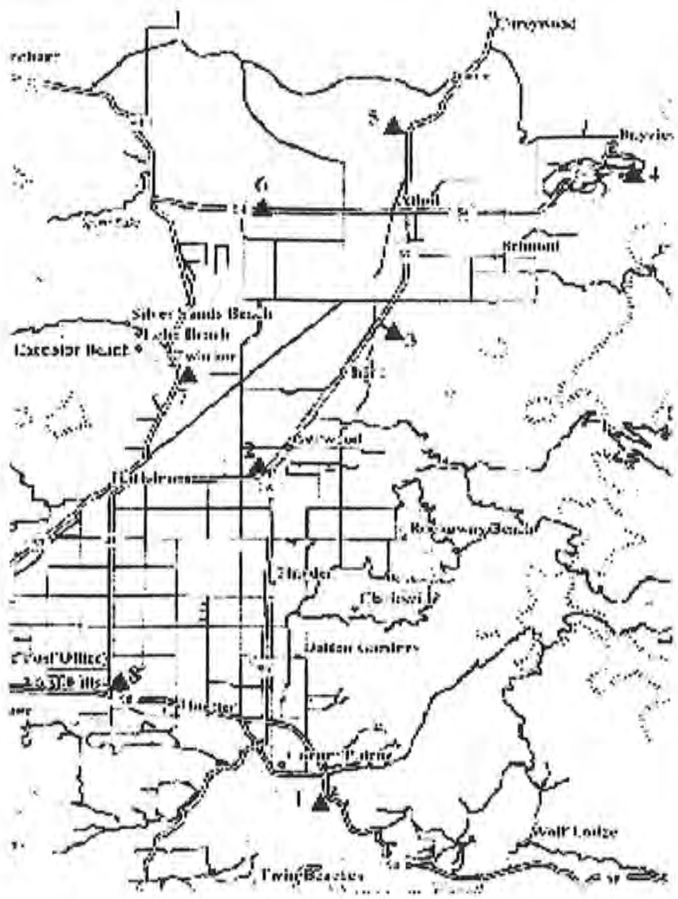

Figure 1. Map of trip route and location of stops.

Rathdrum Prairie and the Spokane Valley except for one overflow outlet at Setters that crossed the Coeur d'Alene drainage divide into Latah Creek. The high water level marked by ice rafted erratics is at least as high as 2,600 feet around the lake (Dort, 1960). Flood scour features are common in the basalt rimrock around the lake. Some early geologists extended the southern ice limit as far as the city of Coeur d'Alene and considered Tubbs Hill as ice scoured. A recent profile of the lake bottom between Tubbs Hill and Arrow Point by the U.S. Geological Survey reveal spectacular giant current ripples.

References: Breckenridge, R.M. and K.L. Othberg, 1999, *Surficial Geologic Map of the Coeur d'Alene Quadrangle, Kootenai County, Idaho:* Idaho Geological Survey SGM-7, 1:24,000.

Lewis, R.S., R.F. Burmester, R.M. Breckenridge, M.A. McFadden, and J.A. Kauffman, in press, *Geologic Map of the Coeur d'Alene 30' x 60' Quadrangle, Kootenai and Shoshone Counties, Idaho,* Idaho Geological Survey, 1:100,000.

Return to Sherman Avenue via Lake Drive. Turn right at the stop light and take the I-90 West entrance. Take I-90 west to the U.S. 95, exit 12, and turn north on U.S. 95 to Highway 93.

11.9

11.9 Stop 2 *Gravel Pits* (all private)

Several sand and gravel operations produce commerical aggregate from the flood deposits near this intersection. Access is by special permission only. By arrangement we will visit one of the operations to observe the texture, fabric and stratigraphy of the flood gravels. The suite of rock types contains clasts derived from the basin of glacial Lake Missoula in Montana as well as from the Purcell trench in Idaho and British Columbia. Large boulders of granitic rock types and metasedimentary rocks of the Precambrian Belt Group are most common. Large intact basalt columns are derived locally from the rimrock nearby. Large scale foreset beds tens of feet thick are common. The high energy clast-supported gravels have little if any matrix and high porosity. The $CaCO_3$ content and bulk density of samples taken from the cemented gravel unit were determined in the laboratory. Measured $CaCO_3$ content within the gravel unit is variable and averages ~10% by weight. This openwork fabric results in the remarkable water capacity of the Rathdrum Prairie–Spokane aquifer that serves nearly 400,000 people in the two-state area.

Reference: Breckenridge, R.M., and K.L. Othberg, 1999, *Surficial Geologic Map of Hayden Quadrangle, Kootenai County, Idaho*: Idaho Geological Survey SGM-8, 1:24,000.

Continue north on U.S. 95 to Corbin Road. Turn right on Corbin Road to Rimrock Road, turn left and stop at overlook.

7.3

19.2 Stop 3– *Rimrock View*

The Purcell Trench, a major topographic depression in British Columbia and northern Idaho, is incised into the margin of a metamorphic and granitic complex that formed during Mesozoic convergent tectonics, but later was subjected to Eocene extension. To the north, the trench is bounded on the west by the Selkirk Range and on the east by the Cabinet Mountains. Here it is bounded by the Mt Spokane upland on the west and the Coeur d'Alene mountains on the east. The Purcell Trench has been the site of several drainage reversals. Prior to the Miocene, an ancestral river flowed within the Purcell Trench from the Canadian border south to the Coeur d'Alene area in a meandering pattern following the least resistant rock exposures and fault zones. This pattern is still apparent in the present day meandering shape of Lake Pend Oreille. During the Miocene, the Columbia River basalt flows filled drainage systems and reversed the drainage in the Purcell trench to the north. Some of the younger valley-filling basalts are exposed in Hoodoo Channel.

From this view the main path of the flood outbursts from the Pend Oreille Lake basin can be followed across the trench and south toward Coeur d'Alene and west to Spokane. Another floodpath was to the north down the Hoodoo valley to the Pend Oreille River and Little Spokane River via Newport, Washington. The water scoured as high as 3,450 feet on Round Mountain. Flood bars filled the side valleys of the Prairie and formed Spirit, Twin, Hayden, Newman, Liberty and Coeur d'Alene lakes.
Return to U.S. 95 and continue north past Silverwood theme park to the Highway 54 stop light in Athol. Turn right on Highway 54 to Farragut State Park. Check in at the visitor center. Fees apply. Take the South Road to the Sunrise/Willow Day use areas.

13.5

32.7 Stop 4– *Farragut State Park, Sunrise - Willow Day use area*

One of the largest and deepest lakes in North America, Lake Pend Oreille was carved repeatedly by a lobe of Pleistocene ice, scoured by ice age floods and filled with glacial outwash and flood deposits. The location of the lake is probably related to an old river valley controlled by faults. The lake is similar to a glacial fiord overdeepened by the combined erosion of the glacier and the release of catastrophic floods from Glacial Lake Missoula. The lake is now dammed at the south end by thick glacial and flood deposits underlying Farragut State Park. During the last-glacial maximum nearly 15,000 years ago a glacier more than 3,000 feet thick occupied the lake basin and terminated at the park area.

Farragut State Park is located at the "breakout" of Glacial Lake Missoula floods. Failure of the ice dam in the Clark Fork valley fractured and broke apart the 20-mile-long tongue of ice occupying the lake basin and a torrent of water and ice burst from the lake. Churning flood waters flowed 2,000-feet deep across Farragut State Park.

J.T. Pardee of the U.S. Geological Survey first studied Glacial Lake Missoula in 1910 but it was until the early 1940s before he presented evidence for rapid drainage of the large ice-dammed lake. He estimated the lake contained 500 cubic miles of water and drained at a rate of 9.46 cubic miles an hour. Pardee's explanation of unusual currents and flood features in the lake basin provided Bretz with the long-awaited source for flooding in the Channeled Scabland. More recent calculations have increased the original estimate. Recently geologists' attention has mostly focused on the recognition of evidence for multiple floods and timing of the ice age events.

One of the most intriguing questions about the catastrophic flooding is how the ice dam failed. Various mechanisms for glacial outburst floods have been proposed: Ice erosion by overflow water, subglacial failure by flotation, deformation of ice by water pressure, and erosion of subglacial tunnels by flowing water. One popular model suggests a self-dumping phenomenon. In this mechanism, flood waters are released when the lake level reaches nine-tenths the height of the ice. At this depth the increasing hydrostatic pressure makes several things happen: The ice becomes buoyant, subglacial tunnels form and enlarge, and drainage occurs until hydrostatic pressure is decreased and the ice again seals the lake. The self-emptying model is used to explain the numerous cycles in the rhythmite deposits and to interpret each cycle as a separate flood. Even so, geologists argue that only the total collapse of the ice dam can explain the largest of the catastrophic floods.

At its deepest, Lake Pend Oreille is now about 1100 feet deep. Little is known about Lake Pend Oreille basin because the lake bottom has never been cored. United States Navy seismic reflection surveys performed on the lake show that the bedrock lake basin has been glacially overdeepened to a depth more than 500 feet below present-day sea level. The seismic sections show a record of subglacial erosion, Missoula Flood deposition, and a post-flood glacial readvance.

Reference: Breckenridge, R.M, and K.F. Sprenke, 1997, *An overdeepened glaciated basin, Lake Pend Oreille, northern Idaho*, Glacial Geology and Geomorphology, RP03, John Wiley.

Return to Highway 54 by turning right off South Road on Kinglet and then left to the highway. Turn right and continue through Bayview. Return to U.S. 95 by turning right off Perimeter Drive on Careywood Drive. Turn left (south) on U.S. 95. Turn right on Homestead Road. **Stop and cross** the railroad tracks with care and park near the large boulders.

13.5

46.2 Stop 5– *Gravel Bar / Railroad Cut*

This railroad cut provides view through the middle of a huge gravel expansion bar deposited by floods from the outburst area. The huge boulders stacked here were removed from the cut which was recently widened to accommodate double track. Position of the boulders in the bar indicates that they were not ice-rafted but carried in the bedload of the high-energy flood waters.

Return to U.S. 95 and turn south to the junction with Highway 54 in Athol. Turn right on Highway 54 to a large turnout at Ramsey Road.

7.6

53.8 Stop 6– *Giant Current Ripples– Ramsey Road*

One of Bretz' most important pieces of evidence for catastrophic flooding was the "giant current ripples." These large-scale bedforms appeared as patterns of parallel ridges and swales on many aerial photographs in the flood channels in the scabland of Washington, but had escaped recognition from the ground because of their large size. A study by Victor Baker found crests range from 50 to 400 feet apart and from 5 to 30 feet high. The ripples form transverse to the current direction and form cusps that are convex upstream. As in dunes the arms point downstream. Furthermore, the size of the cusps appears to decrease in the direction of lower velocity. Internally the ripples consist of gravel and pebble foresets. Giant current ripples exhibit an asymmetrical profile with the downstream (lee) slope steeper than the upstream slope. The height of the crests and distance between crests as well as the particle size show consistent relationships that can be related to flow parameters such as the depth, velocity, and stream power in which they formed.

The Spirit Lake current ripples can also be easily recognized from the air by their characteristic pattern accentuated by vegetation. This ripple field is immediately in the path of the breakout from Lake Pend Oreille and experienced some of the highest energy flows. These ripples are among the largest measured throughout the scabland. The number of crests between highway mile markers can be readily counted while driving this section of Highway 54.

Continue west on Highway 54 to the junction with Highway 41. Turn south on 41 toward Rathdrum. Depending on traffic and road turnouts, pick a safe spot to turn off and inspect one of the boulders along the right of way.

9.3

63.1 Stop 7– *Huge Flood boulders- Scarcello Road*

Several clusters of giant boulders are located along the highway between Spirit Lake and Twin Lakes. The boulders are mostly a granodiorite similar to an outcrop near Bayview. The rock type plus the fact that geophysical surveys of the immediate area reveal an ancestral valley, shows the boulders are not outcrop but have been transported. The largest boulder measures 49 by 40 feet and weighs over 1,600 tons. Their size seems anomalously large even for catastrophic floods. Perhaps they were deposited by a tremendous base surge or were rafted in a great berg of the disintegrated ice lobe.

Source: Jim Browne, unpublished report.

Continue south on Highway 41 through Rathdrum to Mullan Ave. Turn left at light on Mullan and right to the Highlands on Sterling Ave. At the top of the grade turn left on Inverness and park in the parking lot.

11.4

74.5 Stop 8– *Ross Point- Highlands*

From this viewpoint one can visualize the size of the catastrophic floods moving across Rathdrum Prairie and west through the Spokane Valley. The trimline of flood-water erosion on the bedrock south of Post Falls is above 2600 feet in elevation. That is a depth of 400 feet across the prairie between Rathdrum and Post Falls and 250 feet above Ross Point. Multiple episodes of flood erosion and deposition have left a complicated record in the Rathdrum gravels. Ross Point is a remnant of one of the oldest floods that has been dissected by later and mostly smaller floods. It is likely that the evidence for even older floods and ice advances have been removed by the latest flood events.

Some early workers did not accept the catastrophic flood hypothesis and considered the deposits and landforms in the Spokane Valley and eastern Washington as glacial in origin. Features like those impounding Liberty Lake, Newman Lake, Coeur d'Alene, and Twin Lakes were interpreted as lateral moraines. Even Bretz did not consider the gravels as flood in origin. Most geologists today consider the deposits in the valley to be of flood origin, although it is not known how much of the deposits may represent reworked till or glacial outwash. In either case, the gravels are an important sole-source aquifer for the region. The hydrology of the aquifer is not well understood. In some reaches the Spokane River recharges the aquifer while in others the aquifer discharges to the river. Little subsurface stratigraphy has been documented, mainly because most wells have been so productive there has been no incentive to study the stratigraphy. No known wells penetrate the entire section of the aquifer. Gravity studies of the Rathdrum Prairie and Spokane Valley indicate the bedrock may be as much as 1000 feet deep at Highway 41.

Reference: Breckenridge, R.M., and K.L. Othberg, 1999, *Surficial Geologic Map of the Post Falls Quadrangle and Part of the Liberty Lake Quadrangle, Kootenai County, Idaho*, Idaho Geological Survey SGM-5, 1:24,000.

Return to Idaho 41. Turn left on 41 to the I -90 intersection.

75.2 End of trip

ROAD LOG TO THE BELT SUPERGROUP ALONG THE NORTH FORK OF THE COEUR D'ALENE RIVER, NORTHERN IDAHO

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INTRODUCTION

This road log to the Belt Supergroup around Wallace, Idaho, is based on the results of recent regional studies by the Idaho Geological Survey and the U.S. Geological Survey. Geologic maps have been produced from a combination of new and existing research on the following four 30' x 60' quadrangles: St. Maries (Lewis and others, 2000), Coeur d'Alene (Lewis and others, 2001), Thompson Falls (Lewis and Derkey, 1999), and Wallace (Lewis and others, 1999). This road log covers the eastern part of the Coeur d'Alene quadrangle and the westernmost Thompson Falls quadrangle. Additional information on the geology of the Coeur d'Alene mining district is available in Bennett and others (1989), White and others (2000), and Winston (2000).

REGIONAL GEOLOGY

The North Fork of the Coeur d'Alene River drains an area almost entirely underlain by low-grade metasedimentary rocks of the Middle Proterozoic Belt Supergroup (Figure 1). The Belt Supergroup is a thick sequence of siliciclastic rocks deposited about 1470-1400 Ma (Anderson and Davis, 1995; Evans and others, 2000). The lower part of the Belt (Prichard Formation) was deposited in relatively deep water under anoxic conditions (Cressman, 1989). Intrusion of mafic magmas to form extensive sills probably contributed to subsidence as the sills cooled. Units above the Prichard were deposited in relatively shallow water (near or above wave base) and under more oxidizing conditions. Algal mats and sedimentary structures such as mudcracks and salt casts are well preserved in the younger Belt rocks (Winston, 1986). Excellent examples of these sedimentary structures are present in outcrops along the North Fork of the Coeur d'Alene River. Isolated outcrops of Cambrian sedimentary rocks are present in the area west of the field trip route. The Cambrian rocks were deposited on a regional angular unconformity (Campbell, 1959).

Much of the Belt Supergroup along the North Fork is gently dipping. A broad open syncline cored by the Striped Peak and Libby Formations is present to the west (Figure 1). The western part of this syncline is disrupted by north-south faults of the Magee fault zone. Rocks in this fault zone are steeply dipping to overturned, and the stratigraphic section is repeated by faults. The Magee fault zone is suspected to be a compressional structure that underwent subsequent extension. However, no detailed mapping has been done in this area, and neither the dip direction nor the vergence of the fault zone is certain. Two large down-to-the-west normal faults displace the Belt Supergroup along the North Fork. The westernmost fault (Big Pool fault) will be viewed during the trip.

REGIONAL NOMENCLATURE

The nomenclature for Belt Supergroup units is complicated by formation names in northern Idaho that differ from those developed separately in western Montana (Figure 2). We have adopted "Idaho terminology" similar to that of Hobbs and others (1965) and Griggs (1973), with the exception of the term lower Wallace Formation. Here, we follow the usage

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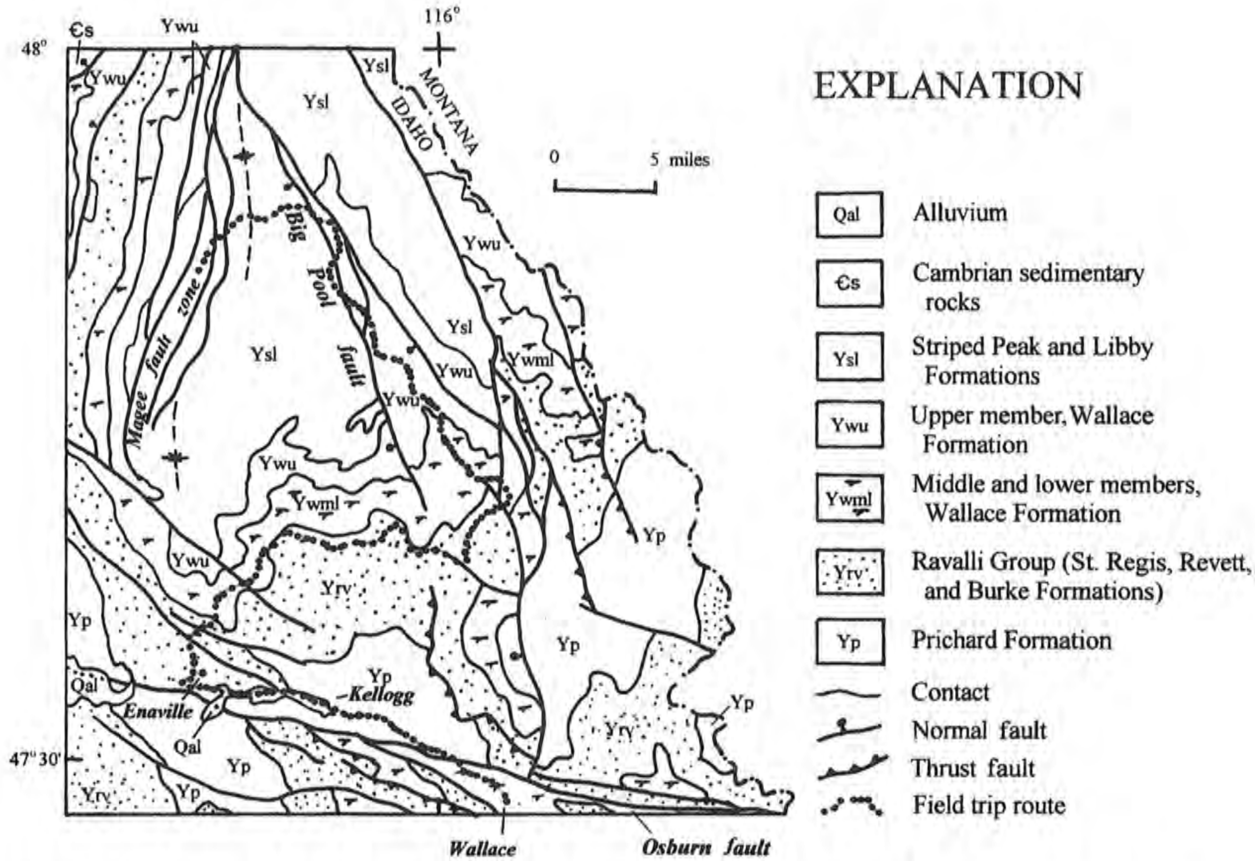

Figure 2. Simplified geologic map of the area north of Kellogg, Idaho. The dotted line shows the field trip route.

of Harrison and others (1986) and subdivide the former lower Wallace into informal middle and lower members. The subdivision of the Striped Peak Formation parallels the divisions Harrison and Jobin (1963) used in the Clark Fork quadrangle, immediately north of the area, although we assign numbers (1-4) rather than lithologic names. A more straightforward regionwide stratigraphic nomenclature is currently being pursued by Don Winston and the authors. A likely outcome includes assigning formation rank to the present member 1 of the upper Wallace Formation, and assigning upper members 2 and 3 to the easily recognized Shepard Formation. Descriptions of sedimentary structures in this guide follow the terminology of Winston (1986).

GEOLOGIC FIELD TRIP ALONG THE NORTH FORK OF THE COEUR D'ALENE RIVER

The field trip will depart Wallace and proceed west on I-90 to the Sunshine Mine Disaster Memorial at the mouth of Big Creek. Take Exit 54 on I-90 approximately 5 miles west of Wallace. The memorial and Stop 1 are on the north side of the Interstate. From this point, the trip will continue about 11 miles west to Kingston, where it will progress generally northward along the North Fork of the Coeur d'Alene River for approximately 55 miles to the historic U.S. Forest Service Ranger Station at Magee (Figures 3 and 4). Because the local strata are dipping gently north, stops proceed roughly in stratigraphic order from the Prichard

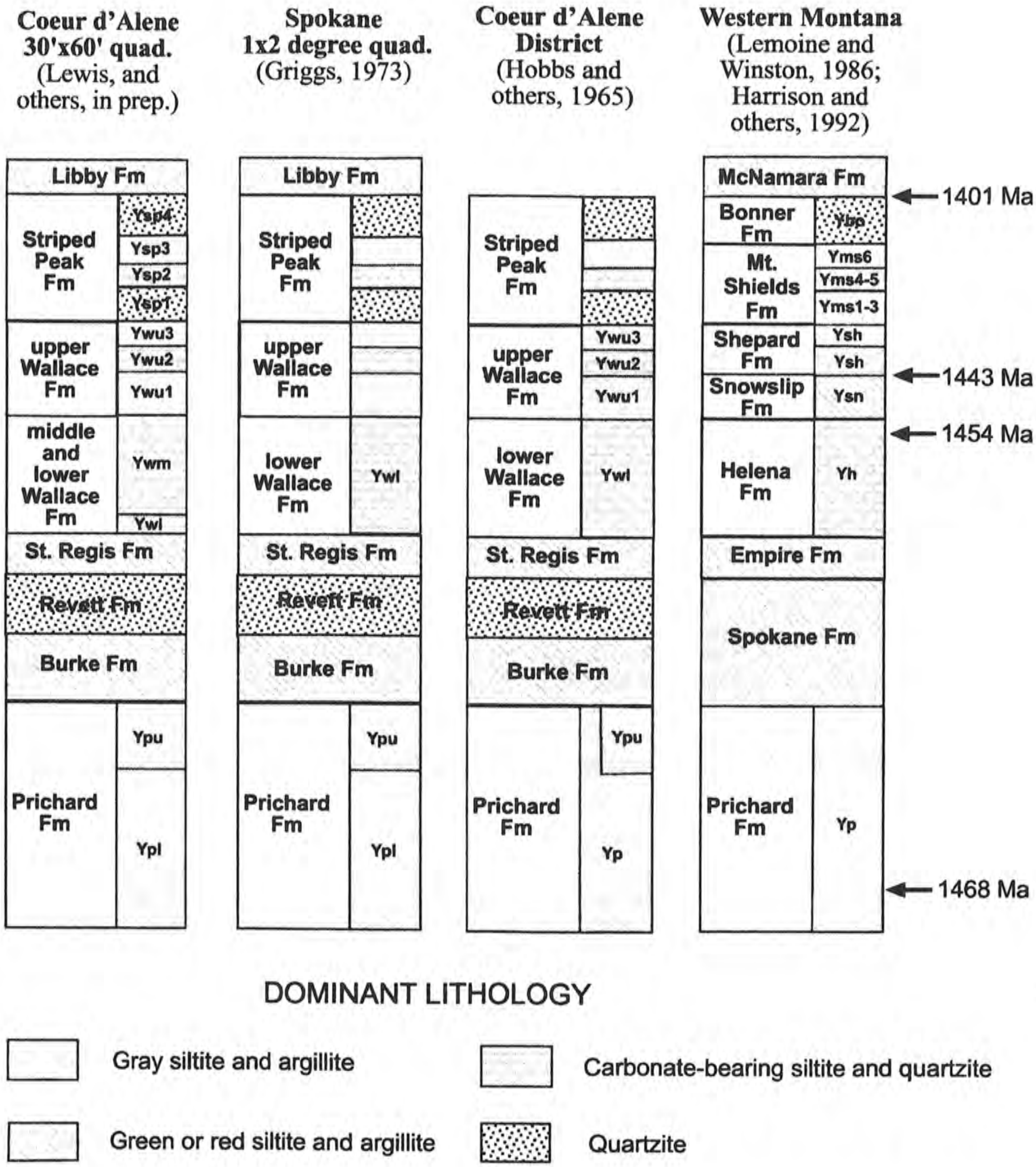

Figure 2. Summary of Belt Supergroup nomenclature in the Coeur d'Alene quadrangle and surrounding area. Ages are from igneous rocks (sills, tuffs, and flows) within the stratigraphic sequence (Evans and others, 2000; Anderson and Davis, 1995).

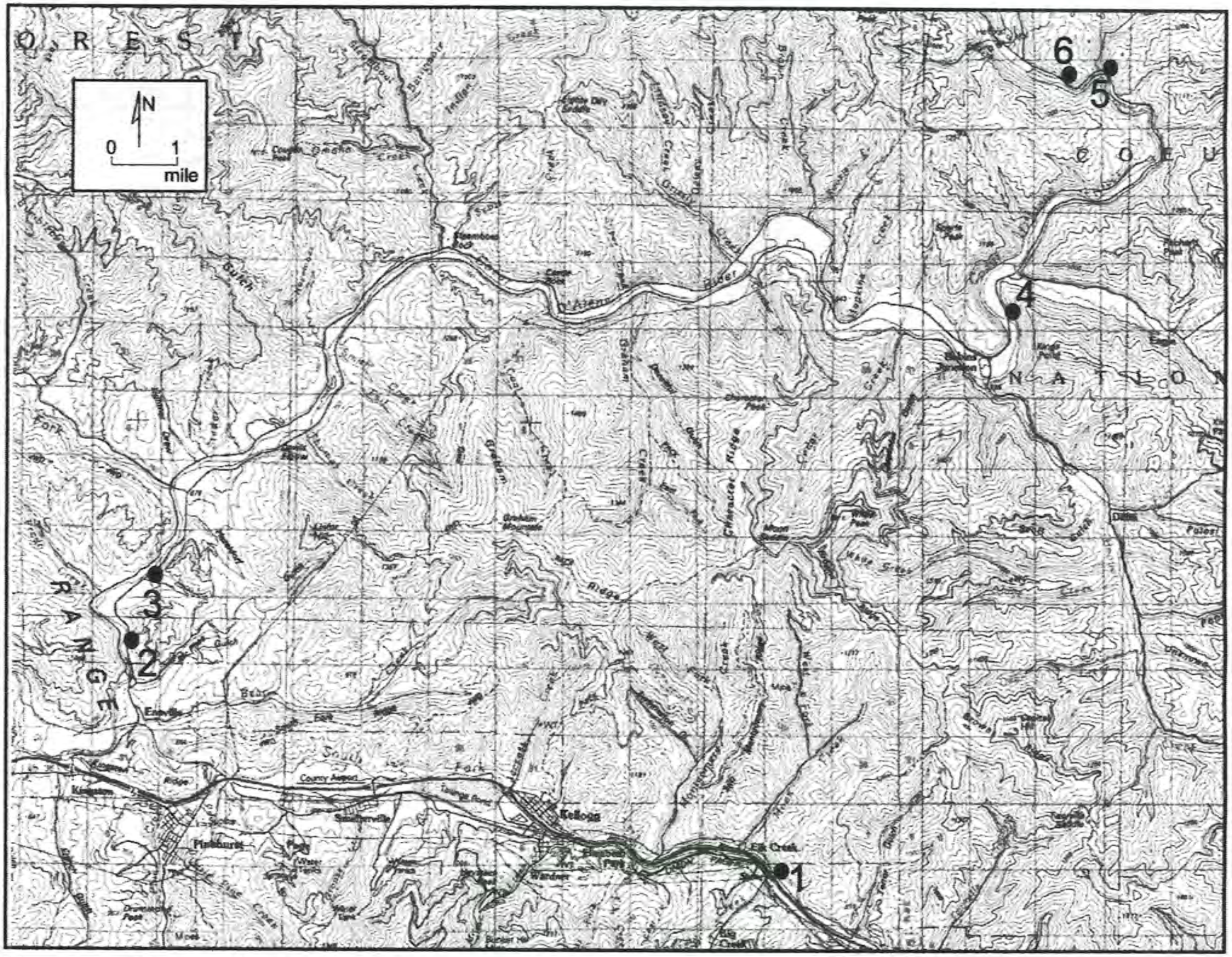

Figure 3. Location map showing stops 1-6.

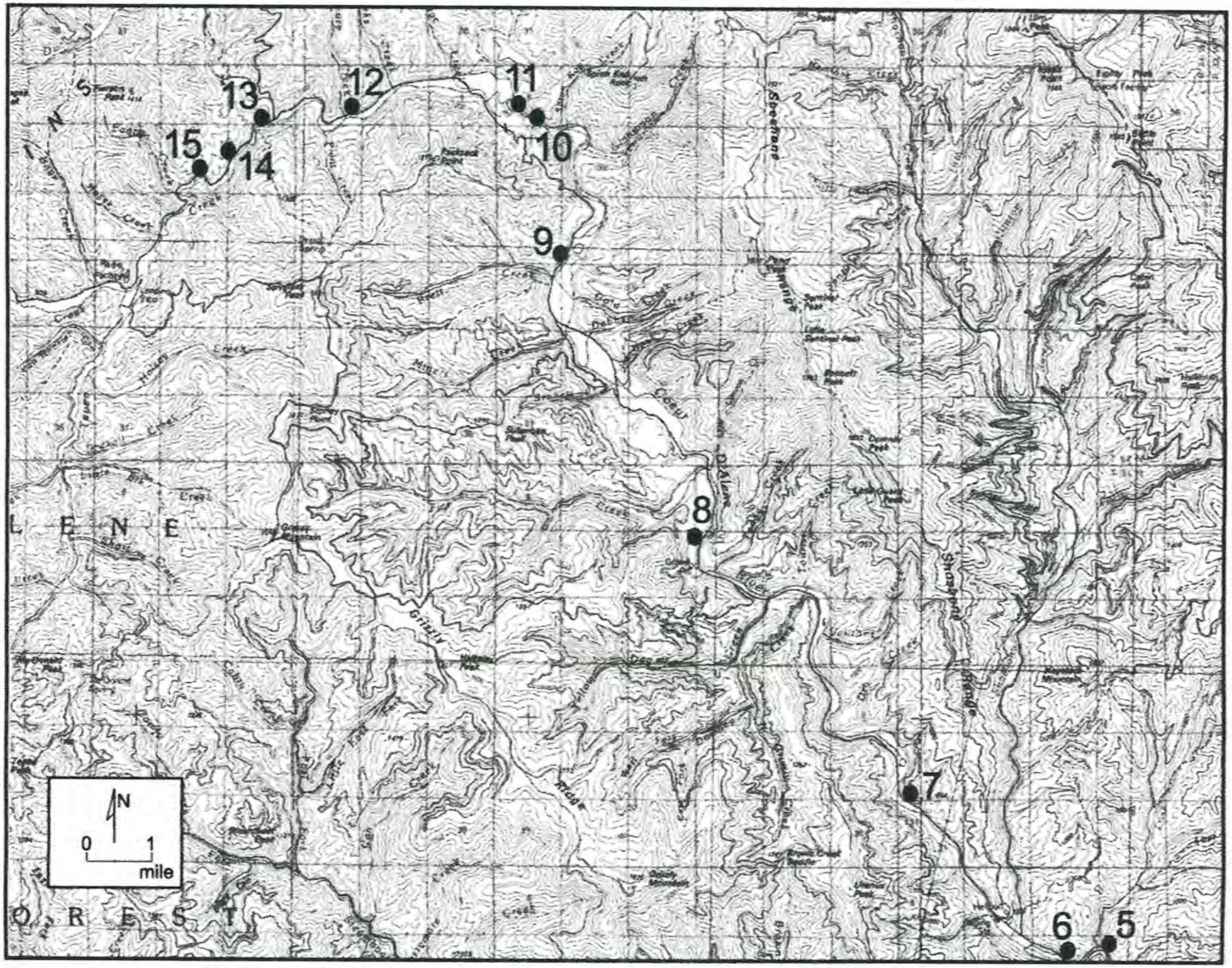

Figure 4. Location map showing stops 5-15.

Formation through the Ravalli Group, the Middle Belt carbonate, and the Striped Peak Foramation. Beware that the mileages given in the road log are from an uncalibrated odometer, but differences from mileposts should be fairly accurate in the road log are from an uncalibrated odometer, but differences from mileposts should be fairly accurate.

Mileage

0.0 Stop 1 – *Prichard Formation.*

The recently closed Sunshine Mine to the south in the Big Creek drainage is the nation's largest silver mine, with more than 100 miles of tunnels extending to depths of over 1 mile. On May 2, 1972, a fire in the mine took the lives of 91 miners. The memorial's sculpture with the eternal flame in the miner's headlamp commemorates the men and the tragedy.

Outcrops of the Prichard Formation of the Belt Supergroup surround the Sunshine Mine Disaster Memorial. Dark gray, rusty-weathering, very thinly bedded to laminated siltite and argillite couplets are present. Minor 10-cm-thick quartzite beds are interspersed in the sequence. Soft sediment deformation features such as small-scale syndepositional folds are common within the outcrops. Although sulfide-bearing, dark, thinly laminated siltite-argillite is characteristic of the Prichard Formation, similar lithologies occur at higher stratigraphic levels too. Take the Interstate entrance and proceed west on I-90.

1.5 Extensive exposures of rusty-weathering Prichard Formation crop out along the north side of the Interstate.

2.2 Crystal Gold Mine portal and outcrops of Prichard Formation are visible on the right (north). Gold is relatively rare in this mining region commonly referred to as the "Silver Valley."

3.5 Kellogg at I-90 Exit 51. Continue westward on I-90. Kellogg and the adjacent town of Wardner were the hub of silver mining in the area around the turn of the century. Tourism, now a major economic draw for the area, is exemplified by the gondola that ferries skiers and tourists to the summit of Silver Mountain to the south.

4.2 The remains of the famous Bunker Hill silver mine are visible on the hillside to the left (south).

4.7 The lining and capping of tailings piles adjacent to the Interstate on the left (south) are part of current efforts to control toxic mine waste and prevent contamination of ground water in the Silver Valley.

5.1 Stream rehabilitation and channel restoration are evident on the South Fork of the Coeur d'Alene River to the right (north).

5.9 Note the damaging effects caused by the old Bunker Hill smelter on vegetation across the valley to the left (south). Smelter gasses proved particularly toxic to young trees, inhibiting the growth of forests for decades following early logging and forest fires.

6.9 The tallest prominent peak to the west-southwest is Striped Peak, the type area for the Striped Peak Formation of the Missoula Group, Belt Supergroup. The unit there includes rocks equivalent to the Mount Shields and Bonner Formations in "eastern" or "Montana terminology" (Figure 2).

8.0 Stream rehabilitation is visible on both sides of I-90. Channel restoration and revegetation of the floodplain are in progress after considerable effort to remove contaminated sediment.

8.6 Quarry in medium- to thick-bedded quartzites mapped as Burke is visible on the left (south). Quartzite is an important local industrial material for roadbuilding and general construction. Several small quarries are evident along I-90 in the Silver Valley.

11.1 Interstate milepost 44. Take Exit 43 (Kingston Exit) to the right (north). Turn north on National Forest Road 9 toward Enaville. The route will now follow the North Fork of the Coeur d'Alene River upstream.

12.5 Bridge over the South Fork of the Coeur d'Alene River.

12.6 Enaville and the legendary Snake Pit bar are on the right. This former "sporting establishment" has been a famous local watering hole and eatery for decades. Be careful to abide by local speed limits; they are enthusiastically enforced.

13.3 The highway crosses under the local "diving bridge," where summer swimmers take the plunge. Optional stop on particularly warm days.

13.9 Stop 2 – *Burke Formation*

Parking turnout to the left (west) along the river. High cliff exposures of the Burke Formation are crosscut by narrow basaltic dikes. Dark gray siltite-argillite couplets with scattered mudcracks dominate the strata here, although flat-laminated gray to white quartzites are also locally common. Macroscopic magnetite octahedra are characteristic of siltites of the Burke Formation. This outcrop has strong cleavage. Continue upriver (northward) on Forest Road 9.

15.2 Stop 3 – *Revett-St. Regis contact*

Parking turnout to the left (west) along the river. Blocky weathering, tabular 0.5-1.0-m-thick quartzite beds of the upper Revett Formation contain abundant load casts. Although faults are visible in the roadcut, offset appears to be minor and does not interrupt upward grading of the Revett into the overlying St. Regis Formation. Strong cleavage evident in the St. Regis at this location obscures mudchip layers and mudcracks typical of the unit. Both red and green St. Regis siltites and argillites are present in this outcrop.

16.6 Junction to left (west) is the turnoff to Bumblebee Campground on the Little North Fork of the Coeur d'Alene River. Continue straight ahead upriver (north) on Forest Road 9.

17.2 Milepost 6 on Forest Road 9.

23.1 Milepost 12 on Forest Road 9.

23.5 Prominent cliffs across river to the left (west) expose thinly bedded St. Regis Formation. Although the St. Regis is predominately composed of siltites and argillites, it typically forms resistant outcrops in this lower section of the river corridor.

23.9 Castle Rock across river to the left (west).

24.4 Panhandle National Forest boundary sign.

25.8 Cliff-forming outcrops of St. Regis Formation across river to the left (west).

28.0 Outcrops of Revett Formation on the right (east) are medium- to thick-bedded, cliff-forming quartzites.

28.3 Milepost 17 on Forest Road 9.

29.7 Highway crosses bridge to the north side of the river.

32.4 Milepost 21 on Forest Road 9.

32.6 Babin's Junction. Babin's Grocery on right (east) is the last chance for gasoline and groceries on the route upriver.

33.3 Stop 4 – *Prichard Bridge Picnic Area*

Milepost 22 on Forest Road 9. Turn off to right (east) into the parking area. This coffee and rest stop area is decorated with large, randomly oriented boulders of the Prichard Formation transported by road crews from the Silver Valley. The boulders are weathered to reveal lithologic details of the laminated "lined unit" of the Prichard Formation, as well as typical soft sediment deformation structures.

34.1 Turnoff to right (east) leads to the Prichard Tavern. Proceed straight ahead northward on an upriver course. Remember this turnoff for "R and R" on return journey downriver.

34.3 Milepost 23 on Forest Road 9.

37.2 Slide area on the right, bridge on left (west) over river. Proceed straight ahead northward on Forest Road 9.

37.4 Milepost 26 on Forest Road 9.

39.1 Stop 5 – *St. Regis Formation*

Good roadcut exposures of upper St. Regis Formation contain abundant mudchip layers and minor tan-weathering carbonate in siltite-argillite couplets. Laminated green siltite-argillite-precursor beds" of the overlying lower Wallace Formation also contain minor tan-weathering siltite and black argillite couplets that resemble the "black and tan" of the middle Wallace Formation.

39.5 Stop 6 – *Lower Wallace Formation*

Turn onto shoulder area on the right (east) next to prominent cliff roadcut. **Caution: This corner offers poor visibility to passing traffic and may be potentially hazardous for groups with several vehicles. A larger and safer pulloff is 0.2 mi further up the road.** Outcrop is stratigraphically near the contact with the underlying St. Regis Formation and contains lithologies typical of the lower Wallace Formation in the region. Laminated green siltite-argillite couplets are interbedded with minor 10-cm-thick white quartzite beds. Common lithologies and structures include brown-weathering, conchoidally fracturing dolostone and dolomitic siltite, and ptygmatic (squiggley) cracks in the siltite-argillite couplets.

39.7 Turnout to left (west): better access to Stop 6 for parking with several vehicles.

40.5 Intersection with Jordan Saddle Road 412 on right (east). Proceed straight ahead upriver (northward) on Forest Road 9.

40.6 Bridge over Shoshone Creek.

40.8 Rest Area on right (east) adjacent to old U.S. Forest Service Shoshone Work Center.

41.0 Little Guard Lookout Road junction to the right (east). Optional side trip to the lookout provides excellent views of the area and good exposures of sedimentary structures in the Striped Peak Formation.

41.2 Outcrops of middle Wallace Formation on the right. Calcareous (tan-weathering) 10-cm-thick quartzites with black argillite caps are common.

41.3 Milepost 30 on Forest Road 9.

42.3 Cross Jupiter Creek.

42.8 Stop 7 – *Middle Wallace Formation.*
Outcrops of typical tan-weathering, calcareous siltstone in couplets with thin black argillite caps (black and tan). Couplets are pinch and swell with prominent gutters apparent in outcrop. Polygonal mudcracks are common in talus at base of outcrop; true mudcracks of this type are uncommon within the middle Wallace to the southeast, where incipient "birdsfoot" cracks abound.

42.9 Road 802 junction to right.

43.6 Cross bridge over North Fork of the Coeur d'Alene River.

43.8 Kit Price Campground entrance on right (east).

45.2 Approximate contact of middle Wallace and upper Wallace units.

46.3 Good exposures on left of cliffy uppermost middle Wallace.

46.5 Pullout on right (east) next to river for parking and access to next entry.

46.6 Stromatolite horizon in uppermost middle Wallace Formation. Stromatolite horizons are unusual in the Wallace Formation in this area of northern Idaho.

47.0 Devil's Elbow Campground entrance to right (east).

48.0 Pullout on right (east) next to river just before Yellowdog Creek. Exposures of upper Wallace I. Note to flyfishers: Here starts the catch and release fishing on the North Fork of the Coeur d'Alene River. Abandon all barbed hooks, ye who would fish here.

49.1 Bridge over North Fork of the Coeur d'Alene River.

49.7 South end of bridge over North Fork of the Coeur d'Alene River. Turn left (west) at north end of bridge for Stop 8.

49.8 Stop 8 – *Upper Wallace member 1*
Unit is exposed in massive roadcut cliffs along abandoned highway loop. The upper Wallace member 1 here is characterized by rusty-weathering uneven couplets and laminations of greenish, fine-grained quartzite or siltite to dark green argillite. Large, straight-sided cracks visible on bedding plane surfaces commonly disrupt lamination to a depth of several centimeters. These cracks are rarely associated with mudchips and are interpreted as water-escape structures; only near the upper contact of member 1 are true desiccation cracks and mudchips common. The crushed and shattered rocks to the west result from movement on a down-to-the west normal fault named the Big Pool fault.

49.9 Re-enter highway after Stop 8 and continue left (northward) upriver.

50.4 Milepost 39 on Forest Road 9.

50.9 Flat Creek.

52.5 Milepost 41 on Forest Road 9.

52.7 Big Pool fault zone visible in roadcut on left that exposes crushed and shattered outcrop with abundant water emerging from springs. Fault has brought Striped Peak Formation down on the west side.

53.1 Bridge over North Fork of the Coeur d'Alene River.

54.3 Bridge over North Fork of the Coeur d'Alene River.

55.2 Brett Creek.

55.6 Stop 9 – *Striped Peak member 1*

Roadcut exposure of Striped Peak member 1 (argillite, siltite, and quartzite member of Harrison and Jobin, 1963). Pink, flat-laminated quartzites on a decimeter scale with 1- to 5- mm-thick red argillite drapes. This outcrop is replete with sedimentary structures and features, including large mudcracks, ripple marks, stromatolites, and characteristic diffuse tan-weathering carbonate wisps in the quartzites. To the north and east in Montana, this would be considered classic Mount Shields member 2 (Harrison and others, 1992).

56.3 Exposures of upper Wallace member 2 on right (east) side of highway.

56.5 Bridge over North Fork of the Coeur d'Alene River.

57.7 Cinnamon Creek.

58.5 Milepost 47 on Forest Road 9.

58.6 Stop 10 – *Upper Wallace member 2*

Pullout for parking on left (west) next to river. Upper Wallace member 2 in roadcut on right (east) side of highway. Unit consists of tan-weathering, calcareous siltites and argillites in uneven laminations to uneven couplets. Isolated ripple trains of fine sand to silt within thicker argillites are "starved ripples." Centimeter-wide straight cracks that penetrate bedding to 10 cm are associated with layers of flat rip-up pebble conglomerates. The upper Wallace member 2 is equivalent to the middle and lower parts of the Shepard Formation in western Montana (Lemoine and Winston, 1986).

58.9 Stop 11 – *Upper Wallace member 3*

Pullout on left, outcrop on right. The upper Wallace member 3 in the area is characterized by rusty-weathering, dark, laminated to thinly laminated siltites and argillites. Thin black argillite mudchips are present within silts as are rare 20-cm-thick very fine-grained white sand intervals. Unit is equivalent to the nondolomitic upper part of the Shepard Formation in western Montana (Lemoine and Winston, 1986).

59.2 Bridge. Cross the North Fork of the Coeur d'Alene River and proceed up Teepee Creek to northwest.

59.5 Milepost 48 on Forest Road 9.

60.0 Orange-weathering outcrop of "boxwork dolomite" of Striped Peak member 2.

60.1 Trailhead for Trail 309 on right (north).
60.4 Milepost 49 on Forest Road 9 – end of pavement! **Road narrows. Watch for oncoming traffic on corners!** Continue on upstream. The unpaved road is now Forest Road 6310.

61.1 Exposures of Striped Peak member 3 on right (north). Dark gray, iron-stained outcrops certainly resemble Prichard from a distance.

62.1 Stop 12 – *Striped Peak member 4*

Pullout on right. Decimeter-thick, tabular beds of flat-laminated pink quartzite with red argillite caps and subordinate wavy laminated green siltite-argillite layers 10-30 cm thick. Mudchips and detrital muscovite flakes are common. A few quartzite beds of 1-2 m thickness, as well as medium-grained sand lags, are present near the base of the unit. Equivalent to the Bonner Quartzite of the Missoula area (Nelson and Dobell, 1961)

62.4 Milepost 2, now on Forest Road 6310.

62.7 Continuous exposure of Striped Peak member 4 on right in roadcuts. More medium-bedded pink quartzites equivalent to Bonner Quartzite.

63.4 Striped Peak member 4. Pullout on left. Thick beds of pink quartzite (a few over 1 m) with 1- to 5- mm-thick red argillite drapes. Most beds are 0.5-0.3 m thick. Quartzites are generally flat laminated, although a few tangential cross beds are visible.

63.7 Striped Peak member 4. Intersection with Forest Road 3099 to north. Here Striped Peak member 4 is finer grained than typical Bonner Quartzite in type area. Continue straight ahead (west) on Forest Road 6310.

63.8 Bridge over Independence Creek. Continue straight ahead (west) upstream along Teepee Creek.

64.0 Stop 13 – *Striped Peak members 3 and 4*

Contact between Striped Peak member 3 (dark unit) and overlying Striped Peak member 4 (Bonner equivalent). Trail 407 across Teepee Creek to left. Contact is visible at first small tree on right (north). Rusty-weathering, dark laminated siltites and argillites are typical of Striped Peak member 3. Equivalent to member 6 of the Mount Shields Formation in the Kalispell quadrangle (Harrison and others, 1992) and the laminated argillite and siltite member of Striped Peak in the Clark Fork area (Harrison and Jobin, 1963). Gradation upsection into light green or pink flat-laminated quartzites typical of Striped Peak member 4. A few 1 mm coarse lags of sand; the thickest lags are white rather than green. Note detrital muscovite on bedding planes.

64.4 Milepost 4 on Forest Road 6310.

64.8 Stop 14 – *Striped Peak member 2*

"Boxwork dolomite" of Striped Peak member 2 (dolomite member of Harrison and Jobin, 1963), equivalent to Mt. Shields members 4 and 5 of Harrison and others (1992), is characterized by tan-weathering, white stromatolitic dolomite and tan-weathering, green dolomitic siltite. The distinct "boxwork" weathering pattern is formed by resistant, 1- to 2- mm thick vertical and horizontal siliceous stringers within typically flat algal mats. Rare 5-10-cm-thick layers of ooids are present in places. Striped Peak member 2 unit typically weathers recessively, resulting in benchlike topography in areas with relatively flat dips.

65.4 Stop 15 – *Striped Peak member 1*

Pullout on right (north) just before crossing of Cool Water Creek. Exposure of upper part of Striped Peak member 1 (Mount Shields member 3 "salt cast" member) contains both salt crystal casts and domal stromatolites. The bedding in these outcrops is slightly overturned. The steep dips in this area are features characteristic of the Magee fault zone. This fault zone, first recognized by Griggs (1973), is a series of north-south faults with steep(?) dips (Figure 1). The rocks are broken, and the stratigraphic sequence is repeated several times from here west beyond Magee Ranger Station. The timing, dip direction, and style of movement in this fault zone are uncertain. It may have been a compressional structure with later normal movement, but detailed mapping is needed to verify this hypothesis.

66.1 Road to left (south) leads to small local quarry in Striped Peak member 1 with shallow water sedimentary structures common.

67.6 Milepost 7 on Forest Road 6310. The historic Magee Ranger Station was built in 1932. The remaining facilities include a nice picnic area complete with rustic outhouse for visitors.

END OF TRIP – Return to I-90 either back down the road the way you came, or, to save a little time, continue south-southwest to Leiberg Saddle and down the Little North Fork of the Coeur d'Alene River. The Little North Fork road will pass Bumblebee campground and join the North Fork at mile16.6 of this road log.

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GUIDE TO A TOUR OF REMEDIAL EFFORTS AND APPROACHES IN THE COEUR D'ALENE BASIN OF NORTHERN IDAHO

Doug Parker - ASARCO
Geoff Harvey – Idaho Department of Environmental Quality

The goal of the tour is to demonstrate in the field remedial efforts and approaches to remove trace (heavy metals) threats to human health and the environments. The tour will require the entire workday. It will visit some remote sites where a substantial vehicle is required. Lunch will be taken at a site. Lunch is to be provided by the participant. Substantial clothing and foot ware is appropriate.

Participants will meet at the Wallace Idaho rest stop of Interstate 90 at 8:15 AM.

Proceed via Interstate 90 to the second Mullan Idaho Exit; follow the Mullan Highway to the Shoshone Park Picnic Area above most mining impacts.

Stop 1: Reference site for the water and environmental quality above most mining impacts; short discussion of site specific metals standards and background conditions in a mineralized area.

Proceed via the Mullan Highway and Interstate 90 west to the Golconda exit from Interstate 90 to the Golconda mine and mill site.

Stop 2: The Golconda mine and mill provide an example of waste rock and mill tailings impacts prior to any remedial efforts. The mechanisms of metals loading and detection in-stream will be briefly discussed.

Proceed via Interstate 90 to the first Wallace (Canyon Creek) exit and via state highway 4 to the Standard-Mammoth Mine site in the Canyon Creek watershed.

Stop 3: The Standard Mammoth Mine Site. View and discuss waste rock stabilization.

Return on State highway 4 towards Wallace to the Tamarack Reach of Canyon Creek.

Stop 4: View a reach of the Canyon Creek where metals contaminated sediment were removed relatively recently and the Tamarack Mine adit discharge. Discuss removal actions in stream corridors and stream reconstruction; discuss the impact of discrete discharges in metals loading to streams.

Proceed on state highway 4 towards Wallace to the Gem adit discharge treatment project.

Stop 5: Gem adit passive wetland treatment approach. Discuss passive treatment in contained wetland systems.

Proceed on state highway 4 towards Wallace to the Formosa Reach of Cañyon Creek.

Stop 6: View the Formosa reach of Canyon Creek where contaminated material were removed five years ago and the stream was reconstructed. Discuss the recovery process from contaminated sediment removal and the overall effectiveness of the Canyon Creek removal project.

Proceed to Wallace via state highway 4. In Wallace turn up the Dobson Pass Road into the Ninemile Creek watershed. Proceed to the East Fork Ninemile Creek turnoff and up the East Fork Road to its end at the Success Mill site.

Stop 7: View the remedial work completed at the Success site and the corral and gate treatment of metals contaminated ground water using fish bone apatite to remove the metals. Discuss water management on mill sites and semi-passive treatment of metals contaminated ground water.

Proceed back to Wallace and travel west to

Osburn Flats on interstate 90.

Stop 8: View Osburn Flats removal area. Discuss the removal and restoration efforts to bring water and soil replacements onto the river's floodplain. Discuss the fact that topsoil was not used and other substrate tilth building approaches.

Proceed west on Interstate 90 to the first Kellogg exit. Drive south to Wardner and up the Jackass Road to the radio tower hill.

Stop 9: View the Bunker Hill Superfund Site. Discuss the remedial actions taken in the site yard removal (to be discussed at a later stop), hillside restoration, principle threat materials containments, secondary materials containment in the CIA, the Smelterville Flats removal and its use of topsoil and conventional active metals removal from mine water at the CTP.

Proceed back to Interstate 90 and travel west through Smelterville Flats to the Pinehurst exits. Travel into Pinehurst to a site of yard removals.

Stop 10: Yard soil removal and replacement to protect children's health. Discuss the Bunker Hill yard removal program.

Proceed back to Interstate 90 and travel west to the Cataldo Mission exit. Follow the road past the Mission and to the Cataldo Boat Ramp Site. Lunch Stop.

Stop 11: View the Cataldo Boat ramp restoration project. During lunch discuss the remediation of signed recreational areas contaminated by metals. Discuss the Coeur d'Alene River, its hydrology, sedimentation and pattern of contamination.

Proceed back to Interstate 90 and travel west to the Rose Lake exit. Travel south on state highway 3 to a pull out near Rose and Porter Lakes.

Stop 12: View Rose and Porter Lakes. Discuss the resources of the Coeur d'Alene River valley, the affects of metals and preview some remedial approaches to be illustrated at later stops.

Proceed on highway 3 towards St Maries to the Bull Run Bridge at Rose Lake. Turn across the bridge and follow the dirt road along the north shore of Bull Run lake.

Stop 13: View the soil treatment plots Discuss approaches to binding metal in-situ into less bio-available chemical forms and the study underway to test stabilized soils in duck feeding studies.

Proceed back to highway 3 and travel towards St Maries to turnoff to the Rainy Hill Recreational site.

Stop 14: View the remedial and public exclusion measures at Rainy Hill. Discuss recreational area remediation and manage-ment of public use.

Proceed to the Medimont Road and turn north towards Medimont. After crossing the railroad corridor turn right to the Medimont Boat Ramp.

Stop 15: View Medimont bank stabiliza-tion. Discuss riverbanks as major lead source to the lake. Discuss bank stabilization methods used to date and some additional bank stabilization approaches. Preview the Union Pacific rails to trails settlement.

Proceed back to Medimont Road and to state highway 3. Follow state highway 3 to the Swan Lake overlook.

Stop 16: View the lower river valley. Discuss the extent of the wetlands in the lower river and wetlands contamination problems.

Follow highway 3 to route 97 to Bell Canyon Road. Follow Bell Canyon road to route 97 at the Harrison Bridge. Turn right immediately across the Harrison Bridge and proceed up the road to the Thompson Lake and Marsh overview.

Stop 17: View Thompson lake and Marsh. Discuss approaches to barrier lateral lakes and wetlands with clean materials.

Return via route 97 and Bell Canyon Road to highway 3 and to the Rose lake inter-change of Interstate 90. Participants can return from this point either to Wallace or to Coeur d'Alene.

1-2

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