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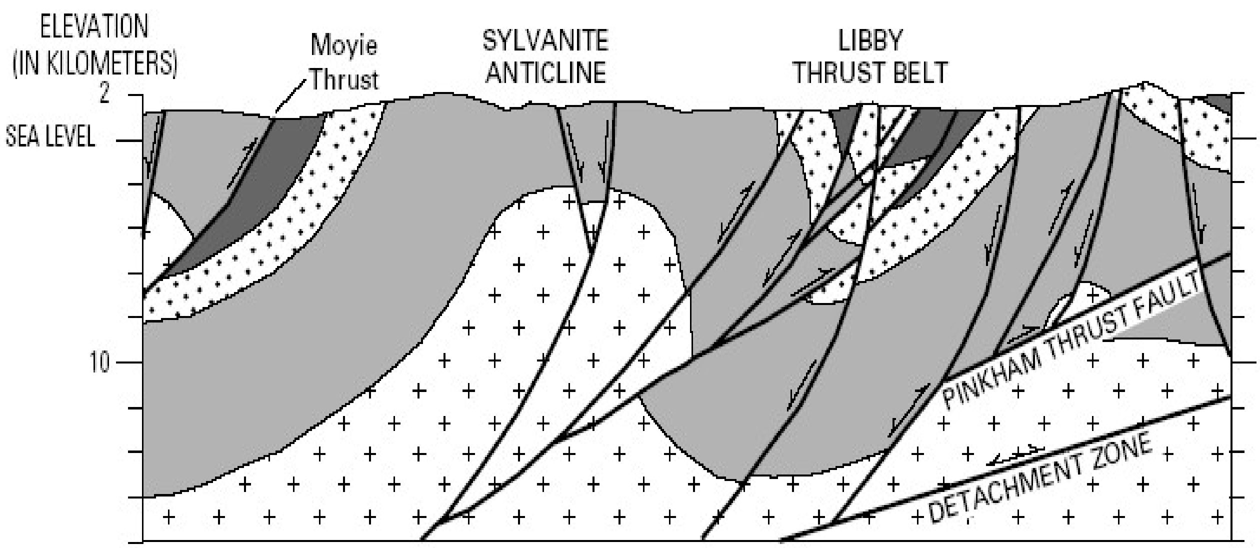
Volume 35, 2006

31st Annual Field Conference

Libby, Montana

August 3-6, 2006



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Cover: Miners, Snowshoe Gulch, 1897. From Mrs. Sam Ratekin and Spokane Statesman-Review, 1959.
Above: Cross section based on gravity modeling. From M.D. Kleinkopf, Geophysical Interpretations of the Libby Thrust Belt, U.S.G.S. Prof. Paper 1546, 1997.

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Libby Field Conference

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Welcome!

The 31st annual TRGS conference focuses on the diverse geology of northwestern Montana, ranging from engineering geology of Libby Dam to details of stratigraphy and mineralization in the Revett Formation of the Belt Supergroup. Mining, glacial studies, and geophysics are all here. We hope that you enjoy the meeting and find this volume useful.

—Bruce Cox, Marie Marshall Garsjo, Ann Marie Gooden
Conference Organizing Committee

Note from the Editors:

We thank all the contributors to this volume, and we especially thank Bruce Cox for exceptional assistance in procuring papers, ensuring their delivery in a timely manner, and for his ideas for how to make this guidebook as broad and comprehensive as possible. We also appreciate Bob Martin, editor of the Canadian Mineralogist, for permission to reprint the paper by Brandli et al. (last paper in this volume, not paginated for this volume; the TRGS does not claim copyright on this paper).

—Dick Gibson, Rob Thomas, Editors

LIBBY MINING DISTRICT, LINCOLN COUNTY, MONTANA
Historic Mining District Narrative

Montana State Department of Environmental Quality

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HISTORIC CONTEXT

The Libby district, also known as Snowshoe, is located south of the town of Libby, along Libby Creek, Big Cherry Creek and their tributaries. The lode claims are on the eastern slopes of the Cabinet Mountain range. The Libby district was important for both its long-lived placer operations and several of its silver-lead mines.

Sedimentary rocks of the Belt series underlie the Libby district. Diorite sills intruded into these rocks during Precambrian or Paleozoic time, after which the rocks were uplifted and slightly deformed. Extensive mountain building occurred during late Mesozoic or early Tertiary time, with the rocks folded and cut by thrust faults. At the close of this period, magma invaded the rocks, forming dikes that cut both stocks and sedimentary rocks. This magma contained solutions that formed ore deposits as the molten material cooled (Gibson, 1948). "The lode deposits are veins extending along faults and shear zones in the Belt rocks and in the accompanying metadiorite dikes and sills. They have been formed partly by fissure filling and partly by replacement" (Gibson, 1948).

The only gold-quartz vein of any significance is found in the Herbert claims on Prospect Creek; it occurs in the Prichard formation where veins parallel bedding planes. Silver-lead-zinc veins are found primarily along the Snowshoe fault, where they "fill steeply dipping fault fissures and shear zones in Belt rocks, metadiorite dikes, and to a lesser extent, metadiorite sills" (Johns 1970).

Over the years, there have been numerous theories about the source of placer gold in the Libby district. While prospectors for many years believed that the source was a dike crossing Libby Creek, geologists were unable to substantiate the existence of such a feature. Instead, studies indicate that gold from the Midas vein eroded into both Libby and Howard creeks, while the quartz-sulfide veins along the Snowshoe fault supplied placer gold to Big Cherry Creek (Johns, 1970).

Prospectors first tested the gravels of the Libby district in the early 1860s. John S. Fisher and several other men came through the area at that time looking for gold. They also named a number of the local creeks including Fisher River, Libby Creek (after Stephen Allen's daughter Elizabeth or Libby), and Sherry Creek (after Jack

Sherry), later changed to Cherry Creek. Activity increased during the summer of 1867 when a group of prospectors started placering along Libby Creek. Their success attracted as many as 500-600 men to the camp by September. Fortunes varied, however, with some making as much as $1.25 per pan while others washed only two cents per pan. Most men left for the winter, and those who stayed helped dig a ditch to bring water to some claims. While the camp increased again the following summer, the boom was brief and it was virtually deserted by the 1870s (Renk, 1994).

Libby Creek revived in the summer of 1885, beginning a long period of placering. Tom Shearer and B. F. Howard arrived in the camp to find several other men working on claims. They located their own claims, built sluices, and soon were washing out $20 a day in gold. Over the next few years, the camp gradually took on a look of permanence. Placering in the Libby district concentrated along Libby Creek and its tributaries Howard, Ramsey, and Little Cherry creeks, as well as along Big Cherry Creek (Renk, 1994).

One of the best known placer operations was known as the Howard placers, located around 1887 by members of the Howard family and their associate, William Williams. They formed the Howard Placer Mining Co. around 1900 and then sold out two years later to a group of investors who formed the Libby Placer Mining Co. The company expanded operations and initiated the first use of hydraulic giants on Libby Creek in 1905. Six years later, the company kept 24 men working, washing 1000 feet of gravel daily through box and ground sluices. The company mined actively through 1915, and the claims saw sporadic work through the 1930s (Renk, 1994).

Other placer operations used similar techniques for mining, although most on a smaller scale. For instance, lessees washed gravels through a ground sluice on the Vaughan and Greenwell claims, making $5000 a year from 1904-1908. The Comet Mining Co. took over a number of claims on Little Cherry Creek in 1908 and soon had two giants at work. Twelve men washed 100,000 cubic yards of gravel through sluices in 1911. They lived at the company camp which contained a bunkhouse, cook house, blacksmith shop, and miscellaneous other buildings. The operations ended in 1916 (Renk, 1994).

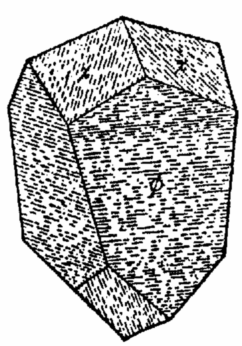
Placering was almost nonexistent during the late 1910s and 1920s. Gold production in Montana dropped from a high of 241,000 troy ounces in 1915 to a little more than 40,000 troy ounces in 1931, and Lincoln County production mirrored this trend. Adjustments in the price of gold during the Depression stimulated production, however, and placering resumed in the Libby district. This time, older hydraulic equipment was supplemented with heavy machinery on many claims. Operators on the Vaughan and Greenwell placer used power shovels and a stationary washing plant in 1938, switching to a dryland dredge the next year; in 1940 they made $770 in just seven days in an especially rich area. The Nugget placer was worked with a dragline and bucket in 1930-1932, washing gravels through 200 feet of sluice boxes (Klett, 1991; Renk, 1994).

After reaching a high of 272,000 troy ounces in 1940, Montana gold production once again dropped and then plummeted with the onset of World War II. Owners worked the Vaughan and Greenwell placer during the summer of 1947 and then for the last time in 1964, ending the long period of placering on Libby Creek (Klett, 1991; Lyden, 1948; Johns, 1970).

Three Libby district placers reported production in Mineral Resources: Big Cherry Creek Placer in 1914, 1924, and 1930-1931; Liberty Placer in 1924 and 1930; and Nugget Placer in 1916 and 1930-1931. Figures for total placer production from Libby Creek and its tributaries vary from over $100,000 to $213,230 (WPA, 1941; Dingman, 1932; Griffith, 1948).

Prospectors discovered lode deposits in the Libby district during the late 1880s. In 1887, George Blackwell and his partners located the Silver Mountain and Silver Crown claims on Granite Creek. Two years later, John G. Abbott and Albert Dunlap located the Snowshoe mine in October; this lead-silver-gold lode became the most important producer in the district. Tom Shaughnessy and William A. Hillis discovered the Buzz Saw and Hazel T claims on Shaughnessy Hill the same year, while William Criderman located the Silver Cable mine on Cable Creek in the early 1890s. Closing out the decade, G. W. Walker and P. Portugal found the Copper Reward in 1899 (Renk, 1994; Johns, 1970).

Development work proceeded on many of the Libby district's lode mines during the 1890s. Libby Creek Mining Co., owner of the Buzz Saw, worked the mine throughout the decade and finally constructed a 150-ton concentrator in 1899. Both equipment and finances failed the following year, and the mine closed abruptly. Owners also developed the Silver Cable mine during the same time, installing a 50 to 75-ton mill in 1898. Unfortunately, the mill never operated due to mismanagement and/or insufficient ore (Renk, 1994).



The Snowshoe mine experienced many problems over the years, including a number of different owners and lessees, mismanagement, litigation, inefficient milling, and difficult transportation. Despite these challenges, owners erected a concentrator around 1897, enlarging it to 225 tons by 1906; electrified the mine; and purchased up-to-date drilling equipment. The mine produced well until closing in 1912 (Renk, 1994; Johns, 1970).

The Buzz Saw was reactivated during the 1910s when the Lukens- Hazel Co. took over the mine and consolidated it with neighboring claims. The company built a 200-ton concentrator around 1920 and operated for much of the decade. The Victor-Empire and other small mines operated during the same period of time. The district was then pretty quiet until the 1930s when work proceeded on the Mountain Rose mine, and the 1940s when the Snowshoe operated sporadically. There are no figures for total district production (Renk, 1994).

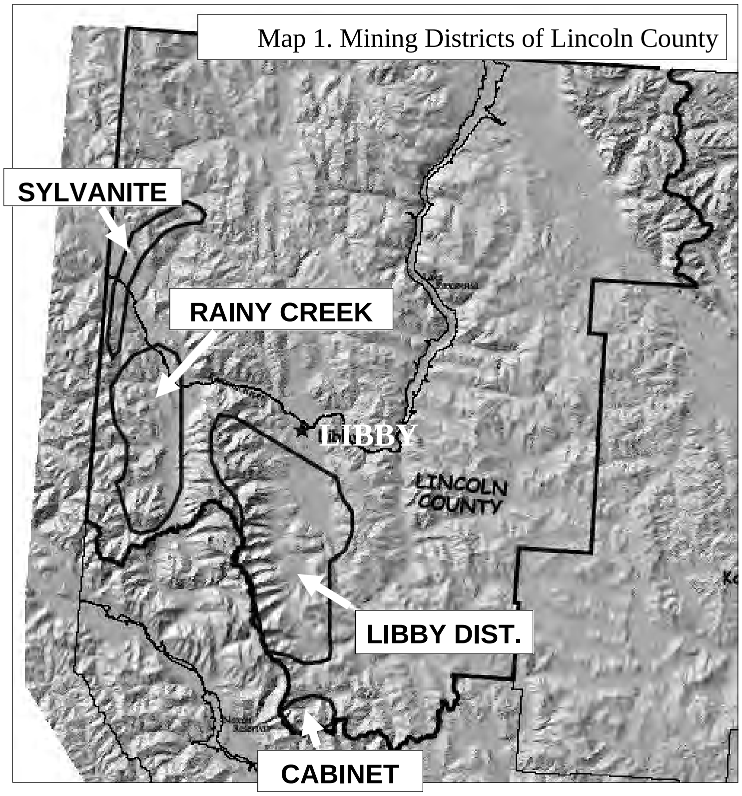
BOUNDARIES OF THE DISTRICT

Sahinen (1935), the only one to describe the district boundaries, places the Libby district in the region drained by Libby Creek and its tributaries. Map 1 shows the district as mapped by Albright (2004).

HISTORIES OF SELECTED MINES

Copper Reward

The Copper Reward includes five claims, four on the north side and one on the south side of Cherry Creek. G. W. Walker and P. Portugal located the claims in 1899, and the partners hoped that the 25 foot shaft and 50 foot tunnel would intersect with the Snowshoe vein. The main tunnel eventually extended 440 feet along the shear zone. An assay report in 1899 showed values of $68.78 per ton in lead, silver, gold, and copper. It is unknown how long the



mine operated; there are no production records (Libby Montanian, 1899b; Gibson, 1948; Johns, 1970).

Glacier Silver-Lead (Lukens-Hazel)

The Glacier Silver-Lead mine includes 17 patented claims on the north side of Shaughnessy Creek. Tom Shaughnessy and William A. Hillis located the original claims around 1889, and development proceeded over the next few years on the Buzz Saw claim. The owner, Libby Creek Mining Co., invested approximately $50,000 on development work and built a 150-ton concentrator in 1899. Misfortune plagued the venture, however: the machinery proved inadequate, most of the value of the sulfide form of ore was lost during concentration, and creditors closed the operations in 1900. Lessees A. J. McCorkle and John Town operated the mine from around 1909-1912, shipping several carloads of ore in 1910. That summer, the mine buildings burned in a forest fire, but McCorkle and Town planned to rebuild (Gibson, 1931; Weekly Montanian, 1900; Walsh and Orem, 1910, 1912; Western News, 1910b).

Things finally picked up when the Lukens-Hazel Co., under the direction of C. Ed Lukens, took over the mine in 1914 and invested $200,000 in development work. It built a 200-ton concentrator around 1920, enlarging or replacing it in 1930 to handle 325 tons per day. The larger mill contained a Harding conical ball mill, a Dorr classifier, and Fahrenwald flotation machines. It is not known whether the mine operated much during the 1930s, but by 1939 or 1940 eleven men were employed blocking out ore to be processed in the company's 150-ton flotation mill. The underground workings totaled about two miles in length (Gibson, 1931, 1948; Western News [compiler], 1920; WPA, 1940).

There are no production totals for the mine, but the Hazel T mine reported production in 1911, 1924, and 1929-1931, while the Lukens-Hazel property reported production in 1916 and 1919-1928. Concentrates shipped from the mill in early 1930 averaged 47.4 percent lead, 1.74 ounces of gold, and 60.8 ounces of silver to the ton (Gibson, 1948; WPA, 1941).

Granite Creek (Mountain Rose)

The Mountain Rose mine, operated by the Granite Creek Mining Co., is located on the south side of Granite Creek, near the west line of sec. 7, T29N, R31W. In 1930, operators moved ore from the mine to the camp with a small aerial tramway. Buildings at the camp on Granite Creek included cabins and a blacksmith shop. The mine made some shipments of ore during the early 1930s, and by 1936 had four men driving the lower adit. In 1938, the last year of operations, the adit had reached 1100 feet in length, with the upper adit 950 feet long with drifts and crosscuts (Gibson, 1948; Johns, 1970; WPA, 1940).

Silver Cable

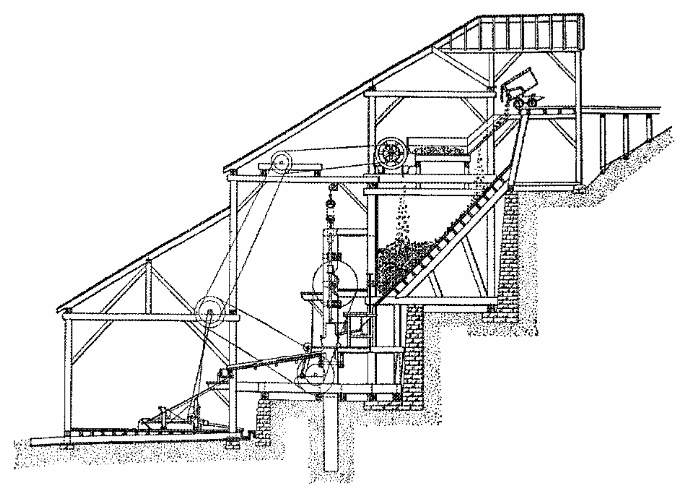
William Criderman located the Silver Cable mine, on the south side of Cable Creek, in the early 1890s. Development proceeded well, and by 1897 the Cable Mining Co. was working a crew of 10 men. The next year, the company constructed a tramway to carry ore half a mile from the mine to the new 50-ton concentrator. Before the mill was placed in operation, internal problems within the corporation caused the mine to close, but it was active again from 1901-1902 and 1905-1906. J. H. Town bonded the property in 1910 and planned to begin operations, but it is unclear if this actually happened. Underground workings included 2,000 feet of tunnels. There are no production records for the mine (Gibson, 1948; Johns, 1970; Libby Montanian, 1899a; Western News, 1910a).

Silver Mountain

George Blackwell and a group of prospectors located the Silver Mountain mine in 1887. The group of claims, which includes the patented Silver Crown, is on the south side of Granite Creek. Reports on the mine are sporadic, which may indicate that mining activity was also intermittent. The Silver Crown Mining Co. operated the property from around 1909-1912 and possibly longer. The mine made several shipments of high grade lead-silver ore in 1910, leaving the mill idle, a pattern that continued for the next couple of years. Operators shipped ore to the Glacier Silver-Lead mill for processing in 1926. Ten years later lessees controlled the mine. The last operations occurred in the 1940s when a new mill was built, but the mine closed within a short time. The mine included three adits, an aerial tram, and a mill. While there are no production records for the mine, sample assays show 8-18 percent lead; 8 to 21 ounces of silver; and 0.4 to 1.2 ounces of gold per ton (Gibson, 1931, 1948; Johns, 1970; Walsh and Orem, 1910; 1912).

Snowshoe

John G. Abbott and Albert Dunlap discovered the Snowshoe lode in October 1889 while prospecting up Leigh Creek. Within a short time, they brought Bragg Parmenter and H. G. Lougee in as partners. Control of the mine changed hands many times over the years as various owners and lessees took charge. Individuals and companies included the Chicago and Montana Mining Co. in the early 1890s; D. P. Bowers during the same decade; Pacific Northwest Mining Co. from 1898 to around 1901; Rustler Mining and Milling Co. from 1901



to around 1911; Pacific Coast Smelting-Refining Co. from 1911 to an unknown date; Snowshoe Consolidated Mines from 1928-1940; and various smaller owners and lessees through the 1940s and 1950s (Renk, 1994).

The rich deposit at the Snowshoe encouraged operators to develop the mine. A crew of 30 men worked there in 1897, increasing to 32 the following year. The concentrator was operating by 1897, milling the ore before shipment to the smelter at Great Falls. By the end of the decade, the mine was electrified, a telephone line linked it to

Libby, and a six-drill Rand compressor supplied power to the crews (Byrne and Hunter, 1897, 1899; Libby Montanian, 1899a).

The Snowshoe was plagued with closures during the early 1900s. The mine was shut down from 1900-1902 as operators tried to resolve a dispute over location of the concentrator. Work stopped briefly in 1906 when a water shortage cut off power to the concentrator. A more serious shutdown caused by stockholder litigation occurred in 1910, and major operations closed in 1912 with more litigation (Byrne and Hunter, 1901; Byrne and Barry, 1902; Walsh and Orem, 1906, 1910; Western News, 1921).

The Snowshoe also experienced difficulties with milling and transportation. In 1907, operators believed that the method of concentration caused a high loss in gold values, possibly as much as $400 per day. Later owners estimated that up to 40 percent of the concentrates was lost with the inefficient milling. Concentration was important for a mine as remote as the Snowshoe because it helped reduce transportation costs. Although a good wagon road connected the mine to the Great Northern Railroad at Libby by the early 1900s, the 20 mile trip was accomplished with horse teams and wagons up to the time the mine closed. Operators tried using trucks but found they did not have sufficient power on the hills (Renk, 1994; Gibson, 1931; Western News, 1911).

The Snowshoe may have operated sporadically during the long shutdown, but no major work occurred until the 1940s when operators installed a portable selective flotation concentrator to work both new ore and old tailings. Several thousand tons of ore processed in 1940-1942 yielded $125,000 worth of concentrates (Johns, 1970).

Despite the many problems, the Snowshoe was the most important lode producer in the Libby district, reporting production every year from 1905-1912. The total is estimated at 145,000 tons, with smelter returns of $1,211,000 in lead, silver, and gold. Underground workings included two shafts (475 and 550 feet deep) and 11,000 feet of tunnels, drifts, and connecting raises (WPA, 1941; Johns, 1970).

Victor Empire

The Victor Empire mine is located on the north side of Granite Creek, about two miles past the Glacier Silver-Lead property. Development work was in progress by 1908, and four years later the crosscut tunnel was 1350 feet long, eventually reaching 2,000 feet in length. Crews used power drills that were operated by a water-powered compressor. Continued work was spotty at best, and the mine has been idle since at least 1940. There are no production records (Gibson, 1948; Johns, 1970; Walsh and Orem, 1912).

REFERENCES

Albright, L.A., 2004, Historical Mining Districts of Montana, 1860-1972: Montana Bureau of Mines and Geology Open-File Report 477 (CD-ROM).

Bowman, A. H., and Barclay Craighead, 1926, Montana, Resources and Opportunities Edition, Vol. 1: Department of Agriculture, Labor and Industry, Division of Publicity.

Byrne, John, and Frank Hunter, 1898, Ninth Report of the Inspector of Mines of the State of Montana: State Publishing Company, Helena.

———, 1899, Tenth Annual Report of the

Inspector of Mines of the State of Montana for the Year ending November 30th, 1898: Independent Publishing Company, Helena.

———, 1901 Twelfth Annual Report of the Inspector of Mines of the State of Montana: Independent Publishing Company, Helena.

Byrne, John, and John J. Barry, 1902, Fourteenth Annual Report of the Inspector of Mines of the State of Montana: Independent Publishing Company, Helena.

Calderhead, J. H., 1898, Montana Bureau of Agriculture, Labor, and Industry, 6th Annual Report.

Calkins, Frank Cathcart, see also Emmons, 471, and MacDonald, D. F., 1909, A Geological Reconnaissance in Northern Idaho and Northwestern Montana: U. S. Geological Survey, Bull. 384, pp. 7-112.

Dingman, Oscar A., 1932, Placer-Mining Possibilities in Montana: Memoir No. 5. Montana School of Mines, Butte, Montana.

Ferguson, Henry Gardiner, and L. P. Benedict, 1906, Montana Bureau of Agriculture, Labor and Industry, 10th Report.

———, 1908 Montana Bureau of Agriculture, Labor and Industry, 11th Biennial Report.

Gibson, Russell, 1931, Gold in Northwestern Montana: Min. Truth, Vol. 16, No. 9, pp. 5-6.

———, 1931, Gold-Quartz Veins South of Libby, Montana: U. S. Geological Survey, Circ. 7, 1934; Dept. of Interior, Memo. for the Press, 1931.

Gibson, Russell, Jenks, William F., and Campbell, Ian, 1938, Stratigraphy of the Belt Series in Libby and Trout Creek Quadrangles, Northwestern Montana and Northern Idaho: Geol. Soc. America Bull., Vol. 52, pp. 363-380, 1941; (abst.) Geol. Soc. America Proc., 1937, p. 83, 1938.

———, 1948, Geology and Ore Deposits of the Libby Quadrangle, Montana: U.S.G.S. Bulletin 956.

Griffith, Robert Fisher, 1948, The Liberty Placer Near Libby, Montana: Unpublished Bachelor's thesis, University of Washington, Seattle.

Hall, J. H., and M. L. Rickman, 1912, Montana Bureau of Agriculture, Labor and Industry, Thirteenth Report, for years 1911 and 1912.

Johns, Willis M., 1970, Geology and Mineral Deposits of Lincoln and Flathead Counties, Montana: Bulletin 79, Montana College of Mineral Science and Technology, Butte.

Klett, Gerald W., 1991, Tables of Annual Production of Gold, Silver, Copper, Lead, and Zinc for the States of California, Idaho, Montana, Nevada, Oregon, and Washington: U.S. Bureau of Mines, Western Field Operations Center, Spokane.

Libby Montanian, 1899a, Libby, Montana, the Rising Meroplis [sic] of the Cabinets, 10 March.

———, 1899b, A Big Strike on Big Cherry, 21 September.

Lyden, Charles J., 1948, The Gold Placers of Montana: Memoir No. 26, Montana Bureau of Mines and Geology, Butte, Montana.

MacDonald, D. F., 1909, Notes on the Economic Geology, *in* A Geological Reconnaissance in Northern Idaho and Northwestern Montana, by F. C. Calkins: U.S.G.S. Bulletin 384.

Renk, Nancy F., 1994, Mining, *in* Historic Overview of the Kootenai National Forest, Vol. 1, Christian J. Miss, ed.: Northwest Archaeological Associates, Inc., Seattle.

Sahinen, Uuno Mathias, 1935, Mining Districts of Montana: Unpublished Master's thesis, Department of Geology, Montana School of Mines, Butte.

Schrader, Frank Charles, 1911-1912, Gold-Bearing Ground Moraine in Northwestern Montana, U. S. Geological Survey, Bull 470-B, pp. 62-74.

———, 1911, (abst.) Econ. Geology, Vol. 7, No. 1, p. 97.

———, 1912; Min. and Sci. Press, Vol. 103, No. 15, p. 458, 1911.

Trauerian, Carl J., 1941, Strategic Minerals of Montana; Tungsten: Western Min. News, Vol. 15, No. 6, p. 9.

Walsh, William, and William Orem, 1906, Biennial Report of the Inspector of Mines of the State of Montana For Years 1905-06.

———, 1910 Biennial Report of the Inspector of Mines of the State of Montana For the Years 1909-10.

———, 1912 Biennial Report of the Inspector of Mines of the State of Montana For the Years 1911-12.

Weekly Montanian, 1900, The Company Broke. 3 February.

Western News, 1910a, J. H. Town Bonds Silver-Cable, 3 February 1910.

———, 1910b, Mine Buildings Are Burned, 10 August.

———, 1911, Working on Cherry Creek, 5 October.

———, 1921, Full Description of Famous Snowshoe Mine, 8 January.

Western News (compiler), 1920, Lincoln County, Montana: History, Resources, Industrial Development, and Record in the Great War: Western Montana Publishing Co., Libby.

Work Projects Administration (WPA), Mineral Resources Survey, 1940, Directory of Montana Mining Properties: Memoir No. 20. Montana School of Mines, Butte.

———, 1941, Montana Mine Index, and Alphabetical Index Arranged by Counties, Districts and Mines of Information on Montana Mines from 1867-1940: Montana School of Mines, Butte.

Forest Fire Sweeps Over Sylvanite Camp

Mining Camp is Wiped Out by the Flames.
Thousands of Acres of Timber in Lincoln County Burned Over.
Light Showers Relieve Situation and Help the Fire Fighters to Check the Flames.
Worst Year for Forest Fires in the History of this Part of the State.
Forest Supervisor Skeels Outlines Situation.
Large Area Burns Over in Southern Part of Lincoln County.
Western News, August 25, 1910

The town of Sylvanite, the home of Lincoln Gold Mining company, was wiped out by a forest fire which swept through the place on Sunday, only one building escaping the flames. The residents of the town all escaped to places of safety. The new stamp mill, which had been completed by the Lincoln Gold Mining Company only a short time ago, was burned. The greatest loss in connection with the fire comes upon this company, which has expended a large sum during the past few months in rejuvenating the mining properties there and getting them in shape for operation.

The forest fire situation is the worst on record in this part of the country. Dozens of fires, many of them of large extent, are burning in various parts of the Kootenai forest, and thousands upon thousands of acres of timber have been burned over.

A number of settlers living in the Lake creek country, south of Troy, have been burned out, in some cases losing livestock, crops, buildings and all their belongings. Throughout the week ranchers have been moving into Libby from the southern portion of the country to get away from the fires.

Some uneasiness has been felt in Libby from the fire, which burned over Shaughnnessy Hill mine, but it has been kept from coming towards the town by a large force of fire fighters. In answer to a call for help the Warland Lumber company on Saturday closed down their mill, and Walter Wilder brought in a force of 30 men from there to help check this fire. Men were also secured from Spokane and other places, over 100 coming in from Spokane on Monday night.

A fire has been raging near Troy and reports have reached Libby on several occasions during the week that the town was in imminent danger. Some very exaggerated stories were received here relative to the situation at that place, one report being that the town had been burned. Forest Ranger Raymond, who came in from Troy Tuesday, stated that there was a fire about three miles from the town, which was getting nearer to the place and might possibly make trouble under certain conditions.

The situation throughout Lincoln county was greatly relieved by light showers yesterday morning, which checked the fires.

Forest Supervisor Dorr Skeels on Monday gave out the following information as to the general forest fire situation in the Kootenai forest at that time.

"Fires have crossed from Vermillion river, on the Clark Fork, over Silver Butte mountain and have a crescent-shaped front about fifteen miles around on the Kootenai forest. The fire has crossed the East Fisher and is burning east toward the head of Elk creek and McGinnis creek, and has crossed the Silver Butte Fisher at the head of West Fisher. A fire has crossed from Fishtrap creek, on the Clarks Fork, and is burning on the head of the South fork of

Miller creek. This fire is burning east towards John Schneider's ranch on Meadow creek. A fire has burned across the summit from Rock creek. On Clarks fork, and is burning on Great Northern mountain and the headwaters of Libby creek. The four fires form a half-circle around the Fisher river watershed.

"The settlers on Fisher river have sent their families to places of safety and are trenching around their ranches in preparation for back-firing, should the fire reach them. The sorest service has stationed four men at Dave Miller's ranch, four men at the Davis ranch, eight men at Kenelty's ranch, four men at Schneider's ranch, and three men at Schreiber's ranch to assist the settlers in protecting their property.

"So far the fires have been high up on the mountains and have burned over inferior timber. A high gale has been blowing along the summit of the Cabinet mountains for the last three days and nearly one hundred government fire fighters who were holding the fire on the summit have been forced back by the flames and brought in to handle the fires near the towns and settlements. But little can be done now with the Fisher river fires until showers clear away the smoke.

"A serious fire has been burning for three days on Granite creek and Shaughnnessy hill. The buildings and machinery of the Shaughnnessy mining company have been destroyed. This fire is burning east, south, and west.

"A fire was reported Saturday evening on Keeler creek and another one on Lake creek, from Troy. Eighty men were secured from Spokane to help keep the fire back from Troy.

"Two serious fires are burning on Seventeen Mile creek and are being fought by small crews of men in charge of Rangers Weidner and Raymond.

"Another fire has stated at the mouth of Seventeen Mole creek and is burning up the Yakt river. Reports from this fire are that the mountains on both sides of the Yakt are in flames for several miles up the river.

"The town of Sylvanite was surrounded by flames Sunday. The telephone line is down. All the inhabitants of Sylvanite left the town Saturday night and all reached Troy in safety. Considerable uneasiness was felt Sunday for Ranger Dennis and his crew of 20 men who were fighting fire on the Yakt, as he was believed to be surrounded by flames. A wire from Troy brought the news that they reached there in safety Monday.

"A crew of 10 men under Wilian Lamey have been fighting serious fires at the head of Pope creek. Sunday morning another fire was reported 15 miles from the mouth of Pope creek, which covers the mountains on both sides of the creek.

"A serious fire is reported at the mouth of Parsnip creek, between Ural and Tweed, and is being fought by a crew of 20 men under Ranger Lawrence. Another fore was started from a spark from a locomotive at Rexford and it is reported that the mountains west of Rexford are in flames. A wire from Rexford reports that the town is as yet in no danger and that the fire is being fought by the railroad section men.

"A wire from Troy reports that the settlers about the head of the Yakt have all succeeded in getting out of the country."

From primary documents compiled by Montana Heritage Project

THE RAINY CREEK ALKALINE ULTRAMAFIC IGNEOUS COMPLEX NEAR LIBBY, MONTANA

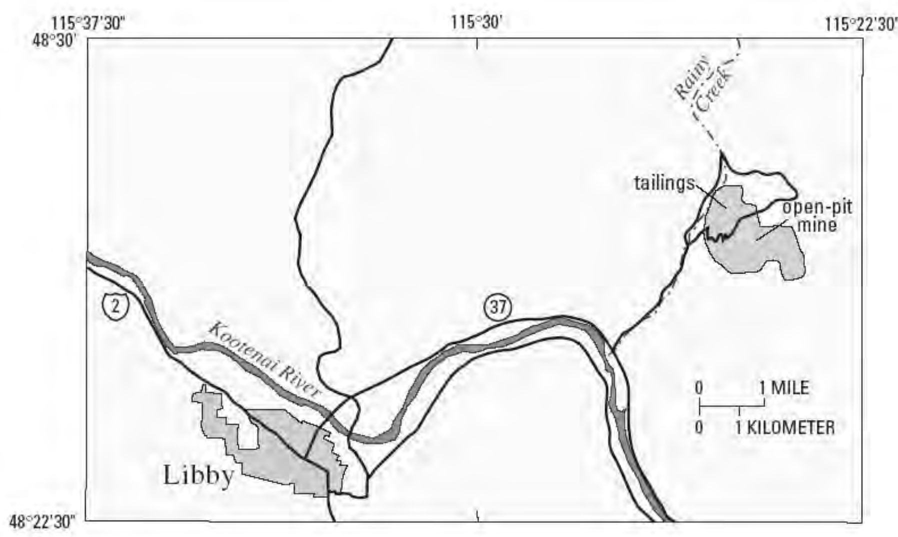
Art Montana
Professor of Earth & Planetary Sciences Emeritus, UCLA

The Rainy Creek igneous complex is a composite of consanguineous intrusions of nearly unique, ultramafic to felsic rocks emplaced in the Precambrian Belt Series in the late Cretaceous or early Tertiary. Large-scale mining in the ultramafic zones beginning about 1939 produced most of the commercial vermiculite used in the western hemisphere for insulation and a myriad of other purposes. Alas, nearly all of the outcrops—natural and man-made—are inaccessible since mining and milling ceased between 1990 and 1992.

My previous publications (Boettcher, 1966, 1967) were based on field and laboratory work conducted between 1960 and 1966, following earlier investigations by Larsen and Pardee (1929), Pardee and Larsen (1929), Kujawa (1942), and Bassett (1959). Mineralogical studies were largely conducted using optical microscopy, X-ray diffraction, and wet-chemical methods. Analyses with the electron microprobe and determinations of stable and radioactive isotopes were just becoming routine in the later 1960s.

As illustrated in Figure 1, the ultramafic complex consists of concentric zones of magnetite pyroxenite, biotite ("vermiculite") pyroxenite, and biotitite, arranged in inward succession. "Vermiculite" here includes biotite, hydrobiotite, and vermiculite (Boettcher, 1966). An irregularly shaped body of syenite (altered nepheline syenite) lies athwart the southwest side of the ultramafic rocks. A small outlier of quite fresh nepheline syenite lies about 150 m southwest of the syenite. As the elevation of Fleetwood Creek on the north side of the complex is less than that of Carney Creek on the south, the shape of the complex is distorted in plan view; it is nearly circular in horizontal section with the biotitite occupying a central position.

This biotitite cropped out at the highest point in the complex prior to mining. Mining and drilling exposed another about 200 m vertically, revealing that it dipped steeply outward, forming a body about 450 m by 250 m in plan view. It consists almost entirely of fresh, coarse-grained biotite,



Location map from Van Gosen et al. (2005)

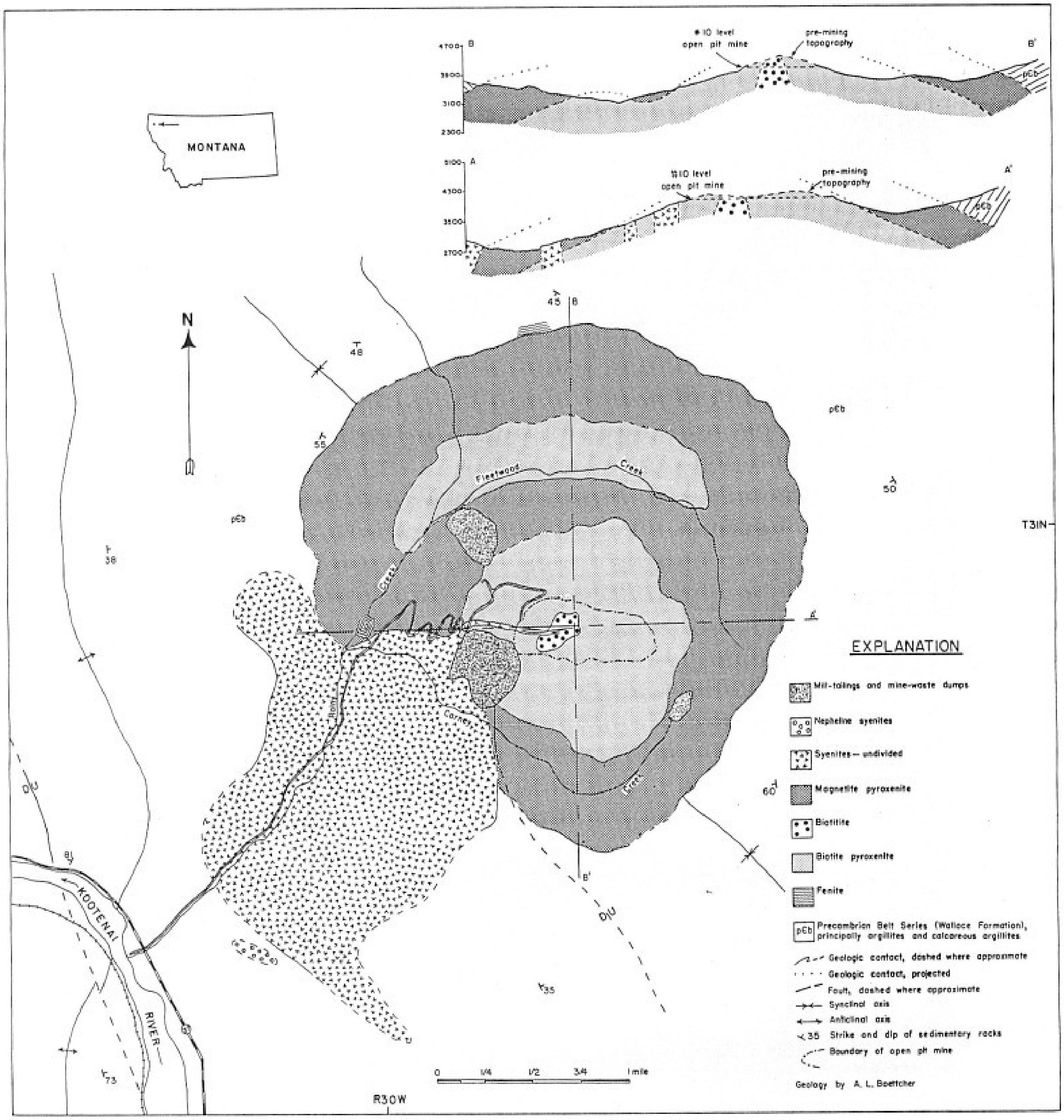


Figure 1. Geologic map and cross sections of the Rainy Creek complex (Boettcher, 1967)

most in books of 0.1 m or more, ranging up to 1 m in diameter. Pyrite, microcline, albite, calcite, sodic tremolite and related amphiboles (“tremolite”), constitute less than 10% of the rock. See Gunter et al. (2003) for a discussion of the nomenclature of the amphiboles based on detailed studies of several samples of “tremolite” from the Rainy Creek rocks. Small alkaline pegmatites consisting mostly of aegirine-augite and alkali feldspars occur throughout the biotitite. Nodular xenoliths ranging from 5 to 35 cm in diameter also are scattered throughout the biotitite, but none were found elsewhere. They consist of talc, dolomite, fresh euhedral pyrite, “tremolite,” magnesite, and phlogopite with reverse pleochroism—similar to phlogopite in carbonatites and ultrabasic rocks (Boettcher, 1967). The carbon and oxygen isotopic ratios of dolomite in these xenoliths are also similar to those in these

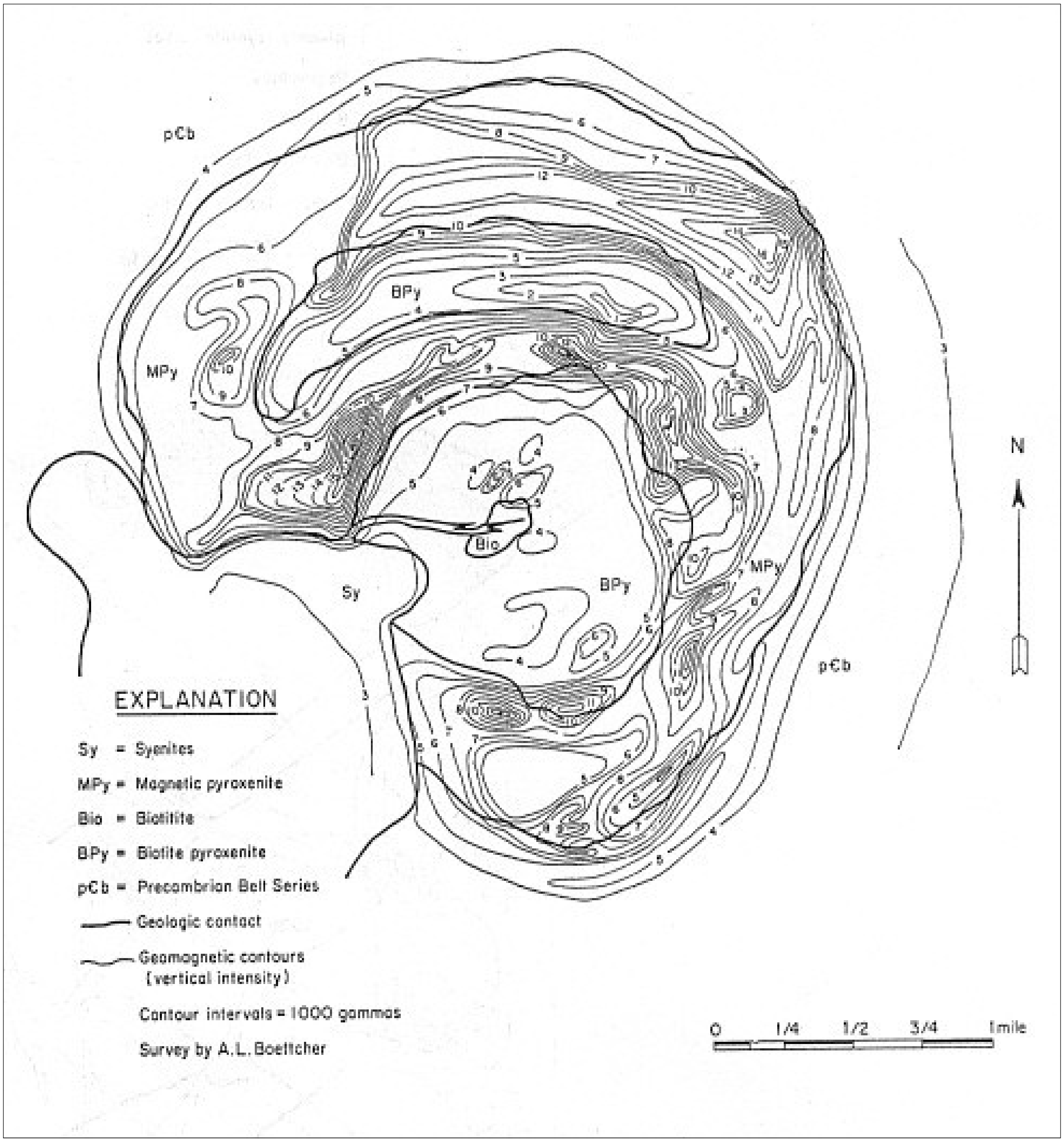


Figure 2. Geomagnetic survey of the Rainy Creek complex (Boettcher, 1967)

rocks. The contact of the biotitite with the surrounding biotite pyroxenite is gradational over 0.3 to 3 m.

The biotite pyroxenite consists of Fe-poor clinopyroxene (emerald-green chrome diopside), "vermiculite," and apatite in all proportions, but with the latter averaging about 25 wt. % over the history of mining. The pyroxene crystals commonly are $\geq$ 4 cm in diameter, with huge crystals up to 1 m near the contact with the biotitite. All of the commercial vermiculite and hydrobiotite were extracted from this pyroxenite and are alteration products of the original biotite by meteoric and hydrothermal solutions.

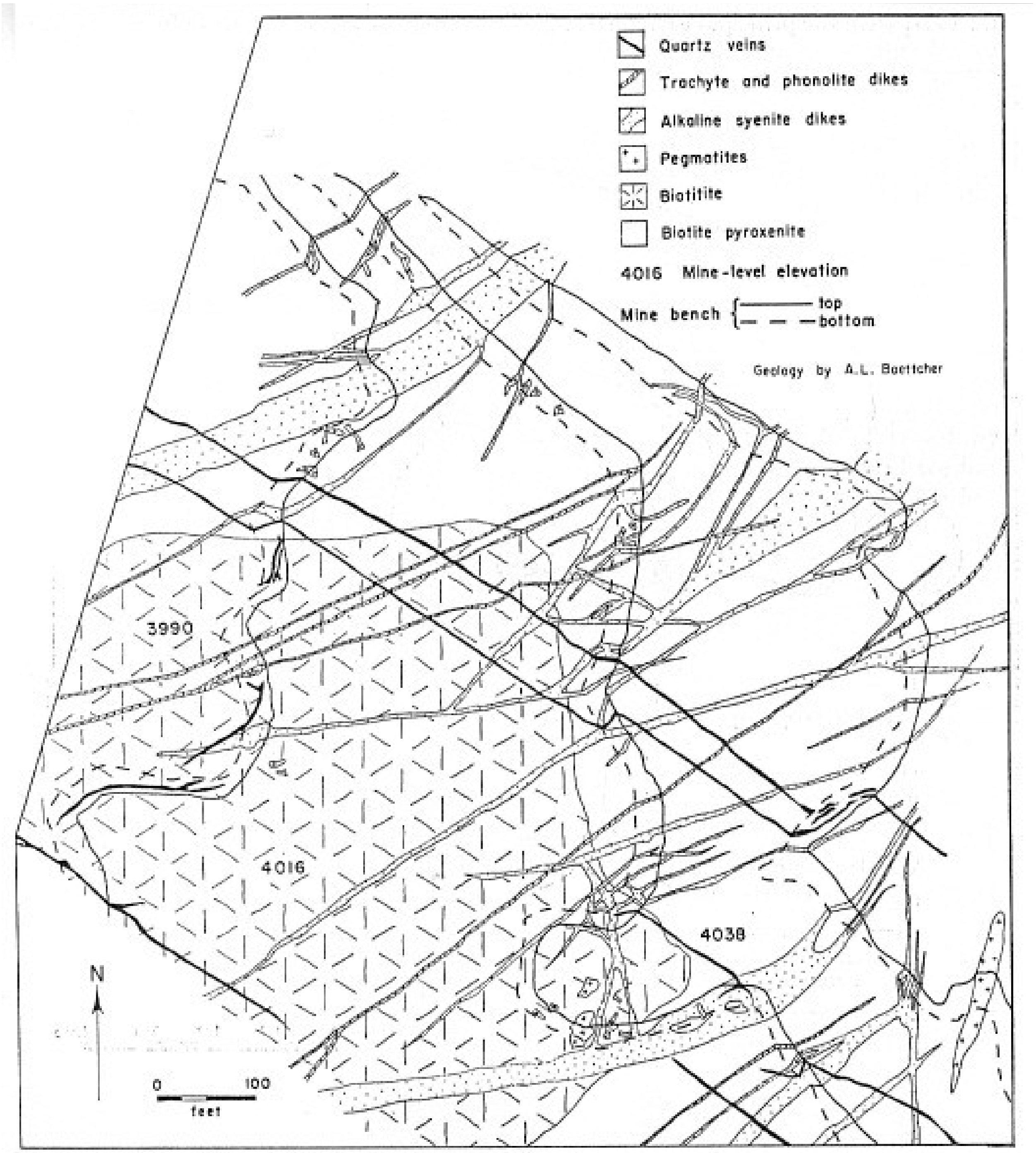


Figure 3. Geologic map of part of the open-pit mine at the Rainy Creek complex (Boettcher, 1967)

The outer zone of magnetite pyroxenite forms a ring dike about 300 m in true thickness and consists of fine-grained clinopyroxene (richer in Fe than that in the biotite pyroxenite), an average of about 25 % magnetite, and about 6 % apatite, commonly with accessory andradite, "vermiculite," and sphene. The distribution of this magnetite-rich body is well displayed in the geomagnetic-survey map (Fig. 2). The average grain size of 0.7-3 mm increases to about 2 cm in a zone within about 10 m of the biotite pyroxenite, and numerous dikes and apophyses of magnetite pyroxenite transect the biotite pyroxenite (not shown in Fig. 3).

All of the ultramafic rocks have been transected by dikes of alkaline syenite and later trachyte and phonolite, most of which trend northeast, and by even later southeast-trending quartz veins (see Fig. 3). Extensive wall-rock alteration of the pyroxenites to “tremolite” accompanied emplacement of the syenite dikes and quartz veins. There is a distinct absence of wall-rock alteration along the trachyte and phonolite dikes, which may have breached the surface, losing pressure on the volatile components. Incipient alteration of the pyroxenes to “tremolite” occurs throughout the pyroxenites.

Two bodies of syenite (Johns, 1959, 1960) and one of syenite and pyroxenite (Johns, 1960) that may be unrelated to the Rainy Creek rocks occur in this region, but they are small and have not been examined in detail. With these exceptions, the Rainy Creek complex contains the only known ultramafic or alkaline rocks in northwestern Montana and contiguous Canada and Idaho.

The mineralogy of these ultramafic rocks, the mantle xenoliths in the biotitite, the fenite at the contact of the magnetite pyroxenite with the Belt rocks, and the associated nepheline syenites all suggest intrusion of a mantle-derived, water-rich magma, producing a complex that bears a striking resemblance to well-known carbonatite complexes (Pecora, 1956), particularly Iron Hill, Colorado (Larsen, 1942; Temple and Grogan, 1951). At Iron Hill, fault-uplifted rocks have counterparts to those at Rainy Creek, whereas the deep-seated rocks include carbonatite and garnetiferous ijolite.

At Rainy Creek, the sequence of emplacement of most of the rocks is evident from the crosscutting relationships, and it appears that the rocks exposed in the open-pit mine occupied a position near the top of the magma chamber, as evidenced by the concentration there of water, other volatile components, alkali metals, pegmatites, and by the extremely large grain size of the biotitite and neighboring pyroxenite.

A reported Sr-Rb age of 94 mybp (Boettcher, 1967) obtained on unaltered biotite from the biotitite core is the only geochemical evidence of the age of the Rainy Creek rocks. This age has been questioned (Alt and Hyndman, 1986)—perhaps justifiably so, but their description of the complex is completely erroneous.

These most extraordinary igneous rocks deserve to be investigated further using modern geochemical, petrological, and geophysical techniques. Of course, all investigators must be aware of the dangers of contact with the asbestiform minerals.

References Cited

Alt, D., and Hyndman, D. W., 1986, Roadside Geology of Montana: Mountain Press, Missoula, p. 80.

Bassett, W. A., 1959, Origin of the vermiculite deposit at Libby, Montana: American Mineralogist, v. 44, p. 282-299.

Boettcher, A. L., 1966, Vermiculite, hydrobiotite, and biotite in the Rainy Creek igneous complex near Libby, Montana: Clay Minerals, v. 6, p. 283-296.

Boettcher, A. L., 1967, The Rainy Creek alkaline-ultramafic igneous complex near Libby, Montana: J. Geology, v. 75, p. 526-553.

Gunter, M. E., Dyar, M.D., Twamley, B., Foit Jr., F.F., and Cornelius, S., 2003, Composition, $Fe^{3+}/\sum Fe$, and crystal structure of non-asbestiform and asbestiform amphiboles from Libby, Montana, U.S.A.: American Mineralogist, v. 88, p. 1970-1978.

Johns, W. M., 1959, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana: Montana Bureau Mines and Geology Bulletin 12, p. 18.

Johns, W. M., 1960, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana: Montana Bureau Mines and Geology Bulletin 17, p. 20-21.

Kujawa, R., 1942, Mineralogy and genesis of the vermiculite deposits at Libby, Montana: B. S. thesis, Montana School of Mines, Butte.

Larsen, E. S., and Pardee, J. T., 1929, The stock of alkali rocks near Libby, Montana: J. Geology, v. 37, p. 97-112.

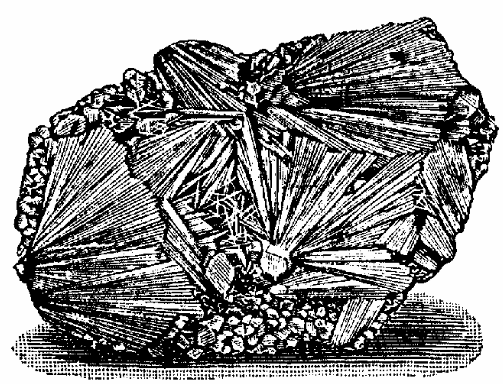
Larsen, E. S., 1942, Alkalic rocks of Iron Hill, Gunnison County, Colorado: U. S. Geological Survey Professional Paper 197-A, 64 p.

Pardee, J. T., and Larsen, E. S., 1929, Deposits of vermiculite and other minerals in the Rainy Creek district, near Libby, Montana: U. S. Geological Survey Bulletin 805, p. 17-29.

Pecora, W. T., 1956, Carbonatites: a review: Geological Society of America Bulletin, v. 67, p. 1537-1556.

Temple, A. K., and Grogan, R. M., 1951, Carbonatite and related alkalic rocks at Powderhorn, Colorado: Economic Geology, v. 60, p. 672-692.

Van Gosen, B.S., Heather A. Lowers, Alfred L. Bush, Gregory P. Meeker, Geoffrey S. Plumlee, Isabelle K. Brownfield, and Stephen J. Sutley, 2005, Reconnaissance study of the geology of U.S. vermiculite deposits—are asbestos minerals common constituents?: U.S. Geological Survey Bulletin 2192. Online at pubs.usgs.gov/bul/b2192/b2192.pdf



SYLVANITE-RAINY CREEK MINING DISTRICT, LINCOLN COUNTY, MONTANA
Historic Mining District Narrative

Montana State Department of Environmental Quality

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HISTORIC CONTEXT

The Sylvanite mining district, also known as Yahk, Yakt, Yaak, or Yaak River, encompasses a large section of rugged and remote land north and west of the bend in the Kootenai River in northwestern Montana. The most important placer and lode mining activity concentrated along the Yaak River valley, especially near the town of Sylvanite. In addition, the Rainy Creek sub-district became well-known for its deposits of vermiculite.

Protozoic rocks of the Belt series underlie the Sylvanite district. Ore deposits are related to the geological structure, i.e., faulting and folding. Gold-quartz veins, such as those located in the Sylvanite district, are found in the Prichard Formation where they "parallel bedding planes, and most ore is produced near high-angle crosscutting faults." The lead which runs through the Keystone and Goldflint mines is found in quartzite between two folded beds (Johns, 1970; Sahinen, 1935).

The first prospectors in the rugged Sylvanite district came as a result of strikes elsewhere in the region. Bill Hall claimed to have found the first placer gold in the Yaak River in 1864 when he stopped briefly to pan for colors while on his way north to the Kootenay rush in British Columbia. More than twenty years later, after the placers on Libby Creek were developed, prospectors fanned out to look for new discoveries. Some found gold along the lower reaches of the Yaak River in the late 1880s and established a temporary camp known as Snipetown around 1890. The number of miners grew three years later with the discovery of placer gold just over the border on the Moyie River in Idaho, and many miners from the new camp came to try their luck in the Yaak. The proximity of the Idaho border confused quite a few miners who recorded their claims in Idaho (Calvi, 1993; Renk, 1994).

While placer mining concentrated along the Yaak River in the vicinity of Snipetown, a few other areas of the district were tested and worked. There are unverified reports of placer mining along China Creek and near China Lake during the late nineteenth century. Solo Joe Perriault worked his claim (24LN90) along the East Fork of the Yaak River in the early 1900s, followed by a Captain Mappot from about 1938-1940; total production was small. An unknown individual worked the Copeland placer during the 1930s. The mine included a cabin, a 75-foot flume, and a water wheel. There are no production figures for the placer, but the total was probably small. The Snipetown placer also revived during the mid-1930s when R. Moore, J. Lewis, M. D. Powely, and Mr. Packingham leased the ground about 3.5 miles below Yaak Falls. They built a flume to wash gravels through sluice boxes, bringing in

$.90 to $3 per cubic yard during 1934 - 1935 (Johns, 1970; Hauge, 1994).

While the placer finds never attracted much attention, the discovery of a quartz lode with free gold brought a small rush. Pete Berg and Bill Lemley made the find on Crawford Creek in 1894, and within a year 100 men were working on claims (Timmons, 1986; Renk, 1994).

William Johnson and S. J. Whitcomb located the Keystone mine, one of the most important claims in the district, in 1895, and before the end of the year they had bonded it to a group of Spokane capitalists for $12,500. Charles H. Bartlett and E. J. Merrin located the Goldflint mine the same year, and it soon joined the Keystone in importance. Development proceeded on both prospects over the next three years. Forty-eight men worked at the Keystone in 1896 when the plant facilities included a water-powered 10-stamp mill, office, ore bins, and bunkhouses (Timmons, 1986; Byrne and Hunter, 1899).

The town of Sylvanite grew with the mines. Originally called Lemleyberg, the camp soon changed its name to acknowledge the type of ore that miners believed they had found. Developers platted streets and lots in 1896, and by the next year the town had two hotels, two restaurants, three stores, a meat market, post office, brewery, and the requisite saloons. A sawmill turned out lumber for mine and town buildings. At its peak, Sylvanite was home to 500 people (Timmons, 1986; Renk, 1994).

The boom soon turned to bust. The year 1898 started off well with the completion of the new 20-stamp Goldflint mill. The Keystone mill ran steadily, processing 30 tons of ore each day. By August, however, the town was nearly deserted and both the Goldflint and Keystone mills were silent. MacDonald (1909) hypothesized that the mines closed when the ore at depth became base so that it could no longer be processed as free milling ore (Byrne and Hunter, 1899; Timmons, 1986; MacDonald, 1909).

After more than a decade of inactivity, Canadian investors formed the Lincoln Gold Mining Co. in 1910 to operate the Keystone and Goldflint. They reopened the mines, constructed a 20-stamp mill and tramway, and infused new life into the district. Before the mill ever operated, however, a forest fire swept through the valley in August and burned the mill and mine structures along with all but one building in town. Although the company planned to rebuild, it never did. The mines revived in the 1930s under different ownership, operating from 1931-1937 (Timmons, 1986; Renk, 1994).

Rainy Creek Sub-district

The Rainy Creek sub-district encompasses a small area northeast of Libby in the Rainy Creek drainage. Prospectors located isolated copper deposits there in the late 1890s and early 1900s. John L. Neihart, of the mining town of Neihart, caused considerable excitement when he examined these deposits and predicted that they would make the Rainy Creek district "another Butte in the production of copper" (Renk, 1994).

Copper mining never developed much beyond the stage of wishful thinking, but the Rainy Creek district became well-known for a very unassuming mineral called vermiculite. Mica particles heated expands up to 15 times their original size. The end product is vermiculite, which is used primarily in fireproofing and insulation from heat, cold, and sound (Renk, 1994; Perry, 1948).

Large deposits of vermiculite and small metallic deposits in the Rainy Creek sub-district are found in a stock of alkaline rocks that intrudes into the Proterozoic rocks of the Belt series. Two-thirds of the stock is coarse-grained pyroxenite, from which vermiculite is derived, and one-third is coarse-grained syenite. Hydrothermal alteration has caused major changes in the stock, producing white mica, aegirite and aegirite-diopside, vermiculite, and fibrous amphiboles (Pardee and Larsen, 1929).

Edward N. Alley discovered the vermiculite deposits during World War I when he was prospecting for vanadium. He experimented with samples, built a small kiln to process the ore, and promoted the material under the trade name of Zonolite. This led to a demonstration plant in 1924, followed two years later by a larger facility capable of processing 100 tons of ore each day. Alley sold his interests in 1934, leaving two different companies working the deposits on Rainy Creek. They merged in 1939 to form Universal Zonolite Insulation Co., altering the name to the Zonolite Co. in 1948. The business came under the control of W. R. Grace and Co. in 1963 and continued operations until 1991 (Renk, 1994).

Operators mined most of the vermiculite ore through large open cuts; several adits, one 750 feet long, also provided access to the ore. Initial processing took place at a concentrator near the mine. Trucks then hauled the concentrate to the Libby plant for heating and expansion into the final product. Some of the concentrates were shipped to plants in Great Falls, other states, Canada, and other foreign countries for final processing there. About 1940, Universal Zonolite mined 500 tons of ore each day, reducing it to 200 tons of concentrates. Twenty-four years later, the company turned out 2400 tons of ore each day, reducing this amount to 500 tons of concentrates. There are no figures for total production since this information was restricted after 1930 (Perry, 1948; Johns, 1970; WPA, 1941).

BOUNDARIES OF THE DISTRICT

Sahinen (1935), the only one to describe the Sylvanite district, places it on the Yaak River, about 10 miles northwest of Troy. He describes the Rainy Creek sub-district as about seven miles northeast of Libby in the Rainy Creek drainage.

HISTORIES OF SELECTED MINES

Black Diamond

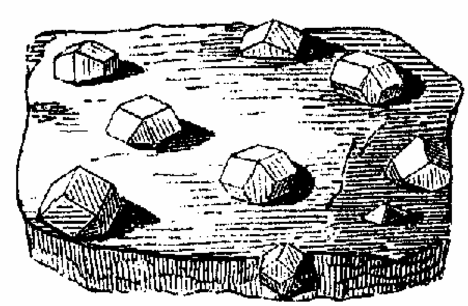
The three unpatented claims of the Black Diamond mine are located 1.5 miles west of Teepee Mountain. After its discovery in the early 1920s, Charles Cone and others formed the Black Diamond Mining Syndicate to develop the mine. Most activity occurred during the 1930s when the company erected a 100-ton gravity flotation mill that produced a lead-zinc concentrate containing 30 percent lead. The company spent $30,000 on improvements which, besides the mill, included a sawmill, bunkhouse, and powerhouse. The Black Diamond reported production in 1922 and 1930 and warranted mention in other mining literature in 1936 and 1938-1940. It was idle by 1941 (Johns, 1970; Gibson, 1948; WPA, 1941).

Morning Glory (Keystone and Goldflint)

The property later known as the Morning Glory encompasses the Morning Glory claim, as well as the important Keystone and Goldflint claims. They are located near the historic town of Sylvanite on the Yaak River.

Both the Keystone and Goldflint claims were located in 1895, the former by William Johnson and S. J. Whitcomb and the latter by Charles H. Bartlett and E. J. Merrin. Within a short time, Johnson and Whitcomb bonded the Keystone to a group of Spokane capitalists for $12,500. Development work proceeded rapidly, and within a year the mine included a 10-stamp mill, office, ore bins, and bunkhouses. During one especially good run in 1897, the Keystone mill recovered $1900 of gold from 308 tons of ore. Work on the Goldflint went well also, with three shifts of men working in a 450 foot tunnel in 1897. Crews had a 20-stamp mill operating there by January of the next year (Timmons, 1986; Byrne and Hunter, 1899).

Although the initial returns from the mines looked promising, the boom turned to bust. By August 1898, the mines and mills were closed and the town of Sylvanite was nearly deserted. MacDonald (1909) suggested that the ore may have turned base as the mines deepened, ren-



dering the mills ineffective. The Keystone and Goldflint mines were consolidated in 1899, the same year that the Keystone was patented; the Goldflint was patented five years later (Timmons, 1986).

After a decade of quiet, Sylvanite came to life again in 1910. Canadian capitalists paid $75,000 for the Keystone and Goldflint claims and formed the Lincoln Gold Mining Co. to run the mines. A 2400-foot tramway carried ore from the Keystone mine, and the mills began processing ore. Both soon shut down as the company started a major renovation project that included a new 20-stamp mill. The first batch of ore had yet to be processed when disaster struck the Sylvanite district. A forest fire on August 26 left just one building in town standing and leveled everything at the mines. Lincoln Gold Mining Co. placed the loss at $40,000, while damage in the town totaled $75,000. The company announced plans to rebuild and even ordered lumber in 1911, but this reconstruction never occurred (Timmons, 1986; Walsh and Orem,1910; 1912).

The Keystone and Goldflint came to life one more time, making a very profitable run during the 1930s. Percy Goodwin and Frank McNees leased the properties, and they and a small crew began operations in August 1932. Within a short time, the mill was processing 40 tons of ore every 24 hours, running continuously. Three hundred tons of especially good ore yielded $4000 in gold in August 1937. The total production from 1931-1937 amounted to 22,200 tons of ore worth $246,000. Work continued intermittently on the mines, and in 1939, a crew of 18 men were driving a 1,500 foot crosscut (WPA, 1940; Timmons, 1986; Johns, 1970).

Joe Thornton, a partner with Goodwin and McNees, formed the Haywire Mining and Milling Co. in 1936. The new corporation acquired a number of claims near Sylvanite and constructed a 10-stamp mill (24LN263) around 1937 on the west side of the Yaak River road. The mill processed ore from the Keystone and Goldflint mines, running until around 1942. Morning Glory Mines, Inc., owner of the Keystone and Goldflint, bought the Haywire Co. in 1946, further consolidating the claims at Sylvanite. They converted the stamp mill to a ball mill and ran from 1946 to around 1951. Morning Glory Mines declared bankruptcy in 1952. The last activity on the Keystone group occurred in the late 1950s (Friedman et al., 1983; Johns, 1970).

Victoria

The Victoria mine is located near the Keystone. Owner Fred Lang worked the property from 1910-1912 when an 800-foot tunnel provided access to the copper-gold-silver ore. Although Lang made several shipments of ore, there are no production totals for the mine (Johns, 1970; Walsh and Orem, 1910; 1912).

REFERENCES

Byrne, John, and Frank Hunter, 1899, 10th Annual Report of the Inspector of Mines of the State of Montana for the Year Ending Nov. 30, 1898.

Calvi, Jim, 1993, Trails & Roads to Sylvanite and the Yahk Mining District, 1864-1897: Report prepared for the Three Rivers Ranger District, Kootenai National Forest.

Friedman, Paul D., James M. Brechtel, Marilyn A. Martorano, and Deward E. Walker, Jr., 1982, Final Report of Cultural Resource Investigations Along Montana Forest Highway #62, Yaak, Montana: Powers Elevation / Archaeology Department, Submitted to National Park Service, Contract No. CX-1200-2-B022.

Gibson, Russell, 1948, Geology and Ore Deposits of the Libby Quadrangle, Montana: U.S.G.S. Bulletin 956.

Hauge, Kristen, 1994n A Cultural Resource Inventory of the Robert Copeland Timber Sale: report, Kootenai National Forest.

Johns, Willis M., 1970, Geology and Mineral Deposits of Lincoln and Flathead Counties, Montana: Bulletin 79, Montana College of Mineral Science and Technology, Butte.

MacDonald, D. F., 1909, Notes on the Economic Geology, _in_ A Geological Reconnaissance in Northern Idaho and Northwestern Montana, by F. C. Calkins: U.S.G.S. Bulletin 384.

Pardee, J. T., and E. S. Larsen, 1929, Deposits of Vermiculite and Other Minerals in the Rainy Creek District, Near Libby, Mont.: _in_ Contributions to Economic Geology, Part I: Metals and Nonmetals Except Fuels: U.S.G.S. Bulletin 805.

Perry, Eugene S., 1948, Talc, Graphite, Vermiculite and Asbestos Deposits in Montana: Memoir No. 27, Montana School of Mines, Butte.

Renk, Nancy F., 1994, Mining, _in_ Historic Overview of the Kootenai National Forest, Vol. 1, edited by Christian J. Miss: Northwest Archaeological Associates, Inc., Seattle.

Sahinen, Uuno Mathias, 1935, Mining Districts of Montana: Unpublished Master's thesis, Department of Geology, Montana School of Mines, Butte.

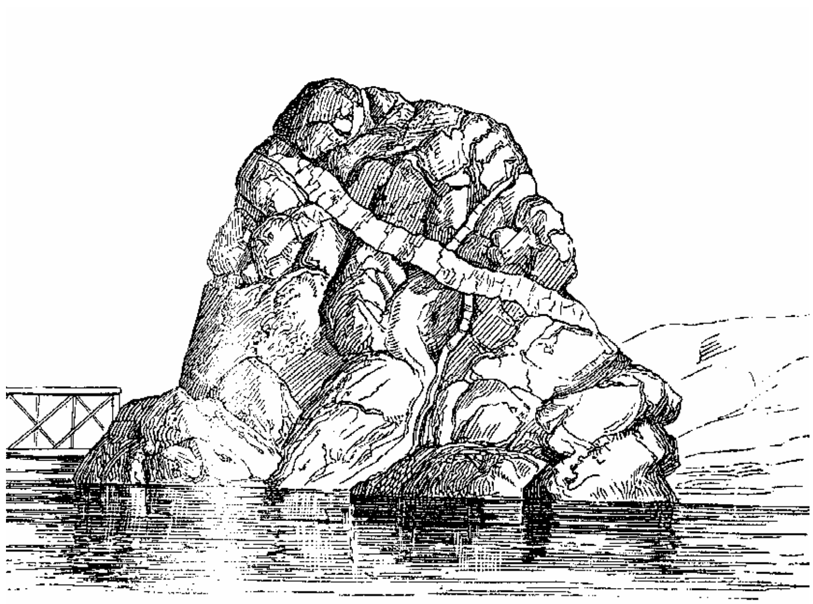
Timmons, Rebecca S., 1986, A Culture History of the Yahk Mining District: Unpublished Master's thesis, University of Montana, Missoula.

Walsh, William, and William Orem, 1910, Biennial Report of the Inspector of Mines of the State of Montana For the Years 1909-10.

-------, 1912, Biennial Report of the Inspector of Mines of the State of Montana For the Years 1911-12.

Work Projects Administration (WPA), Mineral Resources Survey, 1940, Directory of Montana Mining Properties: Memoir No. 20, Montana School of Mines, Butte.

-------, 1941, Montana Mine Index, and Alphabetical Index Arranged by Counties, Districts and Mines of Information on Montana Mines from 1867-1940: Montana School of Mines, Butte.

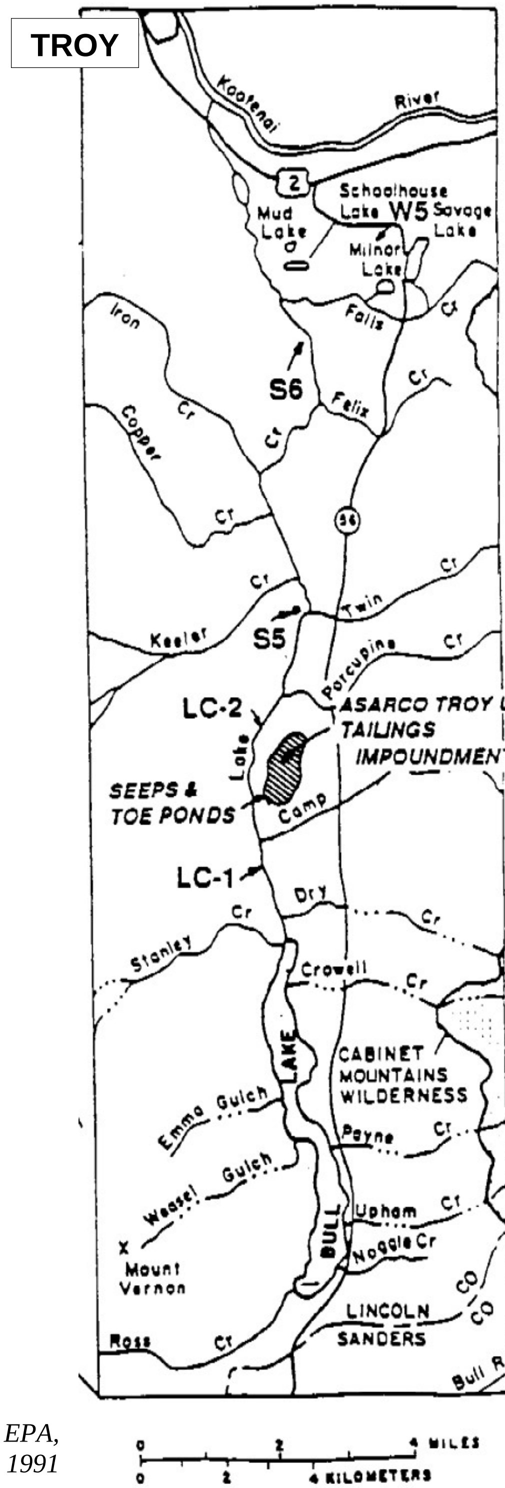


TROY MINE OVERVIEW, LINCOLN COUNTY, MONTANA

Derek L. Feeback
Revett Minerals, Troy, MT

Copper and silver mineralization was first discovered at the Spar Lake Deposit (Troy Mine) by E. B. Williams while dozing in logging roads in 1958. Kennecott's Bear Creek Mining Co. began exploration for stratiform copper deposits in the area in 1961. They acquired Williams' claims, staked the Spar Lake Deposit and acquired the Rock Creek Deposit in 1965. Drilling commenced at the Spar Lake, with favorable results, and the drilling and underground development was mostly complete by 1971. Kennecott entered a joint venture agreement with Asarco in 1973 and Asarco began construction in 1979 at a cost of approximately $90 million. First production began in 1983 and continued until 1993, when the mine was idled due to low metals prices. During this time, Asarco explorationists discovered copper and silver mineralization in the Lower Revett quartzites and conducted several drilling projects in the region.

Revett Minerals acquired the property in 1999, started rehabilitation in 2003 and produced its first concentrates in December of 2004. Exploration drilling in 2004 and 2005 better defined and expanded the East Ore Body reserves. At present, the total proven and probable ore reserves at Troy Mine are over 12 million tons at 1.41 oz/ton Ag and 0.6 % Cu.



Location map from U.S. EPA, Office of Surface Waste, 1991

TROY MINING DISTRICT, LINCOLN COUNTY, MONTANA
Historic Mining District Narrative

Montana State Department of Environmental Quality

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HISTORIC CONTEXT

The Troy district, also known as Callahan, Callahan Creek, or Grouse Mountain. lies south and west of Troy in the area bounded by Callahan Creek on the north and Keeler Creek on the south. It includes the Bull River drainage, a major north flowing river in the Cabinet Mountain range. A small area of placer activity clusters to the east of Troy at Kootenai Falls.

Isolated prospectors worked along Callahan Creek as early as 1884, with more men joining the search later in the decade as they fanned out from strikes on Libby Creek and in the Coeur d'Alene region in Idaho. Among these later miners were Thomas Baggs, William Doyle, Robert Atkins, and James Freeman, prospectors who worked their way over the mountains to Callahan Creek from Hope, Idaho in 1888 (Calvi, 1992; Wood, c. 1910).

Placer miners did not have much luck in the Troy district. The largest placer operations centered around Kootenai Falls where numerous claims were staked from 1892-1896, on both sides of the river, both above and below the falls. Men dug ditches to divert water to their claims, and a group even constructed a large canal 24 - 45 feet in width and 2 - 5 feet in depth. The brief flurry of activity ended around 1900, with a few continuing to work claims for several more years. Arthur V. Corry, a mining expert, examined the claims in 1911 and then issued a report eight years later. In his estimation, the area was "absolutely valueless as placer mining ground." Indeed, the values were so low that the costs of mining would amount to eight times the profit. Despite this dismal assessment, some miners continued to work the area as late as 1919, using dry shaking methods (Schweigert, 1981; Corry, 1919; Renk, 1994).

Callahan Creek gravels attracted a few miners over the years. Some recovered small amounts of gold through sluicing in 1924, 1934, and 1942. The Condor Mining and Leasing Co. worked eight claims along the creek about 1939, using a crew of two to four men with a hydraulic and suction dredge to work 20 cubic yards of gravel a day. The operations had netted $681 at that time (Lyden, 1948; WPA, 1940).

Prospectors staked a number of lode claims in the Troy district in the 1890s. The first two claims of what became the Big Eight mine were located along Callahan Creek in 1889 and then relocated the following year; development work began in 1891. Nearby, Frank and James Stonechest, Robert Hulse, and Maurice Downey located the Bangle claim on 13 June 1893, the same day that Frank and James Stonechest, Robert Hulse, and Bart Downey filed on the adjacent Banner claim. These two claims, called the B and B, later became known as the Snowstorm, the most important claim in the district. Development work began on the B and B in 1895. The Iron Mask and Grouse Mountain claims were located in 1892, while the Montana Morning claims near the Snowstorm were located prior to 1906 and were later taken over by the larger mine (Calvi, 1992; Johns, 1970; Calvi, 1987b).

While some mines, such as the Montana Morning, began producing at an early date, large scale development did not come to the Troy district until after 1915 when Leo Greenough, of the Greenough Investment Co., purchased the Snowstorm mine. The company started construction on a concentrator the following year, built a dam, flume, and powerhouse on Lake Creek, and lay 6.5 miles of railroad tracks up Callahan Creek. At the end of the year, more than 600 men were on the payroll. The concentrator started operations in April 1917 and ran until it burned in May 1927; during that time, the Snowstorm produced over $4 million in ore (Calvi, 1992; Gibson, 1948).

While the Snowstorm mine was the leading producer of the Troy district, other smaller mines operated during the 1920s and 1930s as well. Among these were the Giant Sunrise, Grouse Mountain, Liberty Metals, Silver King, Bimetallic, and Silver Grouse. Following the destruction of the Snowstorm concentrator, local mines had to ship ore outside the district for milling until operators of the Giant Sunrise and Liberty Metals constructed mills in the mid-1930s (Johns, 1970; Gibson, 1948).

Sedimentary rocks of the Belt series, including shales, argillites, sandstones, and quartzites, underlie the Troy district. Igneous sills have intruded in some areas and these, along with the sedimentary formations, have been folded and faulted. Stocks and dikes of a later age have also intruded into the formation (Gibson, 1931).

Much of the ore in the Troy district occurs in dark colored sills and dikes found near shear zones. Ore-bearing solutions moved along the channels created by the faulting and shearing of the rocks, forming mineral deposits in the adjoining sedimentary rocks or in the igneous dikes and sills (Gibson, 1931).

BOUNDARIES OF THE DISTRICT

According to Sahinen (1935), the only one to describe the district boundaries, "Grouse Mountain is a spur of the Cabinet Range between the headwaters of Calahan [sic] Creek and Lake Creek, southwest of Troy." The mines of the district are spread across this area that is bounded by Callahan Creek on the north and Keeler Creek on the south. In addition, there was a small placer district was concentrated in the area around Kootenai Falls east of Troy.

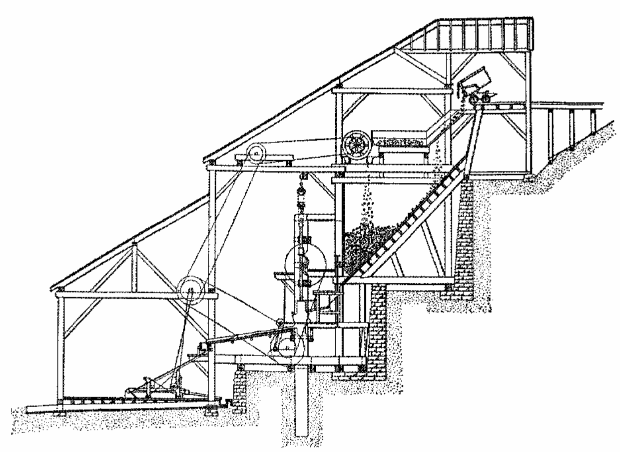
HISTORIES OF SELECTED MINES

Big Eight

The Big Eight mine includes four patented and two unpatented claims on both sides of Callahan Creek just north of the Snowstorm mine in section 19, T31N, R34W. Both mines are either on the same fissure vein or on two parallel but slightly separated fissure veins (Johns, 1970; Calvi, 1987b).

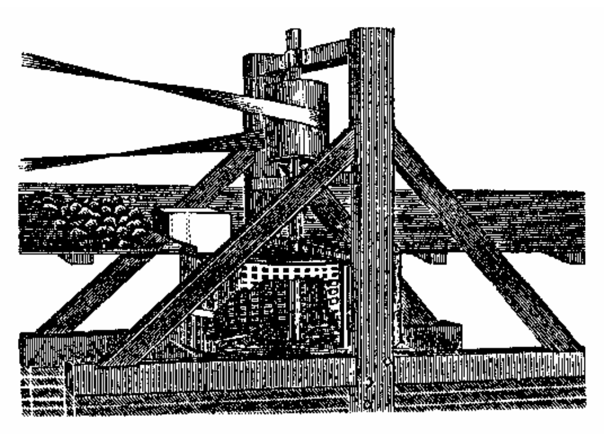
Confusion surrounds the initial claims on the Big Eight mine. Seven partners located the Welcome Guest and Northern Belle claims on Callahan Creek but mistakenly recorded them in Idaho in November 1889. Less than a year later, William Houston recorded the same locations in Montana as the Heron and Cabinet claims. Evidently the eight men formed a partnership which changed in membership and numbers over the next few years, emerging again in 1897 with a total of eight partners which led to the name of the mine (Calvi, 1987b).

Development work began in 1891 when a crew of 17 men worked in the summer and fall. The Big Eight Mining Co. took over operations in 1897, followed by the Silver Torrent Mining Co. by 1906. That year crews sank a 75-foot winze, ran a 450 foot crosscut tunnel, completed 350 feet of drifting, and worked on a new tunnel to tap the vein at 600 feet in depth also. Also that year, the company shipped four



carloads of ore each month to Germany via Seattle. Work continued on the mine at least through 1912 (Calvi, 1987b; Walsh and Orem, 1906, 1910, 1912).

A big push started in 1926 when operators constructed a short rail spur to connect the mine with the Snowstorm mine railroad. This spur, while just one-quarter of a mile long, involved building a 1000 foot trestle up a steep canyon. Once the rail line was completed, the mine began shipping ore to the Snowstorm concentrator in Troy. The mine was sending 60 tons of ore a day in January 1927 and expected to increase it soon to 100 tons. The concentrator burned in May 1927, however, causing mine operators to ship the ore elsewhere after the fire (Calvi, 1987b).



The mine reported production in 1912-1913 and 1925-1928, with the total amounting to 6000 tons of zinc-lead ore during this period. Although the mine was idle by 1931, the Chance Mining Co. reactivated it in 1944, shipping nearly 300 tons of ore. The last ore extraction occurred in the 1960s (Johns, 1970; WPA, 1941; Gibson, 1948; Calvi, 1987b).

The mine workings include three adits on the north side of Callahan Creek and one on the south side, 450 feet of crosscuts, and two winzes (Johns, 1970).

Bimetallic
The Bimetallic group comprises 14 unpatented claims in the Keeler Creek drainage south of Lime Butte. The mine includes five adits, ranging in length from 100 to 800 feet, and several crosscuts. An assay in 1929 gave values of $125.45 per ton, with $.80 in gold; $9.08 in silver; and $115.57 in lead. There are no production records for the mine (Johns, 1970; Gibson, 1948; Troy Mining Chamber, c. 1929).

Giant Sunrise (Montana Sunrise)
Located in section 10, T30N, R34W, the Giant Sunrise was formed with the merger of Consolidated Silver Lead, Silver Grouse, and Montana Sunrise Mining companies. At one time, the mine encompassed the Silver Tip claim, 31 unpatented claims, and a mill site; Johns (1970), however, lists only 19 unpatented claims and the mill site (WPA, 1940).

Following the discovery of a lead-zinc ore body in 1928, the mine was active during the 1930s. Operators built a 100-ton mill in 1934 and employed a crew of about 15 men during 1935-1936. The mill continued operations through 1939 and possibly longer. The mine contained five adits ranging from 255 feet to 6,000 feet in length, and the mine buildings included the mill, a blacksmith shop, and other structures (Johns, 1970; Gibson, 1948; WPA, 1940).

In July 1935, an average run of ore contained 6 percent lead, 8.5 percent zinc, and 1.2 ounces of silver per ton. A shipment of lead concentrates, on the other hand, yielded 72.2 percent lead and 16 ounces of silver per ton, while a shipment of zinc concentrates yielded 50.4 percent zinc, 4.3 percent lead, and 1.7 ounces of silver per ton. There are no production records for the mine (Gibson, 1948).

Grouse Mountain
Although the Grouse Mountain mine was located in 1892, it was not developed until the late 1920s. At that time two shifts of miners were employed. Using hand drills, the workings were extended 3-4 feet a day. The company planned to add compressors and air drills if the work became too difficult. The property encompassed 27 unpatented claims north of the North Fork of Keeler Creek, mostly in section

10, T30N, R34W. Mine workings consist of four crosscut adits and 3,000 feet of drifting. Buildings include several cabins, a blacksmith shop, and an ore bin. The mine was in operation in 1958 (Johns, 1970; Gibson, 1948; Troy Mining Chamber, c. 1929).

Iron Mask

The Iron Mask mine includes two patented claims and two patented fractions in sections. 11 and 14, T30N, R34W, north of Keeler Creek and west of Lime Butte. The deposit was discovered in 1892 and the claim was worked sporadically, yielding 200 tons of ore by 1931. Additional work took place in 1943 when the Montana Mining and Milling Co. leased the Iron Mask and Montana Morning claims. During a five month run, the operators produced nine tons of lead concentrates and 23 tons of zinc concentrates from the Giant Sunrise mill. Mine workings consist of two short adits (Johns, 1970; Gibson, 1948).

Liberty Metals

The Liberty Metals claims are 6 miles south of Troy on Iron Creek, in section 35, T31N, R34W. The number of claims involved is unclear: WPA (1940) credits the property with 21 unpatented and three patented claims, Gibson (1948) notes only eight patented claims, and Johns (1970) lists eight patented and nine unpatented claims.

Development work began as early as 1923 and then intensified after 1926. By the end of the decade, mine structures included bunk houses, a mess hall, office, living quarters, and a shower building. In addition, a sawmill was cutting timbers for the construction of a mill. Up to 1934, the mine had made only one shipment of ore, which yielded $142 per ton with values mostly in lead and silver (Johns, 1970; Gibson, 1948; WPA, 1940; Troy Mining Chamber, c. 1929).

Two events in 1934 were designed to spur the development of the mine. Liberty Metals absorbed the mine's former owner, Silver Strike Mining Co. In addition, crews installed machinery for the 100-ton flotation mill. Unfortunately, neither move paid off. The mine was inactive in 1936 and reported only assessment work by the end of the decade (Johns, 1970; WPA, 1940).

Montana Morning

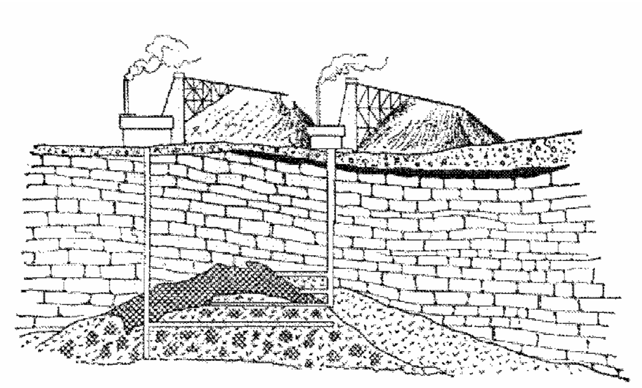
The claims of the Montana Morning property are located near the head of Iron Creek in section 28, T31N, R34W. The July mine, one of the claims, reported development work consisting of a 100 foot shaft and some drifting in 1906. The owners were negotiating a sale at that time and anticipated further work on the mine. The Montana Morning Mining and Milling Co. formed around 1906, combining the July mine with other lead-silver claims. Development work continued under the new management, and the company employed 25 men in 1910. Crews were building a power plant and owners planned construction of a mill soon. Two years later, the underground workings included two tunnels 350 and 700 feet long (Gibson, 1948; Johns, 1970; Walsh and Orem, 1906, 1910, 1912; Calvi, 1992).

The Snowstorm mine purchased the Montana Morning property in 1923, thus gaining claims on the southeast end of the Snowstorm dike. At some point, operators constructed a road joining the mine with the Snowstorm railroad along Callahan Creek and built an ore bin at the junction. Ore from the Montana Morning was then hauled to the concentrator in Troy. This probably ended soon after a fire destroyed the concentrator in May 1927. There are no production totals for the mine (Johns, 1970; Gibson, 1948).

Silver Grouse

The Silver Grouse encompasses nine unpatented claims in section 11, T30N, R34W. The Silver Grouse Mining Co. incorporated in 1929 to work the claims. The small camp included cabins for the crew and a blacksmith shop, while the underground workings consisted of two shallow shafts and a 311 foot adit. Selected samples of high grade galena assayed 4 to 71 ounces of silver per ton. There are no production records for the mine (Johns, 1970; Gibson, 1948; Troy Mining Chamber, c. 1929).

Silver King
The Silver King property includes three unpatented claims on the North Fork of Keeler Creek. Silver King Mining Co. organized in June 1923 to work the claims, and by the end of the decade the mine had shipped 73 tons of ore to the smelter in Helena, netting $4,591.26 for the company. The ore averaged 75 percent lead and 14 ounces of silver to the ton. Gibson (1948) reported that the mine shipped six carloads of ore, with the average smelter returns



showing 60.9 percent lead; 1.0 percent zinc; 0.19 ounces of gold; and 12.3 ounces of silver per ton. There are no production records for the mine. Underground workings consist of seven short adits totalling 850 feet (Troy Mining Chamber, c. 1929; Gibson, 1948; Johns, 1970).

Snowstorm
The Snowstorm mine (24LN1326) is located on the south side of Callahan Creek, in sections 19, 20, and 29, T31N, R34W. The mine started as two patented claims and eventually grew to encompass as many as 60 claims after 1931 (Johns, 1970).

Frank and James Stonechest, Robert Hulse, and Maurice Downey located and recorded the Bangle claim on 13 June 1893, the same day that Frank and James Stonechest, Robert Hulse, and Bart Downey recorded the adjoining Banner claim. When development work began in 1895, the two claims were worked as one mine, known as the Banner and Bangle, or just the B and B (Calvi, 1987a).

E. J. Merrin, from the nearby town of Leonia, Idaho, bonded the B and B for $10,000 in the spring of 1895, and hired the Downey brothers to drive a tunnel. Work proceeded at a good pace, and by the end of the summer Merrin hired packers to haul 100 tons of ore to Troy for shipment to the Everett smelter. The Banner and Bangle Mining Co. incorporated in 1896 to operate the mine, and development proceeded slowly for many years. A small crew of ten continued with development around 1911 (Calvi, 1987a; Walsh and Orem, 1912).

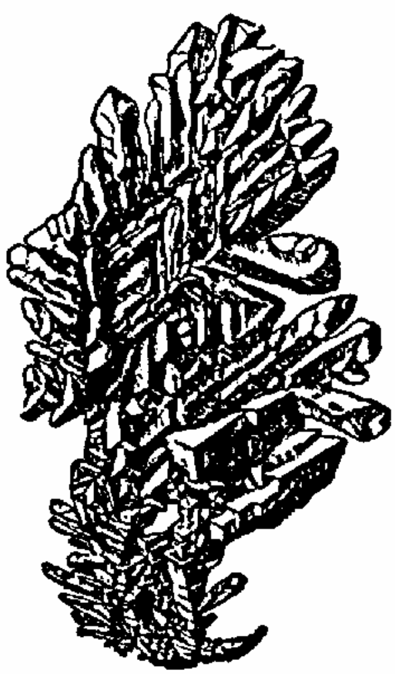
Sometime between 1905-1908, T. L. Greenough of Missoula purchased a large share of stock in the Banner and Bangle. Following his death in 1911, the Greenough Investment Co. took over his shares and eventually bought the mine in 1915 for $150,000. The new owners formed the Snow Storm Consolidated Mines in 1916 and renamed the mine the Snowstorm (Calvi, 1987a; Western News, 1920).

Development proceeded rapidly in 1916, not only within the mine but outside as well. Crews built a dam, flume, and power house on Lake Creek to supply electricity to the mine and concentrator, selling excess power to help light Troy. Work also included building 6.5 miles of narrow gauge railroad up Callahan Creek and construction of camps for the large crews as well as offices and residences in town. The Snowstorm also built a concentrator in Troy, which began operations in April 1917. It included ore bins with a capacity for 1000 tons of ore, a gyratory crusher, trommel screens for sorting, and four Wilfley tables (Calvi, 1987a, 1992).

The Snowstorm began producing steadily after the concentrator was completed, soon becoming the leading producer for Lincoln County. The mine employed 250-300 men during the 1920s. Johns (1970) reported that the mine produced 202,000 tons of ore worth $1,516,000 during 1918-1926, while Gibson (1948) estimated the total production as at least $4 million in lead, zinc, gold, and silver. The concentrator burned in May 1927 resulting in very little production after that time.

Troy Mines Co., headed by William A. Shoup of Missoula, purchased the Snowstorm, Montana Morning, and other holdings of the Greenough Investment Co. at Troy in 1929. Two years later, Gibson (1948) estimated that the ore reserves amounted to 207,000 tons. Despite the apparent potential of the mine, it remained inactive until the mid-1960s (Troy Mining Chamber, c. 1929; WPA, 1940; Johns, 1970).

The extensive mine workings contain two shafts 125 and 600 feet deep, several adits totalling 10,000 feet, 500 feet of drifting, 3,500 feet of crosscuts, and 1,100 feet of raises (Johns, 1970).



REFERENCES

Abandoned Mine Reclamation Bureau (AMRB), 1994, Mining districts of Montana: Map #94-NRIS-129, 1:100,000 scale, compiled and edited by Joel Chavez. Prepared by Montana State Library Natural Resource Information System (NRIS) for Montana Department of State Lands, Helena

Bowman, A. H., and Barclay Craighead, 1926, Montana, Resources and Opportunities Edition, Vol. 1: Department of Agriculture, Labor and Industry, Division of Publicity.

Byrne, John, and Frank Hunter, 1901, Twelfth Annual Report of the Inspector of Mines of the State of Montana: Independent Publishing Company, Helena.

Calkins, Frank Cathcart, 1909, A Geological Reconnaissance in Northern Idaho and Northwestern Montana: U. S. Geological Survey Bull. 384, pp. 7-112.

Calvi, Jim, 1987a, Cultural Site Records, 24LN1326, Banner & Bangle Mine: 28 June.

---------, 1987b, Cultural Site Records, 24LN1267, Big Eight Mine: 29 June.

---------, 1992, Callahan Creek Historic Mining & Logging District, 24LN544, Three Rivers Ranger District, Kootenai National Forest.

Corry, Arthur V., 1919, Report on Portions of Sections 13 and 14 T. 31 N., R. 33 W. Lincoln County, Montana, with Notes on Placer Mining as Addenda: Butte, Montana, manuscript on file, Montana Historical Society Archives, Helena.

Gibson, Russell, 1931, Gold in Northwestern Montana, Min. Truth, Vol. 16, No. 9, pp. 5-6.

---------, 1931, Gold-Quartz Veins South of Libby, Montana, U. S. Geological Survey Circ. 7.

---------, 1934, Dept. of Interior, Memo. for the Press.

Gibson, Russell, 1948, Geology and Ore Deposits of the Libby Quadrangle, Montana: U.S.G.S. Bulletin 956.

Gibson, Russell, Jenks, William F., and Campbell, Ian, 1938, Stratigraphy of the Belt Series in Libby and Trout Creek Quadrangles, Northwestern Montana and Northern Idaho: Geol. Soc. America Bull., Vol. 52, pp. 363-380, 1941; (abst.) Geol. Soc. America Proc., 1937, p. 83, 1938.

Johns, Willis M., 1970, Geology and Mineral Deposits of Lincoln and Flathead Counties, Montana:

Bulletin 79, Montana College of Mineral Science and Technology, Butte.

Lyden, Charles J., 1948, The Gold Placers of Montana: Memoir No. 26, Montana Bureau of Mines and Geology, Butte, Montana.

MacDonald, Donald Francis, 1906, Economic Features of Northern Idaho and Northwestern Montana, U. S. Geological Survey Bull. 285, pp. 41-52.

Nason, Frank Lewis, 1917-1918, Characteristics of Zinc Deposits in North America, Am. Inst. Min. Eng. Bull. 125, pp. 799-824; 1917, Am. Inst. Min. Eng. Trans., Vol. 57, pp. 830-862; 1918, Am. Inst. Min. Eng. Bull. 133, pp. 62-67, 1918.

Renk, Nancy F., 1994, Mining: *in* Historic Overview of the Kootenai National Forest, Vol. 1, edited by Christian J. Miss, Northwest Archaeological Associates, Inc., Seattle.

Sahinen, Uuno Mathias, 1935, Mining Districts of Montana: Unpublished Master's thesis, Department of Geology, Montana School of Mines, Butte.

Schweigert, Kurt P., 1981, Final Report: Historical Cultural Resource Investigations Near Kootenai Falls, Montana: James A. Sewell and Associates, Newport, Washington.

Smith, Lewis A., 1932, Chromite: Minerals Yearbook, 1932, U. S. Bureau of Mines, p. 300.

Swindlehurst, J. W., 1914, Montana Department of Labor and Industry, 1st Biennial Report.

Troy Mining Chamber, c. 1929, The Troy Montana Mining District: Silver, Lead, Zinc, n.p. manuscript on file, Troy Ranger Station, Three Rivers Ranger District, Kootenai National Forest, Montana.

Walsh, William, and William Orem, 1906, Biennial Report of the Inspector of Mines of the State of Montana For Years 1905-06.

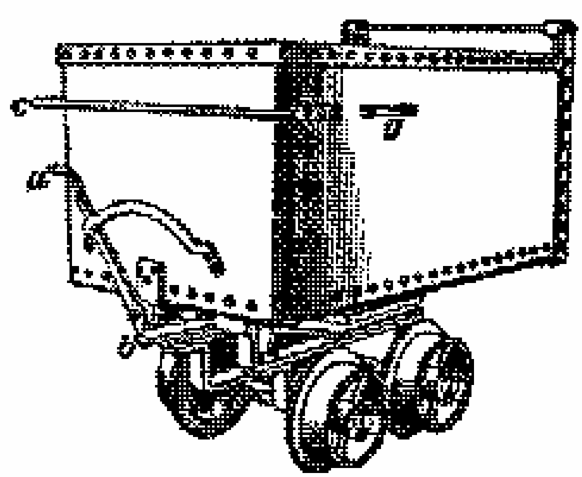
Walsh, William, and William Orem, 1910, Biennial Report of the Inspector of Mines of the State of Montana For the Years 1909-10.

---------, 1912, Biennial Report of the Inspector of Mines of the State of Montana For the Years 1911-12.

Western News (compiler), 1920, Lincoln County, Montana: History, Resources, Industrial Development, and Record in the Great War: Western Montana Publishing Co., Libby.
Wood, Mrs. D. T., c. 1910, Early History of Troy, Montana, From 1888 to 1909: Manuscript on file, Montana Historical Society Archives, Helena.

Work Projects Administration (WPA), 1940, Mineral Resources Survey -- Directory of Montana Mining Properties: Memoir No. 20, Montana School of Mines, Butte.

---------, 1941, Montana Mine Index, and Alphabetical Index Arranged by Counties, Districts and Mines of Information on Montana Mines from 1867-1940: Montana School of Mines, Butte.



GEOLOGY AND ORE OF THE MONTANORE PROJECT, NORTHWEST MONTANA

Eric Klepfer

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INTRODUCTION

Mines Management Inc. (MMI) is currently re-permitting and engineering the Montanore Project. Noranda Minerals Corporation had the project fully permitted in 1993. During their tenure, they initiated the development of a 16,000 foot adit to access the deposit with the intention of doing additional drilling for delineation purposes.

Considerable geologic and engineering work was completed and Mines Management is currently working on updating the project costs and developing a geologic block model to assist in the mine planning activities.

PROPERTY DESCRIPTION AND LOCATION

The Montanore Project is located approximately twenty-three miles south of Libby, Montana and nine miles northeast of Noxon, Montana. The deeded property consists of two patented load claims, HR 133 and HR 134. These two patented claims control the apex and extralateral rights to the Montanore Deposit which is located entirely underneath the Cabinet Wilderness Area with the exception of the outcrop at HR 133 and 134.

Initial application for patenting of the mining claims HR 133 and HR 134 was filed June 10, 1988 with the Bureau of Land Management (BLM). The patents were granted on May 5, 1992. These claims provide the key to development of the deposit within the boundaries of the wilderness area based on prior existing rights.

HISTORY

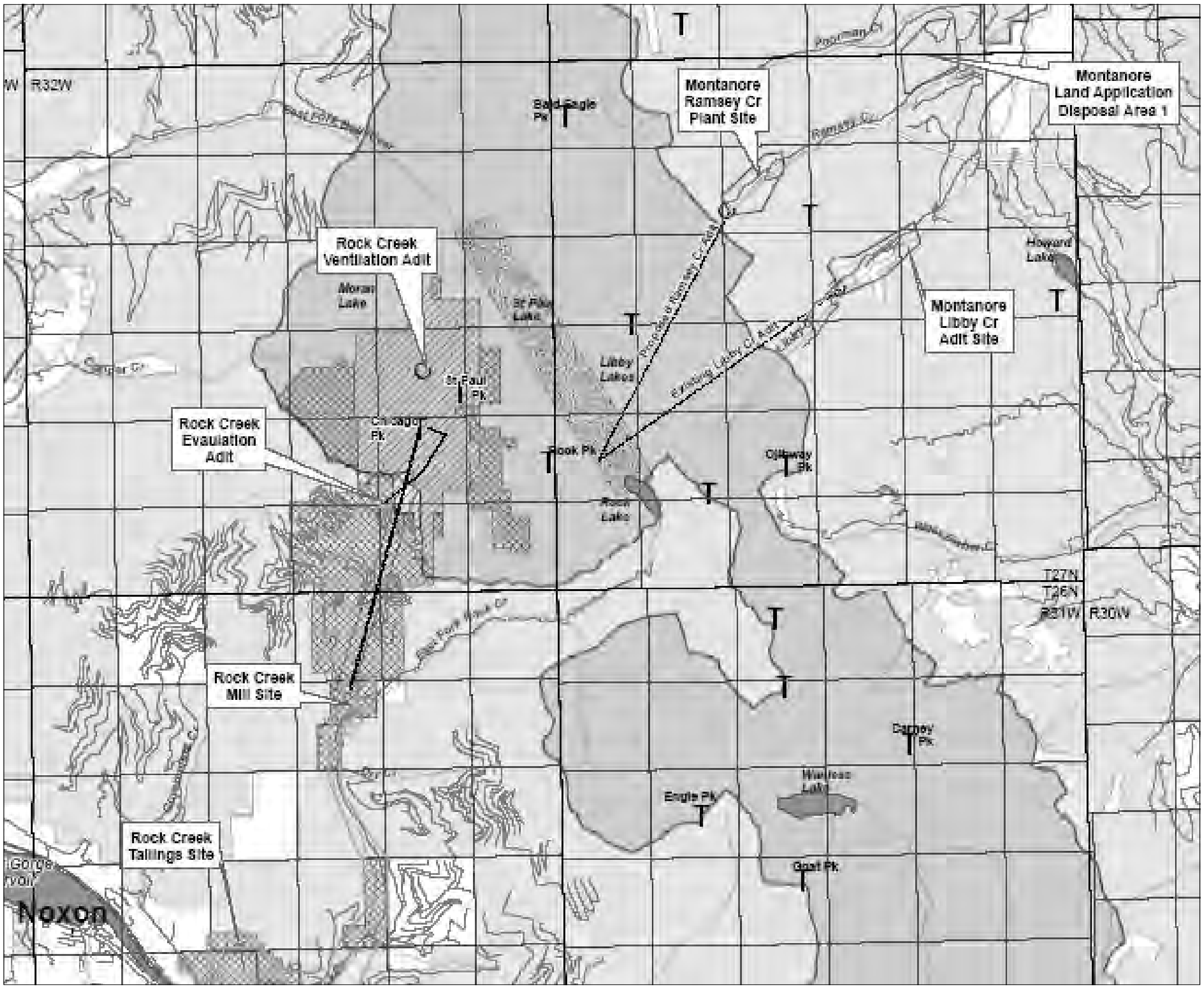
In 1983, U.S. Borax optioned the claims held by Heidelberg Mining Company. In July 1983 Thomas Henricksen and Russel Smith made the first discovery using field glasses to spot green copper oxide stain occurring at the top of the Lower Revett Formation near Rock Lake. Based on this observation, they maneuvered the steep terrain to the oxidized stain area and discovered disseminated chalcopyrite, bornite, and chalcocite.

U.S Borax initiated drilling in 1983 and intercepted copper and silver mineralization. Further drilling occurred each summer season from 1984 to 1987. Almost 10,000 feet of core was assayed with most of the assaying occurring on 2-foot intervals.

Drilling was difficult in the steep terrain and could only be accessed by foot, horseback, and helicopter. Because of the wilderness designation, disturbance for drilling was limited. Ten separate drill sites were developed for 31 drill-holes. Further exploration work from the surface is not possible because of the wilderness area.

U.S. Borax optioned the project to Montana Reserve Company in 1988. Noranda Minerals Corporation, a subsidiary of Noranda Inc. acquired a 55 percent joint venture interest in the project and became the operator. Prior to this action, Mines Management entered into a merger agreement with Heidelberg Mining Company and MMI became the surviving company.

Under terms of the lease agreement with Hei-



Location Map (from U.S. Forest Service) showing Montanore sites northeast of Noxon.

delberg Mining Company, Noranda terminated their interest in the project, reverting the property back to the original lease holder.

In 1988, Noranda initiated the development of an exploration decline from a portal near Libby Creek on the Johnstone patented claims. Noranda intended to drive to the deposit and complete additional infill drilling.

GEOLOGY

The Montanore deposit is a strata-bound silver/ copper deposit located in a series of Precambrian age metasedimentary rocks within the Revett Formation of the Belt-Supergroup series common to Montana, Idaho, Washington, and Canada. Montanore is located in the Western Montana Copper Belt, a mineralized area extending north/south from the Troy Mine to the Coeur d’Alene Silver District and includes the Rock Creek deposit (MDA 2005).

The Precambrian Belt Supergroup sediments were deposited in a relatively stable environment over a time span of 600 million years between 1,450 and 850 million years ago. The formations exposed in the project area include, from the youngest to the oldest, the Wallace, Empire, St. Regis, Revett, and Burke (MDA 2005).

The Revett Formation is a blocky, thinly cross bedded, clean white quartzite layer from 2 to 100 feet thick, with buff-colored silty quartzite, light gray to green siltite and some greenish argillite that alternates with the quartzite layers (MDA 2005). The deposit is primarily located within the Lower Revett formation. The Revett Formation consists of quartzite interbedded with silty quartzite and siltite. The beds are consistent both in mineralogy and grain size and supported by drilling results. The Lower Revett is primarily quartzite with lesser interbeds of siltite and silty quartzite (Stephens and Henricksen, 1989).

The average thickness of the Revett Formation in the Rock Lake area is 2,500 feet. The Upper Revett averages 215 feet compared to 245 at Troy and 180 at Cooper Gulch. The Middle Revett ranges in thickness from 300 feet to over 600 feet near the Rock Lake Fault. The dramatic increase in thickness of the Middle Revett near the Rock Lake Fault suggests that this area was a topographic low during sedimentation and may indicate that the Rock Lake Fault was vertically active during sedimentation. The entire section of the Lower Revett is exposed on the east side of the Rock Peak; here it averages 1,700 feet in thickness. The thickness of the Lower Revett under Montanore is unknown. Drilling to the deepest point has been to a stratigraphic depth of 459 feet below the Middle Revett (Stephens and Henricksen, 1989).

The Lower Revett has been divided into subunits based on lithologic guidelines devised by Asarco geologists. The subdivisions range from the A Bed quartzite at the top to the I Bed quartzite on the bottom of the section. Drilling of the Montanore Deposit did not penetrate beyond the F Beds.

The A Beds consist of vitreous quartzite with thin siltite and silty quartzite interbeds. The B Beds are primarily siltite and silty quartzite which are commonly separated by two thin vitreous quartzite beds. The C Bed is interbedded siltite, silty quartzite, and thin quartzite beds. The E Bed is a thick set of vitreous quartzite with local thin siltite and silty quartzite interbeds. Each of the beds was found to contain significant silver-copper mineralization greater than 0.75 ounces Ag/ton. (Stephens and Henricksen, 1989).

Mineralization occurs in pore spaces between sand grains and as grain coatings. Typically the mineralization is localized on bedding plans and heavy mineral laminations along contacts and also associated with fault structures and joint sets. Montanore lies on the lower limb of a breached overturned syncline with an axis plunging north-northwest gently while the lower limb, where mineralization occurs, is not folded but does dip about 15 degrees to the northwest. This geometry creates a progressively wider lower limb in a northwestward direction (MDA 2005).

The mineralized beds are bounded on the west by the Rock Lake Fault and the Libby Lake Fault bounds the syncline to the east (Stephens and Henricksen, 1989). The deposit extends beyond the boundary used to estimate the resource for the project.

Mineralogy is distinctly zoned, containing bornite, chalcocite, chalcopyrite, native silver, galena, pyrite, and pyrrhotite. The primary mineable ore zones are dominated by bornite-chalcocite and bornite-chalcopyrite assemblages. Sulfide content of the mineralized rock is typically 1-2% and it is unusual to exceeds 4%.

Herberger (1989) reported chalcopyrite and chalcocite coexist with bornite in the mineralized zone drilled near the apex and along the Rock Lake Fault.

The deposit occurs in two sub-parallel horizons separated by a lead (galena) waste zone. These horizons were identified as the B1 and B zones with the B1 in the upper and B in the lower reaches of mineralization. However, current block model work has identified mineralization occurring well outside the two zones selected by Noranda to be included in the mine plan. Prices were expected to be a significant factor in the selection of the B1 and B horizons. The average thickness of each zone is approximately 35 feet with the B zone having a higher grade.

MMI is currently reassessing these designations to determine if sufficient continuity exists within the mineralized envelope to better define the zones based on grade and other criteria. If these zones were modified to include a larger section, then a modification of the mining method could occur that could enhance project mining costs.

RESOURCES

Mine Development Associates evaluated the resource using a tonnage factor of 12.18 cubic feet/ton. A total of 38 silver or copper sample grades were capped prior to compositing. Variograms studies showed thickness and grade thickness ranges of up to 2,600 feet. Grade estimation was done with inverse distance squared methodology. All previous resource estimates used the perpendicular-bisector polygon method. Assay sample verification was completed on numerous drill core, coarse rejects, and pulps available from the drilling program completed by U.S. Borax.

The silver and copper resources were classified by the distance to the nearest sample (MDA 2005):

- 100 feet to the nearest sample for *Measured*;
- 1,200 feet internal to the drilled area and 500 feet external to the drilled area (extrapolation) was used to classify the resource as *Indicated*;
- All other material estimated within 1,700 feet was considered *Inferred.*

The area within the defined resource is restricted by the Rock Lake Fault and the extralateral rights boundary, additional resource exists beyond this area.

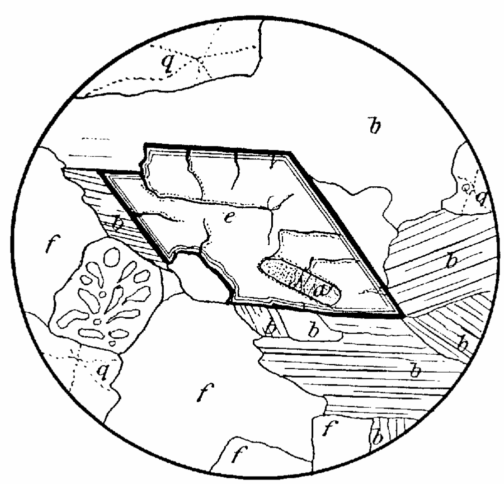
The Montanore Deposit contains approximately 116,000,000 tons of mineralized material, using a cut-off grade of 1.0 oz Ag/ton. This equates to a measure and indicated resource of approximately 85 million tons grading at 2.04 oz Ag/t and 0.75% Cu. An inferred resource of approximately 35 million tons was estimated at a grade of 1.85 oz Ag/t and 0.71 % Cu.

REFERENCES

Herberger, D., 1989, Noranda Minerals Corp., Inter Office Memo, Montana Project, dated May 13, 1989.

Mine Development Associates, 2005, Technical Report on the Copper and Silver Resources, Montanore Project, Lincoln and Sanders Counties, Montana, dated 2005.

Stephens, J.E., and Henricksen, T.A., date unknown, The Geology of the Noxon Ag-Cu Stratiform Deposit of Western Montana, Montana Reserve Co., U.S. Borax.



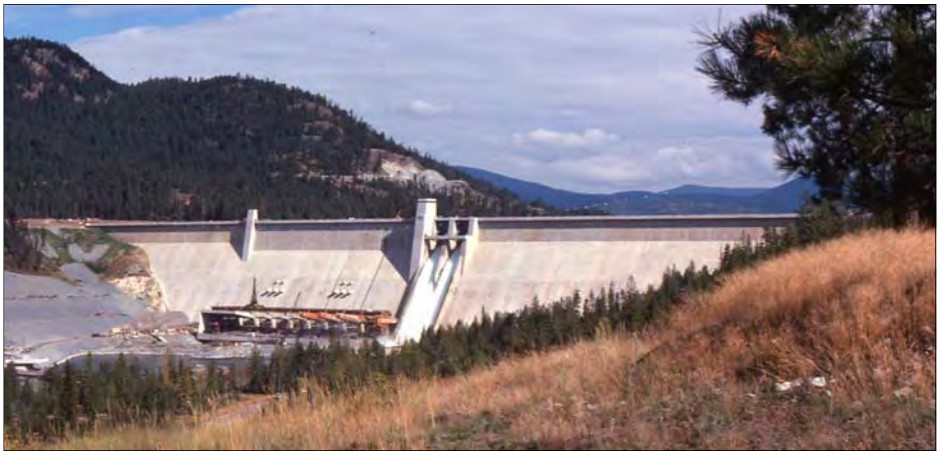


Fig 1: Libby Dam, view of dam from downstream left back in September 1974 while powerhouse was still under construction. Note the T frame character of the powerhouse.

Fig. 2: The Libby Left Abutment slide on 31 January 1971. Photo taken on 2 February 1971. The contractor's cooling plant (ice house) is the horizontal building center, left. The concrete batching plant is the vertical building at lower left with the partly completed dam below. The slide occurred on a bedding plane fault and a near vertical E-W joint.

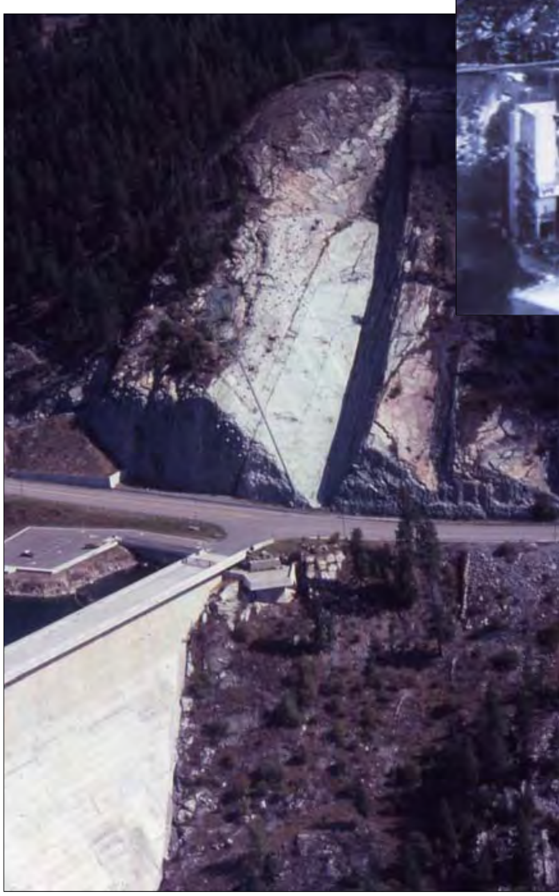


Fig 3: Aerial view of Libby Left Abutment slide area following clean up and tendon reinforcement. Note tendon heads on the face of the Dirty Shame + 122 bedding fault as well as later tendon heads on the cut face left of the notch. Photo taken September 1983.

LIBBY PROJECT, LINCOLN COUNTY, MONTANA

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ABSTRACT

Libby Dam is a major concrete gravity dam on the Kootenai River at river mile 221.9 in northwestern Montana, seventeen miles upstream of the town of Libby. The purpose of the dam is flood control, storage for the lower Columbia system and hydropower. The dam was constructed beginning in 1967 following the signing of the Columbia River Treaty with Canada, and was completed in 1973. The dam is 420 feet high, has a crest length of 3,055 feet at elevation 2472 feet above sea level. It impounds a reservoir ninety miles long extending forty-three miles into southern British Columbia, Canada. The dam is founded on Precambrian metasediments of the Belt Supergroup spanning the transition zone between the Ravalli Group and the overlying Piegan Group.

The project required the relocation of sixty miles of the then Great Northern Railroad (now Burlington Northern- Santa Fe) including the seven-mile-long Flathead Tunnel, along with fifty-two miles of Montana State Highway 37 and an equal length of first class forest development road. The highest bridge in Montana was constructed across the reservoir at its midpoint and the town of Rexford was relocated together with U.S. Forest Service facilities.

The Flathead Tunnel was driven through metasedimentary rocks of the Pritchard Formation, Ravalli Group and Piegan Group. Geologic structure ranged from flat-lying beds in the area of the south (west) portal to near vertical to slightly overturned beds near the north (east) portal. Several regional faults were encountered.

Libby Dam. Image from US Army Corps of Engineers.

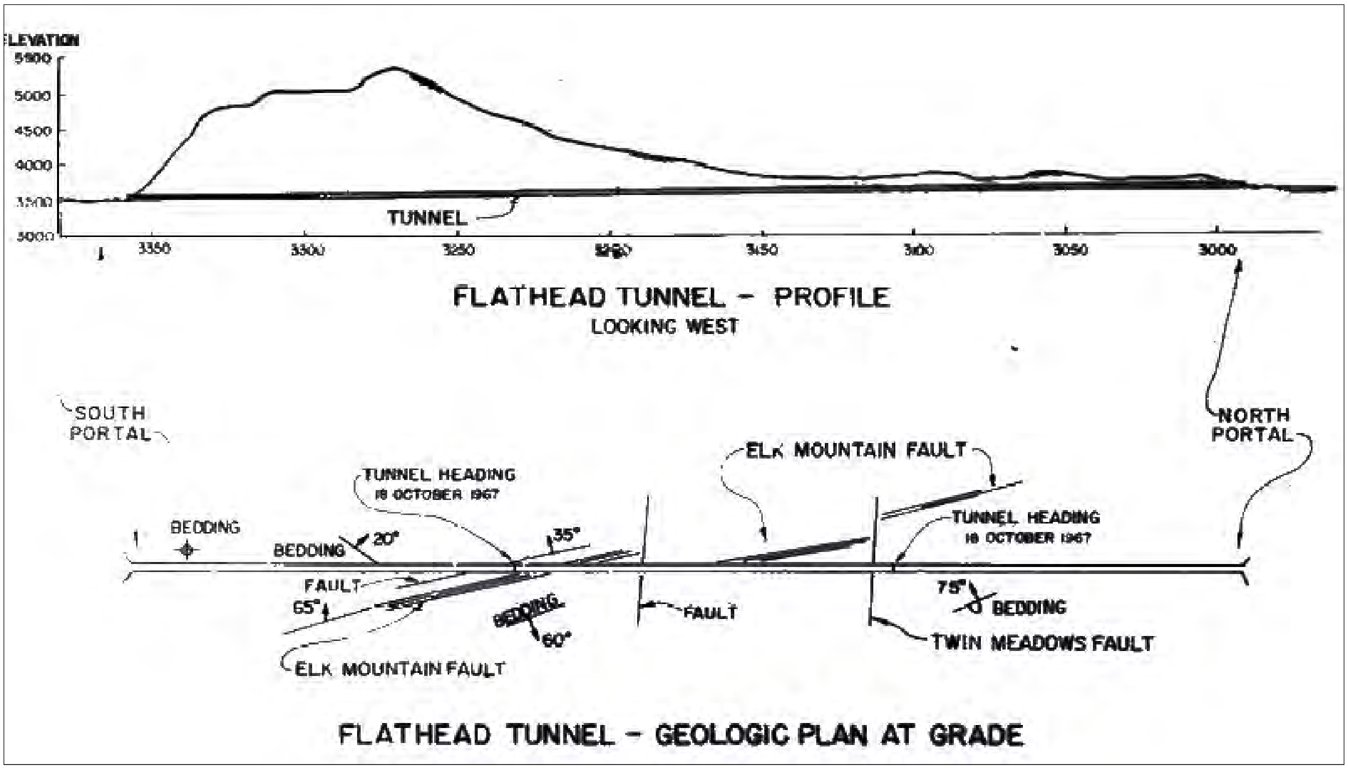

Fig 4: General geology of the Flathead Tunnel (from Galster, 1968.)

GEOLOGIC ROAD LOG, MSH 37, LIBBY TO US 93, LINCOLN COUNTY, MONTANA

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APPROACH ROAD LOG; Libby to Big Bend:

Note: **Mileages for these road logs refer to green and white mileposts along the right side of MSH 37 when traveling upstream. Directions relate to the hill side of the highway or to the lake (or river) side in order to save confusion as to which is east and west and avoiding right and left in deference to those traveling in the opposite direction.**

This approach log to the Libby Project begins at mile 0 on Montana State Highway (MSH) 37 at the intersection of California Ave. and U.S. Highway 2 in Libby, Montana. The town takes its name from Libby Creek that flows into the Kootenai River a short distance east of town. The creek was named for the daughter of Steven Allen, an early gold prospector who camped here in 1866 and was later killed by Kutenai Indians. Libby lies in fault-bounded intermountain trough called the Libby Trough. The trough is about 20 miles long N-S and three miles wide. Between the Salish Mountains on the east and the Cabinet Range on the west. The light material exposed in the bluffs to the east is silt and fine sand deposited in Glacial Lake Kootenai when the Purcell lobe of the Cordilleran ice sheet blocked the valley near the longitude of Bonners Ferry, Idaho.

Mile 0.6: The highway crosses to the right bank of the Kootenai River and follows along the surface of a gravel-topped terrace cut by the river during a time of relative stability as the river cut down through the glacial deposits to its present level.

Mile 1.1: The road entering from the hill side leads to the Turner Mountain ski area and to the upper part of the Yaak Valley, site of the famous Dirty Shame Saloon.

Mile 1.2: USFS Libby Ranger Station on hill side. By mile 1.5 the highway has ascended to the second terrace above the present flood plain of the Kootenai River.

Mile 2.8: The highway drops to the current flood plain of the Kootenai River.

About Mile 3.0: Rock exposure on the hill side is limy argillites and impure limestone of the Piegan Group, named for the Piegan Indians, part of the Blackfoot Confederation. This is the area where the original site for Libby Dam was proposed. At mile 3.3 one of the exploratory adits may be seen on the hill side. It was driven during the early 1950s to study the character of the rock at this site. These rocks stand at high angles to vertical. This segment of the valley trends nearly E-W. Across the valley, a flow of the Purcell Basalt may be seen in a quarry formerly operated by the St. Regis Company.

Mile 5+: The valley trend swings abruptly N-S and follows the trace of the Thompson Lakes Fault. Ahead may be seen the remnants of the Zonolite (open pit) mine

Mile 5.5: Highway crosses the alluvial fan of Rainy Creek. The Rainy Creek road intersects from the hill side. This road served as a haul road to bring raw processed ore from the vermiculite mine in the Cretaceous to early Tertiary Rainy Creek stock on Vermiculite Mountain. Vermiculite is hydrous mica having the property of expanding like popcorn when heated. It was shipped unexpanded, then heated and expanded at its destination and mainly used for insulation. In 1923 E.N. Alley discovered the vermiculite deposit, experimented with the material and determined it useful properties. By the 1930s the Zonolite Co. was mining the deposit, taken over by W.R. Grace in 1963. Mining continued until 1990 after a five-year investigation by the Environmental Protection Agency high showed a high incidence of tremolite-related asbestosis was found in the Libby area. The mine as well as the town of Libby is now a superfund site

Mile 6: Highway continues to follow the trace of the Thompson Lakes Fault but drops onto the current flood plain of the river.

Mile 6.3: Kennedy Gulch Road intersects from the hill side. The Kennedy Gulch terrace is a kame terrace later cut by the river as it worked its way down through the glacial drift. The gulch was named for Dan Kennedy, a gold prospector who frequented the area about 1867.

Mile 7.3: Site of the proposed Libby Reregulating Dam. This part of the Libby Project was designed to regulate the flows owing to expected peaking characteristics of the power plant at the main dam. The project, believed authorized by the original authorization for Libby Dam, was fully designed and a relocation contract for MSH 37 was awarded and under construction when, in 1983, a federal judge ruled that the project was not authorized. The dam would have been constructed across the Thompson Lakes Fault zone requiring a considerable amount of the engineering geology investigation of the site along with geologic mapping and investigations of the fault zone north and south of the site. Ahead several potential road cuts for the relocated MSH 37 around the reregulating dam may be seen on the hill side.

About Mile 9: The valley swings to a more E-W trend and outcrops along the highway consist of the greener argillites with interbedded limestones characteristic of the middle Piegan Group. The highway and valley have crossed to the east side of the Thompson Lakes Fault. The trace of the fault has been mapped for several miles south through low gaps on the other side of the valley.

Mile 10+: Poor exposures of glacial lake silts may be seen on the hillside. Some of the area adjacent to the hill side may be part of an old landslide.

Mile 11: One of several hanging tributary valleys may be seen across the valley, characteristic of the older tributary valleys in this area, probably resulting from the over deepening of the Kootenai Valley during the last ice advance.

Mile 11.2: Cut slope in the upper part of the Piegan Group is on the hill side.

Mile 12.5: U.S.F.S Canoe Gulch Ranger Station is on the hill side. This facility was built as part of the Libby Project to replace the Warland Ranger Station that is now beneath the waters of Lake Koocanusa.. The highway crosses the north-trending Rainy Creek Fault and Rainy Creek Syncline. Maroon colored argillites of the Striped Peak Formation (Missoula Group) are exposed in the synclinal trough. The dip reversal resulting from crossing these structures may be seen more clearly across the valley where the westerly dip now prevails. Across the river was the former town of Jennings, once the lower end of steam navigation on the river when steamboats ran upstream from this point during the springtime to transport people and supplies to the Canadian gold fields.

About Mile 12.9: Glacial fill materials are exposed in the Big Bend Terrace on the hill side. Jennings Rapids are in the river at Mile 13. Just past Mile 13, old MSH 37 intersects from the hill side and provides access to the top of the terrace. Old borrow exploration on the terrace surface show the characteristics of the glacial fill consisting of lake beds and ice-contact sands and gravels. This terrace was one of the potential borrow site for concrete aggregate for the dam, but proved to be inferior to the final selected site now under water..

Mile 13.6: Forest Highway intersects

MSH 37 from the hill side. This road provides access to the right abutment of Libby Dam, powerhouse, and visitor facilities. The road continues north above the west side of Lake Koocanusa to and beyond the Lake Koocanusa Bridge.

Mile 13.8: Highway crosses to the left bank on the Kootenai River Bridge. Here, the Fisher River flows into the Kootenai from the south. The Fisher River carries a high silt load during springtime flooding resulting from the widespread distribution of glacial lake deposits in its drainage basin.

Mile 14: Fisher River Road intersects from the hill side and the highway crosses the former mainline of the BNSF Railway.

Mile 14.2: Exposures of calcareous argillite of the Piegan Group may be seen in highway cuts for several hundred yards. These beds dip 40 degrees SW.

Mile 14.6: Highway cut exposes glacial ice-contact (kame) deposits that form an extensive terrace deposited along the margin of an ice tongue that occupied the valley during the closing stages of Pleistocene glaciation. Good exposures may be seen at Mile 15.

Mile 15.1: Dunn Creek Road enters from the hill side, and the MSH crosses Dunn Creek; named for an early homesteader who settled near the mouth of the creek. Beyond Dunn Creek a variety of glacial ice-contact sediments may be seen in highway cuts.

Mile 15.5: Piegan Group rocks exposed on both sides of the highway along with overlying glacial lake beds on the river side..

Mile 16: Highway traverses the surface of a kame terrace that is extensive in the Kootenai Valley. Glacially-scoured rock hills protrude through the fill on both sides of the highway.

Mile 16.4: Access road leading to the toe of the dam and Project Office intersects from the river side. About mile 16.8 Libby Dam may be sighted.

STOP 1

Mile 17: (**STOP 1)** Left (east) abutment of Libby Dam. A limited parking area and visitors facilities are available. Across the highway from the parking area is a large "V-shaped" notch in the rock cut face. The original highway cut at this point was 120 ft high. At 6:04 AM, MST on Sunday, 31 January 1971 (while the dam was under construction), the lower 235 ft of the wedge of rock formerly occupying this notch, moved about 15 ft into the uncompleted roadway and stopped. The lower 80 ft of the wedge began to break apart along preexisting joints, fell into the roadway and quickly built a pile of rock blocks and smaller fragments across the roadway and toward the excavated left abutment keyway. The contractor's electric substation was destroyed and the aggregate refrigeration plant and concrete/instrumentation laboratories were damaged. Two vehicles were also damaged. The failure took place on a bedding fault (Dirty Shame +122) and an E-W joint (A joint) with a N-S joint serving as the upslope pull-away boundary at elevation 2,700 ft.. The upslope 170 ft of the wedge remained essentially intact, moving about 20 ft down slope before coming to rest against the rubble pile left from disintegration of the lower part of the wedge.

The slope had been instrumented before the highway excavation was made. One of the extensometers installed correctly predicted the eventual failure. The entire event was registered for 45 seconds at the Libby seismograph station about four miles upstream on the right bank. The final 16 seconds of the record registered the tumbling of blocks into the roadway. The volume involved in the failure is calculated at 60,000 cubic yards (in place), leaving about 20,000 cubic yards of material hanging in the upper part of the trough. Removal of the slide material and the rock hanging above it was required for safety reasons.

The rock mass immediately upstream has been reinforced by 91 cable tendons anchored deep into the rock mass. Later, evidence for minor movement behind the face immediately upstream of the slide required addition of 13 tendons along with several deeply anchored rock bolts. Tendon heads may be seen on the cut face as well on the face of the bedding fault (DS+122). The rock ribs upstream for about 3,000 ft, to beyond the Kootenai Narrows slide scar, have been instrumented with a variety of extensometers, inclinometers and piezometers.

The rocks exposed on this side of the dam are the pale green argillites characteristic of the uppermost part of the Ravalli Group. On the opposite valley side are rocks of the Piegan Group. The dam is founded on the transition beds between the two groups.

Mile 17.5: (STOP 2) On the hill side is the deep gully, the source area of the post-glacial, prehistoric Kootenai Narrows slide. The slide debris pile is now beneath the reservoir. On the lake the boom to prevent floating drift from collecting against the dam

STOP 2

Mile 17.7: Glacial ablation till is exposed in the cut on the hill side. Good views of Lake Koocanusa (Libby Dam reservoir). The name was proposed in March 1967 by a group of Rexford residents led by Alice Beer. It was derived from combining the first three letters of Kootenai, Canada and USA. The U.S. House of Representatives officially adopted the name in December 1970.

Mile 18-19: Argillites of the Ravalli Group may be seen in several road cuts along with ablation till and ice contact deposits overlying the bedrock surface. In some common cuts the original material is difficult to see because landscaping covers the cuts, gravel or rock blankets to control erosion.

Mile 19.1: Cross Canyon Creek.

Mile 19.4-20.0: The rock cuts of thinly bedded argillite of the Piegan Group on the hill side are bedding dip slopes that dip directly into the roadway.

Mile 20.5: The deep valley of Jackson Creek enters the Kootenai Valley across the lake.

Mile 21: The highway continues through rocks of the Ravalli Group where dips have flattened to 20-30 degrees SW.

Mile 22: Between this point and Cripple Horse Creek the highway is in a shallow cut across a glacial fill terrace. Deposits include lake beds, and ice contact sands and gravels.

Mile 23.3: Cross Cripple Horse Creek. The Cripple Horse Creek valley appears to follow an E-W fault seen on ERTS imagery and mapped by Johns (1970). The fault has been mapped west of the lake north of Jackson Creek. The fault appear to be the contact between the Ravalli Group and Prichard Formation A story goes that the creek was named by Henry Hackshow, a trapper and carpenter, who wounded a deer that escaped from him in this area. Wounded Deer Creek might have been a more appropriate name, unless the man shot his horse instead.

Mile 24: Road intersection from the lake side provides access to the Cripple Horse Recreation Area. Flat-lying Prichard rocks may be seen from here and for many miles up-valley as the highway follows the crest of the Purcell Anticlinorium. These argillites and metasandstones are drab, but weather rusty owing to high iron content. In this region they are flat-lying although locally warped. Often, especially during springtime melting, water can be seen seeping from bedding joints and faults in the Prichard.

Mile 25: Across the lake the deep valleys of Barron and Bristow creeks are seen entering the Kootenai Valley. In road cuts beyond this point, glacial gravels are exposed. The town of Warland was located by the left bank of the Kootenai River below this area prior to the raising of the reservoir. The buildings were removed prior to pool rise but the road bridge crossing the Kootenai remains beneath the lake's waters.

Mile 25.4: Warland Creek road intersection. Immediately beyond the highway crosses Warland Creek. The stream was originally named Blind Creek but later changed to Warland for the town established near the creek mouth.

Mile 26.: About mile 25.8 a change in rock characteristic may be seen and by mile 26 the highway passes through a rock cut in a granitic (Warland) stock. Small inclusions of Prichard rocks may be seen. Remnants of an old adit is exposed at mile 26.3 along with some mineralization. The site is reported to have been a gold prospect. A scenic turnout is just beyond mile 26. This is an excellent place to observe the characteristics of the stock as well as to observe the deep valleys of Bristow and Barron creeks. E-W regional faults are apparently positioned in these valleys and they counterparts, Warland Creek and Five Mile Creek on this side of the lake. At mile 26.4 the highway leaves the granitic stock and returns into the Prichard Formation rocks.

Mile 28: Beyond this point the highway crosses a glacial fill terrace into the valley of Five Mile Creek and crosses the creek at mile 29.3. Five Mile Creek valley may follow an E-W fault that trends into the known Twin Meadows fault that was intersected during construction of the Flathead Tunnel.

Mile 30.1: Turnout on lake side with excellent views across to the valley of Bristow Creek. Bristow Creek was named for an early homesteader and surveyor, William Bristow, who lived on a claim near the mouth of that creek about 1895. He later homesteaded on the east side of the Kootenai adjacent to the town of Warland. Prichard rocks are exposed in low cuts on the hill side of the highway. From mile 31 a relatively abrupt bend in the trend of the Kootenai Valley is evident permitting an excellent view up lake and down lake. Here the valley trends NE for several miles up valley before abruptly swinging back to a N-S trend. The significance of this "kink" is not fully understood, but may be due to regional faulting.

Mile 32: The highway crosses a debris fan of broke\n rock. Corps geologists gave this gulch the informal name ?No No Gulch". The original highway design called for a substantial cut it this material that the geologists recommended against, believing that such a cut would result in considerable instability of the slope.

Mile 33: Prichard rocks dip as much as 15 degrees NE upstream. In a short distance they flatten with local minor faults some of which may be seen opposite the turnout at mile 33.4

Mile 34+: Highway crosses Ten Mile Creek and the Ten Mile Creek road intersects just beyond the bridge. Ahead Prichard rocks are exposed.

Mile 35.6: A fault and adjacent shear zone are exposed in the Prichard Formation on the hill side of the highway.

Mile 37.3: Highway crosses Sheep Creek.

Mile 37.7: An extensive turnout on lake side. This is a good location to view the lake and examine the characteristics of the Prichard rocks in the adjacent highway cut slope.

Mile 38.6: Highway crosses Peters Gulch.

Mile 38.8: Highway crosses Allen Gulch; named for Steven Allen who named Libby Creek for his daughter.

Mile 39: Here the highway drops on to the surface of an extensive terrace cut in glacial fill. The terrace is the site of a USFS recreation area.

Mile 40: The character of the Prichard Formation rocks begins to change from here upstream for several miles. The rusty character is less prevalent and the argillite is seen to be bluer rather than drab. Some of the rustiness and drabness will continue to be seen as the highway passes up through the upper Prichard and gradationally into the lower Ravalli Group.

Mile 40.9: Highway Crosses Rocky Gorge.

Mile 41: Beyond this point the highway leaves the Rocky Gorge terrace and passes through a deep cut that exposes transition beds between the Prichard and overlying Ravalli. Across the lake at this point the three forks of Parsnip Creek meet and flow into the lake. Parsnip Creek was names for Frank Parsnip, an early trapper who was last heard of in 1895. Early settlers believe he met his death in a bear trap.

Mile 42.3: The highway crosses Tweed Creek that comes over the rock cut as a waterfall then passes through a culvert under the highway. Note the beds of the lower Ravalli are now dipping gently upstream. The highway has now left the NE-trending segment of the valley and trends N-S again.

Mile 43.7: The highway crosses McGuire Creek. There are turnouts on both sides of the highway and a permanent pond created on the upstream side of the fill crossing the stream. The fill was designed and constructed as an embankment dam for this purpose. This has become a favorite place for deer to water during early summer evenings.

Mile 44: Upstream of McGuire Creek the characteristic wide-spaced jointing and quartzitic rock of the lower Ravalli. A considerable part of the cut slope was excavated to correspond with a strong, planer N-S joint. Bedding dips about 15 degrees NE reflecting the eastern side of the Purcell Anticlinorium.

Mile 45.6: Access road to the Peck Gulch boat launch ramp enters from the lake side.

Mile 46: Highway crosses Peck Gulch and climbs to the highest point on MSH 37 at elevation 2,904 ft, 445 ft above the maximum level of Lake Koocanusa. Directly across the lake is the valley of Big Creek. From the high point, the highway drops down through Ravalli rocks where rusty weathering is common along joint faces.

Mile 48.4: The highway crosses Sutton Creek on a high bridge. Watch for mountain sheep on the hill side beyond Sutton Creek. Sutton Creek was named for George or James Sutton (or both), early homesteaders on Pinkham Creek, a few miles upstream.

Mile 48.8: Sutton Creek Road intersects the highway from the hill side. A short distance ahead, the highway drops to the surface of the Sutton Creek terrace, an ice-contact (kame) terrace. Subsequent to the raising of the reservoir, slides from the face of the terrace have been experienced.

Mile 50: The highway climbs up through a series of Ravalli exposures. Early railroad workers named this area Stone Hill. A railroad siding was located in the valley below prior to the relocation of the GNRR during construction of the Libby Project. A small fault is exposed in the Ravalli rocks and many other such faults are seen over the next quarter mile.

Mile 50.5: Turnout on lake side. The reentrant on the hill side is known as Bear Trap. Apparently a difficult area for bears to escape from. Widely-spaced joints in the Ravalli divide exposures into very large blocks. Note glacial scour.

STOP 3

Mile 51: (STOP 3) A through cut in the Ravalli rocks. A turnout on the lake side just beyond the cut is a good place to stop and examine this part of the group. Note the local lavender to purple beds. At mile 51.6 the Lake Koocanusa Bridge comes into view up lake.

Mile 52: Ahead may be seen the Whitefish Range on the east side of the Rocky Mountain Trench. Ravalli beds in this area are generally essentially flat-lying although minor warps can be seen locally.

Mile 52.9: Holdup Gulch. The gulch takes its name from a 1906 holdup of a great Northern Railway train. Across the lake Boulder Creek aligns with Holdup Gulch, perhaps a weak zone or fault may control both creek alignments.

Mile 53.4: Turnout on lake side. Minor reversals in bedding are accompanied by small faults that may be observed in these highway cuts.

Mile 53.8: (STOP 4) East end of Lake Koocanusa Bridge. This is the highest bridge in Montana with the road deck 290 ft above the pre-lake valley floor. A turnout and parking area is adjacent to the east end of the bridge. View upstream extends across the Rocky Mountain Trench to the Whitefish Range.

STOP 4

Mile 54.6-54.8: Highway crosses Cadet Creek then Pinkham Creek on short bridges. A fault trending along the Pinkham Creek valley was mapped by Johns (1970). Here the Ravalli is in fault contact with the underlying Prichard. Pinkham Creek was named for the first homesteaders below Tobacco Plains who homesteaded here in 1882.

Mile 56.8-57.2: A major fault zone with extensive badly-sheared rock may be seen in the adjacent cuts. This was mapped by Johns (1970) who called it the Pinkham Thrust. The high-angle thrust fault trends NNW to SSE. Further south it joins with what the Corps geologists (working the area at the same time as Johns) termed the Elk Mountain Fault through which the Flathead Tunnel passes. Johns (1970) further mapped a series of NE-trending faults of local extent, one of which is mapped as displacing the Pinkham fault. Beyond the Pinkham fault zone the Piegan Group (Siyeh Formation) has been mapped (Johns, 1970).

Mile 57.3: (STOP 5) Turnout on lake side. Looking up valley during periods of minimum reservoir levels, one may see roads and adjacent areas of the former town of Rexford as well as approaches to the old MSH 37 Rexford Bridge. This is a good place to park and walk back to observe the sheared rock in the Pinkham fault zone. Beyond this point the highway traverses a kame terrace through which protrudes rocks ranging from Prichard, Ravalli and Piegan, and into the Purcell Basalt, produced by a series of faults that define the west side of the Rocky Mountain Trench in this area. Note the topographic change as the highway moves from the Kootenai Valley into the trench. Across the lake at mile 58 is the mouth of Sullivan Creek, named for John Sullivan who explored the Kootenai Valley in 1859. The stream provided the old town of Rexford's water supply. The relocated town is supplied by deep wells north of the Tobacco River.

STOP 5

Mile 58.1-58.2: Exposures in these road cuts are apparently Prichard Formation that has been uplifted between several faults.

Mile 58.7: Steeply-dipping beds of the Piegan Group are exposed on the hill side.

Mile 58.9: Pinkham Creek road enters from hill side and road to old Rexford is on the lake side.

Mile 59: Exposures on lake side appear to be argillites of the Striped Peak Formation (Missoula Group).

Mile 59.5: The old Black Lake road intersects from the hill side. Off to the lake side is a road that connects with the former site of Rexford. Just beyond this intersection are limetones and argillites mapped as Piegan Group by Johns (1970).

Mile 60: Exposures of steeply-dipping purplish and blue argillite, probably Piegan are overlain by glacial ablation till. Beyond this point the highway continues to traverse an extensive kame terrace where bedrock knobs rise above the terrace surface. At mile 60.5 some thinly-bedded green argillite of the upper Piegan can be seen dipping NE. At mile 60.8, glacial lake beds are exposed in the cut face.

Mile 61: (STOP 6) At 61.1, across the highway from the Bullpen Bar is an excellent exposure of the Purcell Basalt that overlies the Piegan Group. The basalt is exposed in outcrops for several hundred feet along the highway.

STOP 6

Mile 61.4: Road entering from the hill side provides access to the Rexford water storage tank.

Mile 61.5: The Town of Rexford is on a kame terrace on the lake side. The Corps of Engineers relocated Rexford from the Kootenai valley floor during the construction of Libby Dam and the original town site has been inundated by the reservoir except at minimum reservoir levels.

Mile 61.7: Access to the Rexford Bench Recreation Area on the lake side. Ablation till is exposed on the hill side. The rock outcrops between miles 61.9-62 are argillites of the Missoula group, probably Sheppard Formation. A fault is exposed on the hill side at 61.9 and fossil ripple marks can be seen on bedding faces.

Mile 62.2: (STOP 6) Rocks of the Missoula group showing excellent fossil ripple marks are exposed on both sides of the highway. Across the valley of the Tobacco River on the lake side are badland topography or" hoodoos" developed in glacial lodgment till.

Mile 62.6: Exposures of Missoula Group argillite dipping directly into the roadway exhibit excellent fossil ripple marks.

Mile 63: There is a turnout just beyond mile 63 with views looking down the Tobacco River valley to Lake Koocanusa. "Hoodoo" badlands may also be seen. Beyond mile 63 the highway drops off the kame terrace.

Mile 63.7: Exposures of green argillite of the Missoula group are seen dipping E.

Mile 64: The highway crosses the Tobacco River and an abandoned railway cut, formerly the GN Railway mainline. The highway then climbs back up onto the kame terrace that is capped with silt and ablation till. This extensive terrace is known as Tobacco Plains. Indians grew tobacco in this area and early traders and missionaries also tried this agricultural pursuit. From those efforts came the name for both the plain and the river. Ahead may seen a series of drumlins, some of which are roche mountainees, common features in this section of the Rocky Mountain trench

Mile 64.7: Intersection with road to Carpenter and Sophie lakes. This is also the end of the relocated MSH 37. From this point east the highway is on the pre-project route.

Mile 65: Just past this milepost is a commercial sand and gravel pit on the lee side of a drumlin. Ahead may be seen many drumlins and drumloidal features resulting from the Rocky Mountain lobe of the Cordilleran ice sheet. About mile 66 he highway crosses two drumlins.

Mile 67: End of MSH 37 and intersection and intersection with U.S. 93 a few miles north of the town of Eureka.

End of Road Log

The field trip will continue south through Eureka, without a detailed log, to cover a major part of the GN (BNSF) Railroad relocation beginning south of Trego, MT, continuing south with stops at the North (East) Portal of the Flathead Tunnel, thence south to the South (West) Portal. Beyond the South (West) Portal the tour will continue down the valley of Wolf Creek for about 30 miles to the confluence with the Fisher River, thence another 11 miles to that stream's confluence with the Kootenai, thence back to Libby on MSH 37. This route follows the relocated railroad. Stops along the route will be informal.

Text from primary documents compiled by Montana Heritage Project. Photo in public domain, via en.wickipedia.org.

CARRY A. NATION SPEAKS TO LARGE CROWD

Western News, April 28, 1910

Mrs. Carry A. Nation, the woman with an international reputation as a saloon smasher, spoke in Libby on Friday night, the opera house being packed with people, who seemed to enjoy the lecture greatly, although some of Mrs. Nation's deductions were taken as a joke by most people.

The woman is apparently in deadly earnest, however, in her fight against the liquor traffic, secret societies, prudery of certain kinds and a few other things, and in a harsh- rasping voice she denounced them all. Many of her arguments were good and sound, but some, although probably starting from a right foundation, wound up in a rather illogical manner.

Mrs. Nation spent considerable time in telling her career, and especially in relating her first crusade, when, like Saul of Tarsus, her life's work was miraculously pointed out. " In this life", Remarked Mrs. Nation, at one point in her lecture, "It is a case of smash or get smashed, and so I decided to smash".

The republican party probably came in for Mrs. Nation's severest denunciation, and suspicions began to arise that she was going to take a stand with the democrats because of Bryan's recently developed prohibition tendencies, but such suspicious were brushed away when she stated that the democratic party would be just as bad if they were in power. Then she pointed out the beacon light of safety and salvation the prohibition party.

On Saturday afternoon Mrs. Nation spoke from a dray on the corner of Mineral Ave. and Second Street, giving the much same kind of a talk as at the meeting the previous evening. During the day she took occasion to stop in front of some of the saloons and harangue the inmates. She also "bawled out" the tobacco users whenever the opportunity came, and occasionally stopped some wearer of a lodge pin and gave him a lecture.

RADIUM! GOLD! SAPPHIRES!

Western News, January 12, 1910

Nothing more marvelous has ever been recorded in the mining history of the country than that of the great find of radium, gold and precious stones which has been discovered on Boulder creek, near Leonia. Considerable placer mining has been done here last summer and some years in the past; but while the outlook for gold was showing better every year, not even the most sanguine imagination could conceive of the great wealth which has lain hidden among the rocks and boulders here. A little persistent prospecting has revealed that treasure and the credit of the great find is due to the perseverance of J.H. Snatherly, James Angell, W.A. Guhr and several others. A 15-inch vein of radium ore has been found and gold ore, which runs $356.00 to the ton. Also precious stones, which an expert calls sapphires.

This information was withheld from the public until the indisputable facts were obtained from the expert on radium, who has been called here at a salary of $100 per day. He pronounces this the second and greatest radium vein ever discovered in the United States. The value of this discovery will be better understood when it is known that radium, the rarest of minerals, is quoted in London at from one to three million dollars per pound. In comparison with this startling valuation, gold even running $356 per ton fades into insignificance.

A company has been formed under the name of The Idaho Radium and Gold Co., with J.H. Snatherly president, W.A. Guhr vice president and James Angell secretary-treasurer. A great deal of stock has already been sold. Mr. Angell has been in New York in the interest of the company, where he has met with phenomenal success. He is now called to Chicago by some well known capitalists with whom the company has been negotiating.

The writer of this is placing the facts before the public exactly as they exist without any desire to create a sensation or stampede to this district. The future will verify any statement made herein.

Operations will commence as soon as possible. A sawmill is expected next week to get out lumber for flumes. Arrangements are made to employ 150 men. The first part of the work will consist of the building of a wagon road from the new mine to connect with the free ferry at Leonia. It is to be hoped that the commissioners of both counties will get matters arranged so that there will be as little delay as possible in getting the new ferry in operations. The need for it now is more urgent that ever, as already the freight for Sylvanite us piling up at Leonia.

Ed. note: Leonia, Idaho, was on the Kootenai River, one-quarter mile downstream from the Montana-Idaho border. Boulder Creek joins the Kootenai there, from the west.

From primary documents compiled by Montana Heritage Project

COLLECTION AND CONCENTRATION OF STRATABOUND METALS DURING PROGRESSIVE REDUCTION OF OXIDIZED REVETT STRATA: A 180º VARIATION OF THE REDBED SOURCE MODEL

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Most researchers assert that metals in Revett stratabound copper deposits originated in nearby redbeds and were subsequently redeposited at a convenient, preexisting redox boundary. Although this idea has some appeal, it leaves a host of observations unexplained. As a general observation, an excessive number of loose ends probably means we got things wrong the first time; when the loose ends persist for practically half a century, it behooves us to consider that we may have been grossly mistaken. But, if satisfactory explanations haven't become evident, it is also likely that things are more complicated than they seemed. New ideas based on fundamental principles and rooted in improved concepts of basin geology need to be considered.

As an alternative to the usual red-bed source model, this paper proposes that the metals were actually stripped from redbeds or original brown beds prior to their progressive reduction to green beds; that metals were liberated, swept along, and concentrated at a migrating thermal front; and that they were then deposited when an advancing redox boundary overtook the thermal front. Thus, metals in the deposits would have originated on the reduced, rather than the redbed, side of the present redox boundary, and their deposition would have been coincident with creation of the boundary.

Three geographic elements of Belt terrane are key features in the proposed model: (1) the Noxon arch, (2) the Pend Oreille trough, and (3) the Belt rift (figure 1). The Noxon arch is an elongate region of thin Belt strata along the Idaho-Montana border (White and others, 2000) (after the "post-Ravalli dome" of Harrison, 1972). The arch separates the eastern Flathead trough from the Pend Oreille trough (White and others, 2000). Most provenance data indicate that Belt sediments, and the Revett Formation, in particular, had a southwestern source and that sediment transportation and deposition involved an extensive distributary

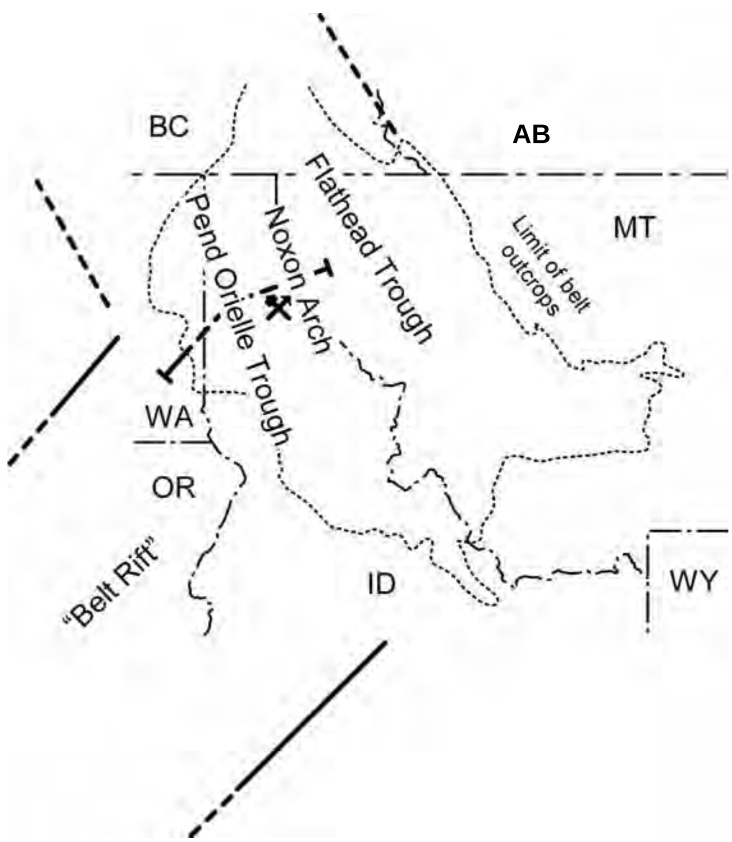

Figure 1. Location of the Belt basin at the intersection of two limbs of "Belt rift", and Noxon arch, which separates the Flathead and Pend Oreille troughs. Dashed line across Noxon arch and Pend Oreille trough is line of cross section of figure 2.

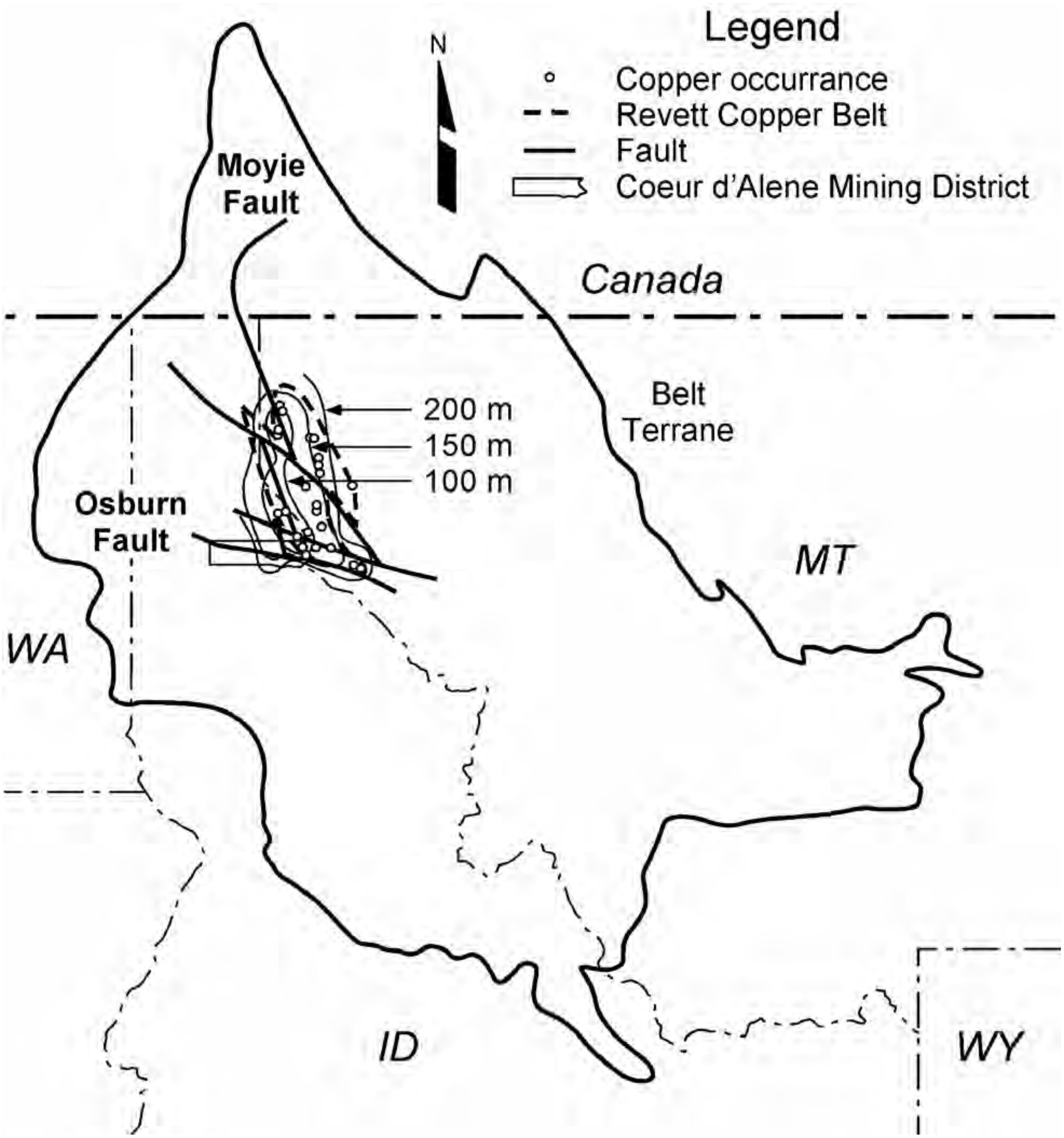

Figure 2. Location of Revett copper belt as defined by distribution of individual stratabound copper occurrences; and thickness (meters) of middle member of Revett formation, which partially defines the Noxon Arch (Figure 1).

river system within a probable intracontinental rift ("Belt rift"). In the context of a continental rift, the Belt basin was simply a local sump formed at a dogleg in the rift (figure 1).

Widespread continuity of the fine-grained fluvial sand and argillitic siltite units that define the Revett indicates that sediments abundantly filled the Pend Oreille subbasin so that streams and sheet wash frequently spread across the Noxon arch. All known major Revett stratabound deposits are clustered within thinned Revett sands near the top of the arch (figure 2). Buried aquifers extending far to the southwest within the rift valley could have provided relief-generated head capable of driving groundwater through the Pend Oreille trough and onto the arch. The more deeply buried sediments within the Pend Oreille trough would have been subjected to advanced diagenesis, which is characterized by creation of permeability in otherwise impermeable lithologies such as shale. While sandstones in the Prichard and Revett formations would have formed key parts of such a system, a permeable smectite dehydration horizon that transgressed formation boundaries would have enabled late diagenetic waters from the Prichard to enter Revett aquifers (figure 3). This is the fundamental hydrologic system that could have led to formation of the stratabound deposits.

The presence of ore stage overgrowths on detrital k-spar grains within the stratabound deposits (Hayes, 1990) firmly identifies the conditions of late diagenesis as occurring contemporaneously with deposition of ore minerals. The key reactions are hydrothermal alteration of detrital k-spar grains at temperatures from 70 to 140 °C and involvement of the released K+ in the collapse of smectite clay to illite. In the stratigraphically deeper, argillaceous Prichard Formation in the Pend Oreille trough (figure 3), all K+ would have been consumed in the latter reaction, so that water passing upward into the Burke and Revett formations would initially have been depleted in K+. However, heated water passing through the sandstone aquifers of the Revett would have liberated more K+ than could be consumed by the small amount of smectite present, so waters would have become K+-enriched as k-spar was progressively destroyed. Support for this hypothesis comes from the complete absence of detrital K-spar in the vicinity of the Coeur d'Alene district, which may be additional evidence that the ore fluids came from this direction.

Evolving conditions, such as an increase in pH associated with upstream hydrolysis of detrital k-spar, caused k-spar to be re-precipitated downstream as overgrowths. However, the presence of excess K+ in the stratabound deposits requires that smectite dehydration was actively taking place within the deposits as

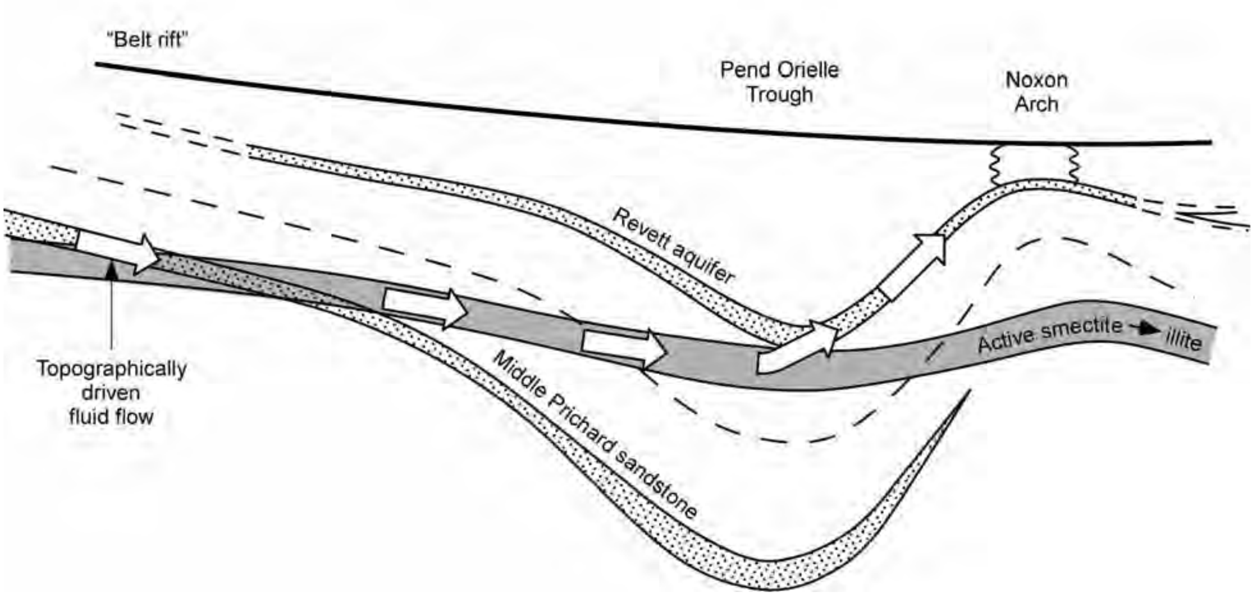

Figure 3. Schematic cross section extending along southwest limb of Belt rift onto Noxon arch. Zone of active smectite dehydration creates permeable conduit connecting Prichard sandstone to Revett sandstone aquifer. Relief-driven hydraulic head generated in buried Prichard aquifer in southwest limb of Belt rift drives deep fluids onto Noxon arch. Wiggly lines on Noxon arch define zone of bleached redbeds above Revett aquifer where water ultimately escapes the conduit.

they formed. Therefore, the deposits coincide not only with the redox boundary, but also with the smectite-illite boundary, an occurrence unlikely to have been coincidental.

A fundamental feature of solute transport through permeable materials is that solutes interact to various degrees with the solid substrate, with the result that all solutes travel more slowly than the fluid itself. Even suspended species such as hydrocarbons are affected. This behavior is the basis for the extremely important chemical separation and analysis procedure known as chromatography. The extent of adsorption is influenced by changes in pH, which cause some solutes to slow down, others to travel faster. Unfortunately, the complexities and behaviors of species transported in evolving geothermal systems are poorly known, although some speculation is possible. For example, Na+ is adsorbed more poorly than K+, so that NaCl might advance far ahead of other components with which it was mobilized.

Water is cooled during transit through rocks, so that the water temperature lags behind the water itself. This behavior is similar to chromatographic delay of transported solutes. Temperature is vital in some reactions and in solution/dissolution processes. Also, species dissolved, transported, and concentrated as a result of increasing temperature may have traveled either faster or slower than species mobilized, concentrated, and transported as a result of reactions that are somewhat independent of temperature. Thus, species traveling separately can ultimately mingle so that reactions causing ore deposition can take place.

It is likely that the fluvial sediments of the Revett were pre-redbed "brown beds" during sedimentation and early diagenesis, the result of contained detrital hydrous ferric oxides. Where iron oxides were later removed, rock colors vary from green to white and simply reflect the proportion of greenish phengitic illite (usually called sericite).

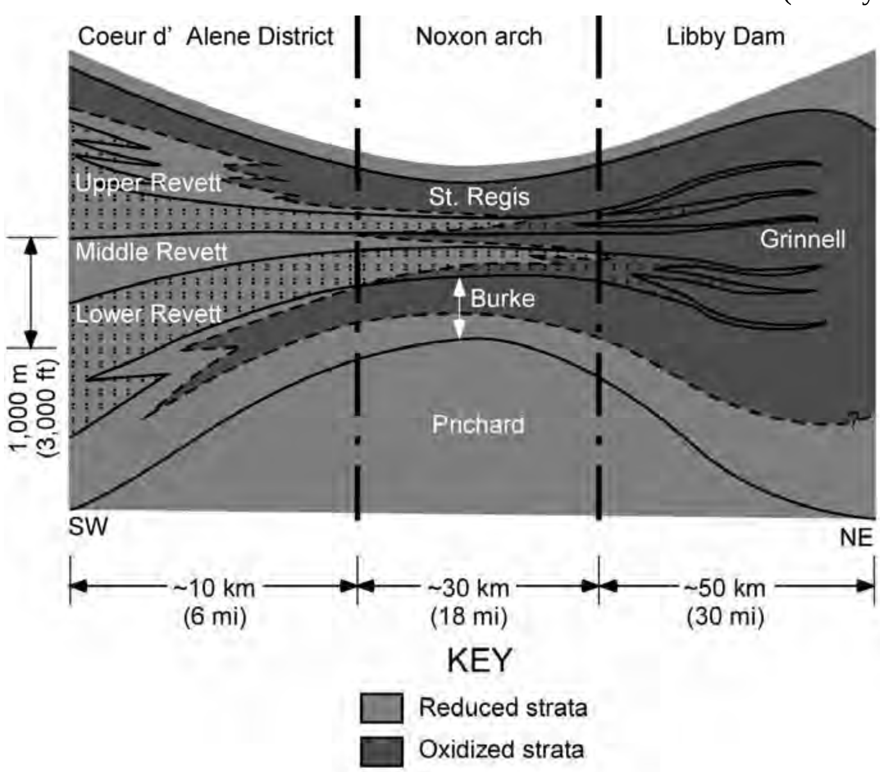

Figure 4. Stratigraphic cross-section across Noxon arch from Coeur d'Alene district in Pend Oreille trough past Libby Dam in Flathead trough. Note redox boundary and the termination of reduced tongues on the Noxon arch.

Two tongues of reduced Revett extend onto the Noxon arch from the vicinity of the Coeur d'Alene Mining District in the Pend Oreille trough, and identify the reducing waters as having come from the south or west (figure 4). The upper tongue follows the upper quartzitic member of the Revett, which hosts the Troy ore body, while the lower tongue follows the well-sorted quartzites at the top of the lower Revett member. Most stratabound occurrences are in the lower tongue. All stratabound deposits occur where the reduced tongues terminate northeastward against redbeds.

At least three separate mechanisms could have stripped metals from Revett brown beds. (1) A large portion of the metals in sediments is adsorbed onto hydrous iron oxides. Heating the oxides to 80-100 °C dehydrates them to hematite, which probably has less adsorption capacity than hydrous iron oxide (figure 5A). (2) Reduction of iron oxide to ferrous iron would effectively and completely liberate adsorbed metals (Figure 5B). (3) Smectite also adsorbs metals, as well as other dissolved species, such as barite. Dehydration of smectite to illite, which takes place at 70 to 140 °C, would liberate substantial amounts of extraneous metals and other species, plus Mg++, Fe++, water, and silica, which are part of the smectite structure (figure 5A). Once liberated, the metals could have remained

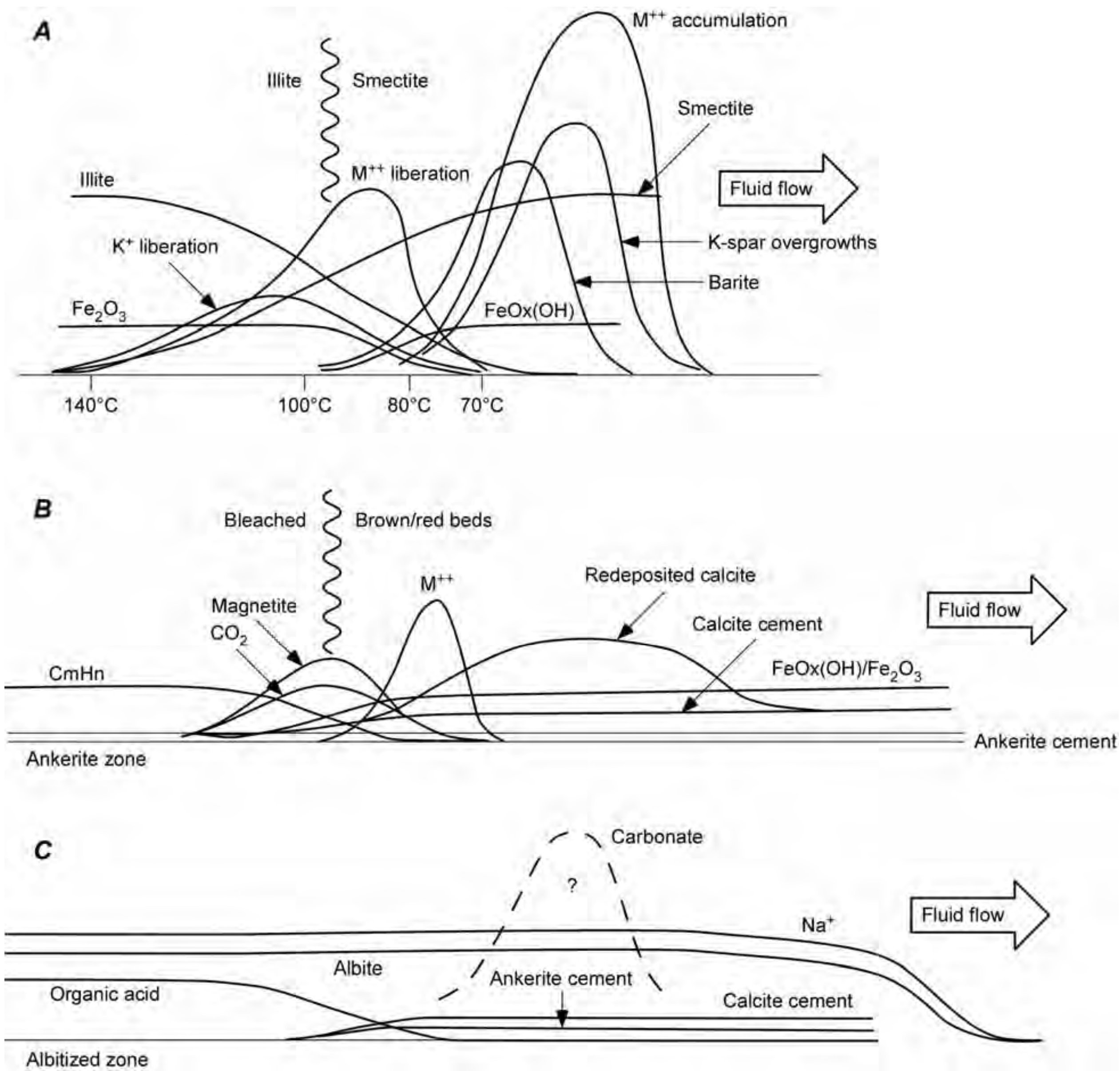

Figure 4. Key dissolution-desorption/precipitation-resorption relationships in Prichard/Revett aquifers as water flows from left to right. A. Temperature-dependent relationships at the illite-smectite and hematite-hydrous iron oxide boundaries. Barite, K+, and adsorbed metals are mobilized within in the temperature ranges indicated and resorbed or temporarily reprecipitated downstream. B. Redox boundary forms where hydrocarbons CmHn reduce iron oxides and liberate any adsorbed metals. Carbonic acid that is generated preferentially dissolves calcite, creating ankerite zone. C. Organic acid strips all carbonate while Na++ albitizes silicates.

soluble as chloride complexes, with NaCl possibly having come from the Prichard formation. However, as metal chloride complexes were swept into the environment of unaltered hydrous iron oxide and smectite, they would have been substantially resorbed onto these minerals and would have continuously accumulated ahead of their advancing liberation front (figure 5A, 5B).

Magnetite occurs widely at the redox boundary throughout northwest Montana. In more recent geologic environments, hydrocarbon reservoirs sometimes have magnetic signatures resulting from reduction of iron oxide to magnetite by the hydrocarbons. Therefore, it is a reasonable assumption that the formation of magnetite in Belt strata and its ultimate complete destruction in reduced strata resulted from reduction by hydrocarbons, provided that a possible source for the hydrocarbons can be found. The carbonaceous Prichard Formation (figure 3) is such a source. Late diagenesis is associated with the generation of hydrocarbons from otherwise impermeable carbonaceous shales, as water released from smectite temporarily reestablishes permeability. It is this permeability that creates part of the plumbing conduit identified in figure 3.

Reduction of iron oxides by hydrocarbons would form carbonic acid, which is capable of dissolving calcite but not ankerite. Therefore, iron reduction by hydrocarbons may explain the prominent ankerite zones of the deposits, as well as the abundance of calcite in the remaining zones (figure 5B). Accumulation of calcite ahead of the advancing redox boundary could have resulted from a simple decrease in pressure. This distribution of carbonate species resembles that seen in the Coeur d'Alene district, where calcite has clearly been transported farther from veins than ankerite or siderite (White, 1998). By comparison, it is likely that the chalcopyrite-ankerite zone of the Troy deposit type is most closely related to the chalcocite-chlorite zone (which also contains ankerite but no calcite).

Barite and barium-containing silicates are present in the Troy deposit (Hayes, 1990). Berg (1988) notes that barite veins in Belt terrane are consistently associated with redbeds, either within the redbeds themselves or immediately above them. Berg also notes that barite is most soluble about 100 °C. Hence, temperatures near 100° would dissolve barite and enable it to be transported. If the barite traveled slower than the temperature front in a stratabound plumbing system, it would spread out and be left behind. If barite traveled faster, it, too, would accumulate downstream, where decreasing temperatures would reverse dissolution (figure 5A). The latter mechanism explains mobilization and concentration of barite and is a reasonable explanation for barium and barite enrichment at Troy. In general, faster travel of dissolved species and temporary resorption or precipitation downstream from their critical solution or reaction temperatures provides the most satisfactory explanation for accumulation of various minerals and adsorbed species along the thermal or reaction fronts.

In a more complete scenario, the chemistry and temperature of fluids originating in Prichard and Burke-Revett strata created separate thermal and redox fronts that would have mobilized K^+, $CaCO_3$, barite, and metals. Metal sulfides would have been deposited when hydrocarbons caught up with and reduced the sulfate to sulfide in the presence of the metals. The metals themselves would have undergone some chromatographic separation and so could have been precipitated in a sequence that produced the metal zonation observed in the deposits. Some components of the deposits, such as iron-rich-chlorite and manganiferous calcite, may have resulted substantially from contributions of Mg^{++}, Mn^{++}, and Fe^{++} during smectite dehydration along the way or directly within the chlorite zone, while others, including the metals, mainly reflected gathering and concentration over a great distance.

Hayes (1990) emphasized that the stratabound mineralization involved extensive pore filling by silica, K-spar, and sulfides, which would have tended to choke off permeability. Later, hotter, compositionally different fluids would have been forced to find new routes. Unlike the ore fluid, which may have accumulated and swept along metals over a distance of a hundred miles or more, the later fluids would have had no such opportunity, because the metals were already gone. These fluids would have been K+-depleted, but rich in NaCl, and possibly carried organic acids as well as hydrocarbons. They would have had the potential to remove all carbonate cement in strata marginal to the sulfide deposits and create the extensive albitized zones that Hayes (1990) has suggested as the redbed source of the metals.

ACKNOWLEDGEMENT

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REFERENCES CITED

Berg, Richard B., 1988, Barite in Montana, Montana Bureau of Mines and Geology Memoir 61, 100 pp.

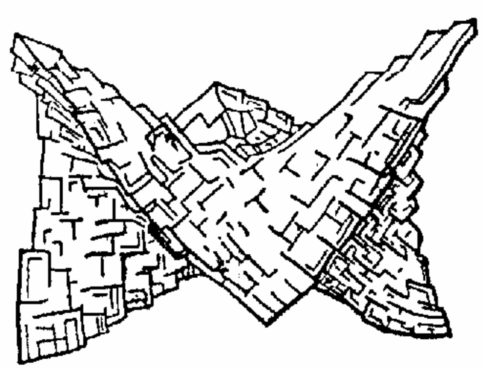
Harrison, J.E., 1972, Precambrian Belt basin of northwestern United States—Its geometry, sedimentation, and copper occurrences: Geologic Society of America Bulletin, v. 83, no. 5, p. 1215-1240.

Hayes, Timothy S., 1990, A preliminary study of thermometry and metal sources of the Spar Lake strata-bound copper-silver deposit, Belt Supergroup, Montana: U.S. Geological Survey Open-File Report 90-0484, 30 pp.

Krauskopf, K.B., 1967, Introduction to Geochemistry: McGraw-Hill, Inc., 721 pp.

White, B.G., Browne, J.L., and Appelgate, L.M., 2000, The Noxon line: a longitudinal arch in the central Belt basin: GSA Abstracts with Programs, v. 32, no 5, p. A-42.

White, B.G., 1998, New tricks for an old elephant: Revising concepts of Coeur d'Alene geology: Mining Engineering, August, p. 27-35.



STRATIGRAPHIC CONTROL OF COPPER-SILVER DEPOSITS IN THE MESOPROTEROZOIC REVETT FORMATION, IDAHO AND MONTANA

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ABSTRACT

Grain-size and bedding-thickness characteristics of the Mesoproterozoic Revett Formation in the western Montana copper belt controlled the location and stratigraphic occurrence of diagenetic copper-silver deposits by directing fluid flow within the basin. Thickness and grain size versus ore and gangue mineral-assemblage zonation within the upper, middle, and lower members of the Revett Formation suggests that thick, coarse-grained strata acted as aquifers during deposit formation. Pre-ore redox boundaries (mineral zones is an equivalent descriptive term) within the aquifers localized the deposits.

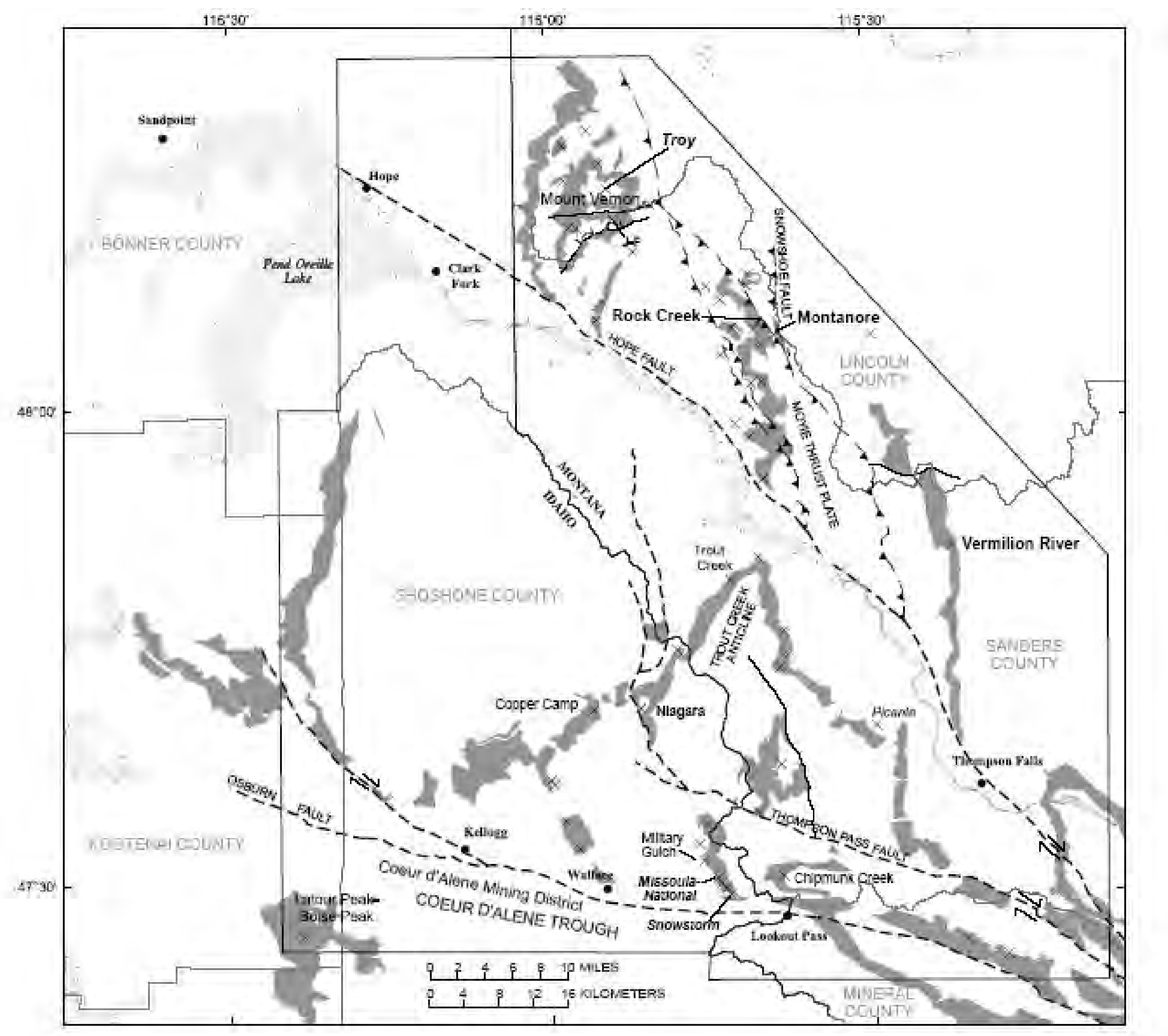
Syndepositional normal fault movement on the Hope and Osburn Faults affected the thickness of sedimentary rocks accumulating during Mesoproterozoic time; distribution of thickened sequences of the Revett Formation also contributed to localizing ore mineral deposition in the western Montana copper belt.

In thick, relatively coarse-grained units, the best indicator for copper-silver mineral deposits is the gradational zone between the authigenic chalcopyrite-ankerite and pyrite-calcite mineral zones. The location of this boundary and recognition of its importance is the basis for creating a new mineral resource assessment for strata-bound Revett subtype stratabound copper-silver deposits. The mineral resource assessment indicates that an approximate 556-mi^2 area within the Kootenai, Lolo, and Idaho Panhandle National Forests is considered permissive for occurrence of undiscovered stratabound copper-silver deposits.

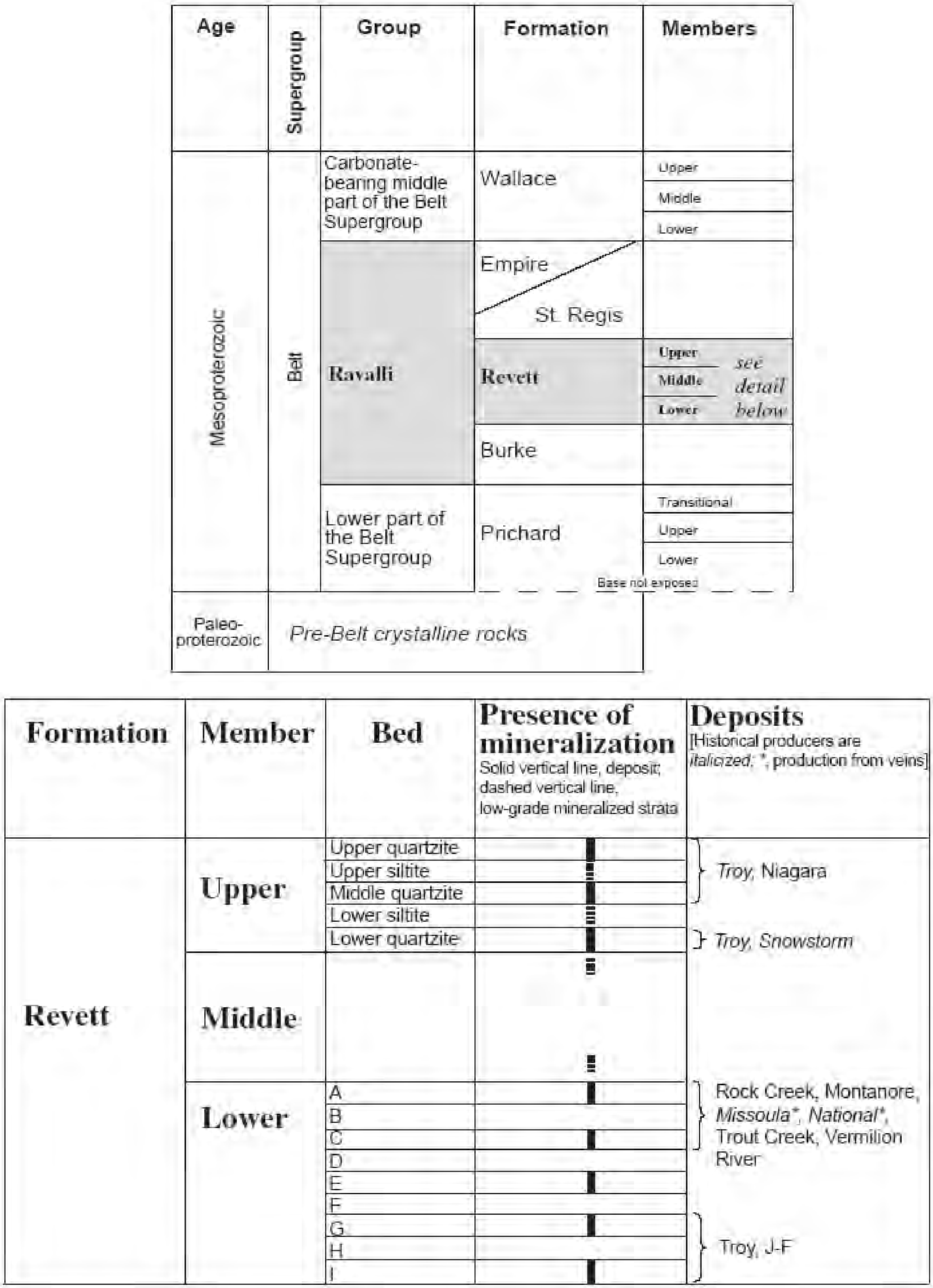
Spatial associations of basin geometry and paleoslope, paleoaquifers, and pre-ore redox boundaries permit two regional-scale speculations on origins and controls of distribution of the Revett subtype copper-silver-lead deposits. 1) Deposit formation along the south flank of and/or near the periphery of the juvenile Belt Basin was likely coeval with the compaction-

dewatering period of the juvenile Belt Basin. Compaction-dewatering was most pronounced at the center of the Belt Basin syncline located several miles north of the western Montana copper belt. 2) Stratabound copper-silver deposits in the Revett Formation are localized along north-to-south-trending paleoaquifers that likely acted as preferred pathways of fluids derived from deeper parts of the Belt Basin.

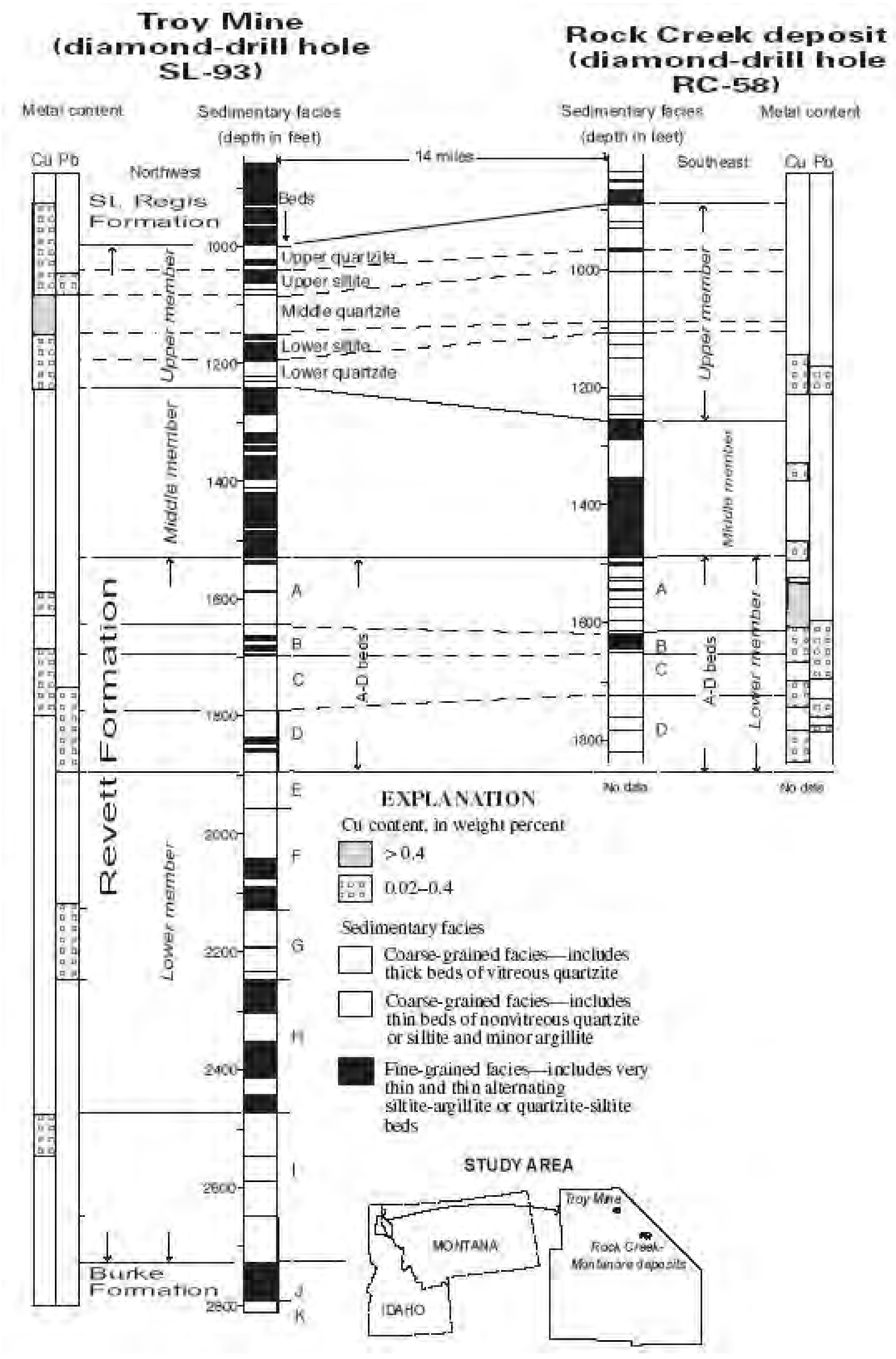
Editors' note: The figures are not a formal part of this abstract, but have been added from the U.S.G.S publication as indicated. They have been slightly modified (changed from color to grayscale).



From *Stratabound Copper-Silver Deposits of the Mesoproterozoic Revett Formation, Montana and Idaho,* by David E. Boleneus, Larry M. Appelgate, John H. Stewart, and Michael L. Zientek: USGS Sci. Inv. Rep. 2005-5231, available online at:http://pubs.usgs.gov/sir/2005/5231/. Revett outcrop areas are shaded; much of this mapping is by Larry Appelgate for ASARCO, Inc.



From *Stratabound Copper-Silver Deposits of the Mesoproterozoic Revett Formation, Montana and Idaho,* by David E. Boleneus, Larry M. Appelgate, John H. Stewart, and Michael L. Zientek: USGS Sci. Inv. Rep. 2005-5231, available online at:http://pubs.usgs.gov/sir/2005/5231/. Modified from Harrison and others (1986) and Hayes and Einaudi (1986).



Generalized stratigraphic columns, from *Stratabound Copper-Silver Deposits of the Mesoproterozoic Revett Formation, Montana and Idaho*, by David E. Boleneus, Larry M. Appelgate, John H. Stewart, and Michael L. Zientek: USGS Sci. Inv. Rep. 2005-5231, available online at:http://pubs.usgs.gov/sir/2005/5231/. Much of the work on the Troy section derives from Tim Hayes (1983; Ph.D. thesis, Stanford University).

DIAMOND DRILL CORE GEOLOGIC LOGS OF MINERALIZED INTERVALS IN PROTEROZOIC REVETT FORMATION STRATA, NORTHWESTERN MONTANA AND NORTHERN IDAHO

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ABSTRACT

In 1908, Ransome and Calkins published what may be the earliest data on the stratiform character of Revett-hosted copper-silver mineralization. Deliberate exploration of Revett deposits was most intense during the 1970s and 1980s as the market price for silver soared. Drilling on Revett targets peaked in December 1983 when drilling on federal wilderness lands was suspended under terms of 1964 Wilderness Act.

During the initial Revett boom, geologists from mining companies, government and academia wrestled with the great variety of data that could be gleaned from drill core. Some of the questions were: (1) what mineral assemblages represent the most economically viable ore, (2) is there recognizable mineral (chemical) zoning in the deposit(s), (3) what sedimentary, stratigraphic, diagenetic and metamorphic features are present, (4) what structural features are evident or indicated and (5) what combination of the preceding features are most-indicative of the ore-forming environment(s).

Selecting the drill log data fields became important for defining the subject deposit and to develop a model for finding the next deposit. Revett drill log formats evolved through the efforts of many geologists. Probably the most detailed logs were developed by ASARCO geologists for the Spar Lake and Rock Creek deposits and by U.S. Borax geologists for the Rock Lake deposit. Logs from six deposits or occurrences are presented in this poster. These are intended as a guide to future Revett workers as the second Revett boom begins. Many thanks to Tim Hayes and Michael Zientek (USGS), David Boleneus (USDI - BLM) and Eric Klepfer (Mines Management, Inc.) for granting permission to use some of the drill logs presented in this poster.

REFERENCES

Hayes, T.S., and Einaudi, M.T., 1986, Genesis of the Spar Lake Strata-Bound Copper-Silver Deposit, Montana: Part I. Controls Inherited from Sedimentation and Preore Diagenesis: Econ. Geol., Vol. 81, pp 1899-1931.

Ransome, F.L., and Calkins, F.C., 1908, Ore Deposits of the Coeur d'Alene district, Idaho: U.S. Geol. Survey Prof. Paper 62.

Trammell, J.W., 1975, Strata-Bound Copper Mineralization in the Empire Formation and Ravalli Group, Belt Supergroup, Northwest Montana: Univ. of Washington Ph.D. dissertation, 71 p.

Kootenai River Ferry, circa 1900. Public domain photo via Montana Heritage Project.

SHEPARD, MOUNT SHIELDS, AND BONNER FORMATIONS OF THE MIDDLE PROTEROZOIC MISSOULA GROUP IN LIBBY SYNCLINE, KOOTENAI FALLS, NORTHWEST MONTANA

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6606 Jocko Canyon Road, Arlee, MT 59821

STRATIGRAPHIC OVERVIEW

Missoula Group rocks are beautifully exposed where the Kootenai River cascades over Kootenai Falls and flows down through the gorge below. Outcrops also extend up the canyon walls and are exposed in highway cuts through the canyon, making the Kootenai Falls area an excellent locality to study the Missoula Group in the northern part of the Belt basin. The Shepard, Mount Shields, and Bonner formations of the Missoula Group are the focus of this field trip (Fig. 1).

Grain size, mineral composition, and, most importantly, sedimentary structures are combined into sediment types, which describe the essential lithologies of Belt rocks (e.g.. Winston, 1986b, Winston and Link, 1993). Principal sediment types of Missoula Group rocks discussed on this field trip are described and interpreted in Table I. An outstanding characteristic of most Belt rocks is that they contain graded layers recording deposits of individual sedimentary events. Graded layers more than 10 cm. thick are referred to as beds, layers from 10 cm to 3 cm thick are called couples, layers from 3 cm to 0.3 cm are called couplets, and graded layers less than 0.3 cm are called microcouplets. Within these graded layers are additional sedimentary structures such as flat laminae or ripple lenses which further define the sediment types.

The Missoula Group represents the final filling phase of the middle Proterozoic Belt basin that was initiated by block faulting within the large, early Proterozoic Columbia continent about 1.80 Ga (Sears and Price, 2002). Fine sand and mud that filled the initial deep-water basin, now preserved in the Prichard Formation, came from the western side of the basin (Cressman,1989). Western-derived sediments filled the basin, and a large alluvial apron complex prograded from the west and southwest, depositing the Burke, Revett and St. Regis formations. Tabular, flat-laminated fine-grained arenite beds of the Revett Formation were deposited by sheetfloods that flowed northeastward down across the alluvial apron. The flood waters ponded against the tectonically quiescent Laurentian land mass, forming playa lake deposits of the Grinnell Formation (Winston, 1986). Coarse quartz sand from the Laurentian craton east of the Belt basin was mixed with the fine western-derived sand, forming the sharply bimodal sand and mudstone beds of the Grinnell Formation in Glacier National Park. Perennial lake complexes again began to fill the Belt basin, depositing the Empire Formation, and became more fully established as first the Helena, and then the Wallace formations of the Piegan Group were deposited (Winston, in press). Fine-grained sediments that deposited the Helena Formation continued to come mostly from the west, but the overlying Wallace Formation records subsidence of the western part of the Belt basin and westward expansion of the Wallace lake (Winston, in press).

Snowslip Formation. The Missoula Group marks a change in the sedimentary configuration of the Belt basin. Figure 1 shows that sediments in the Missoula Group coarsen to the south, beginning with the Snowslip Formation. Within the lower and middle Snowslip are three tongues of mudcracked, red, hematitic arenite and mudcracked argillite termed Snow-

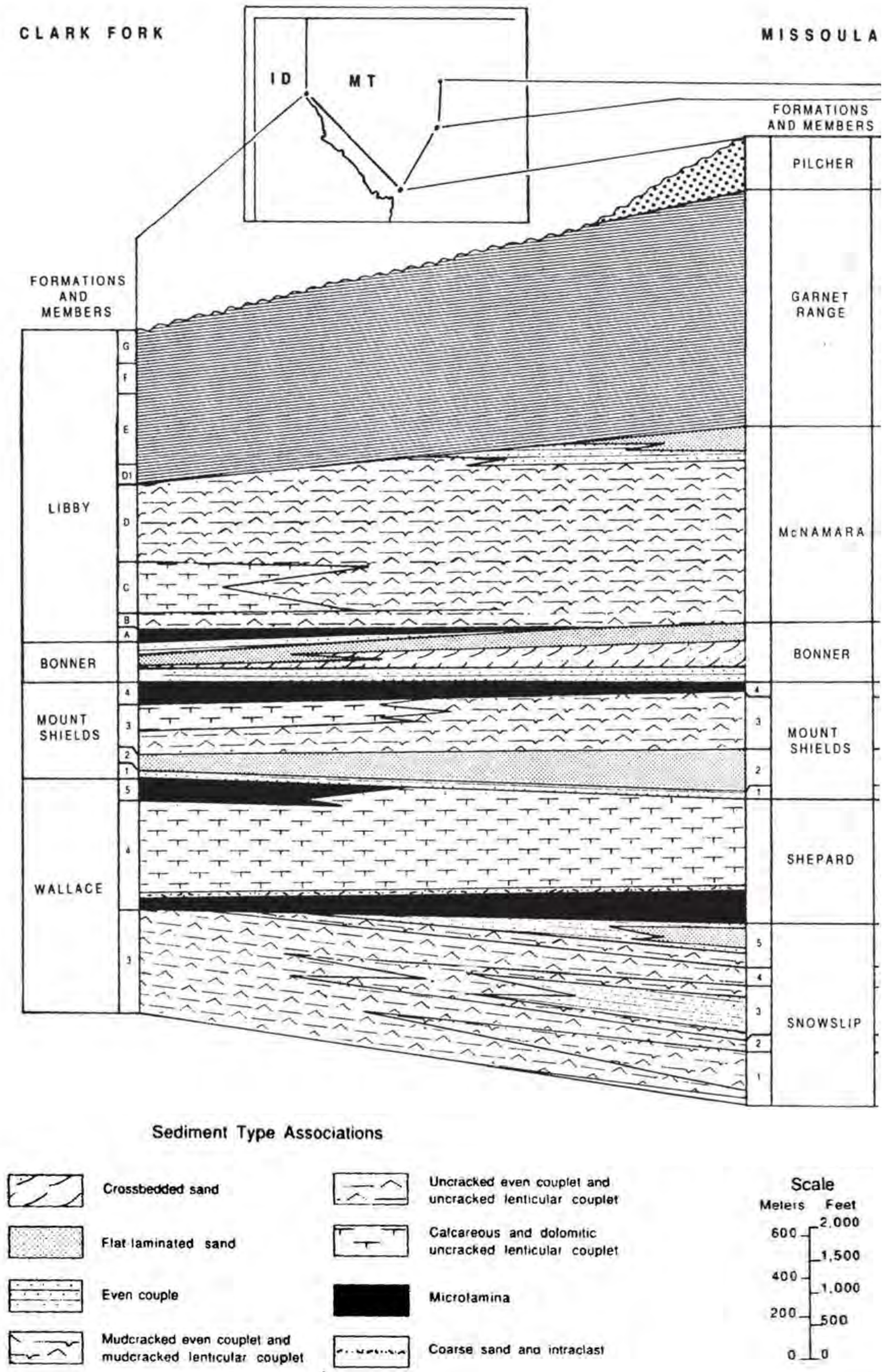
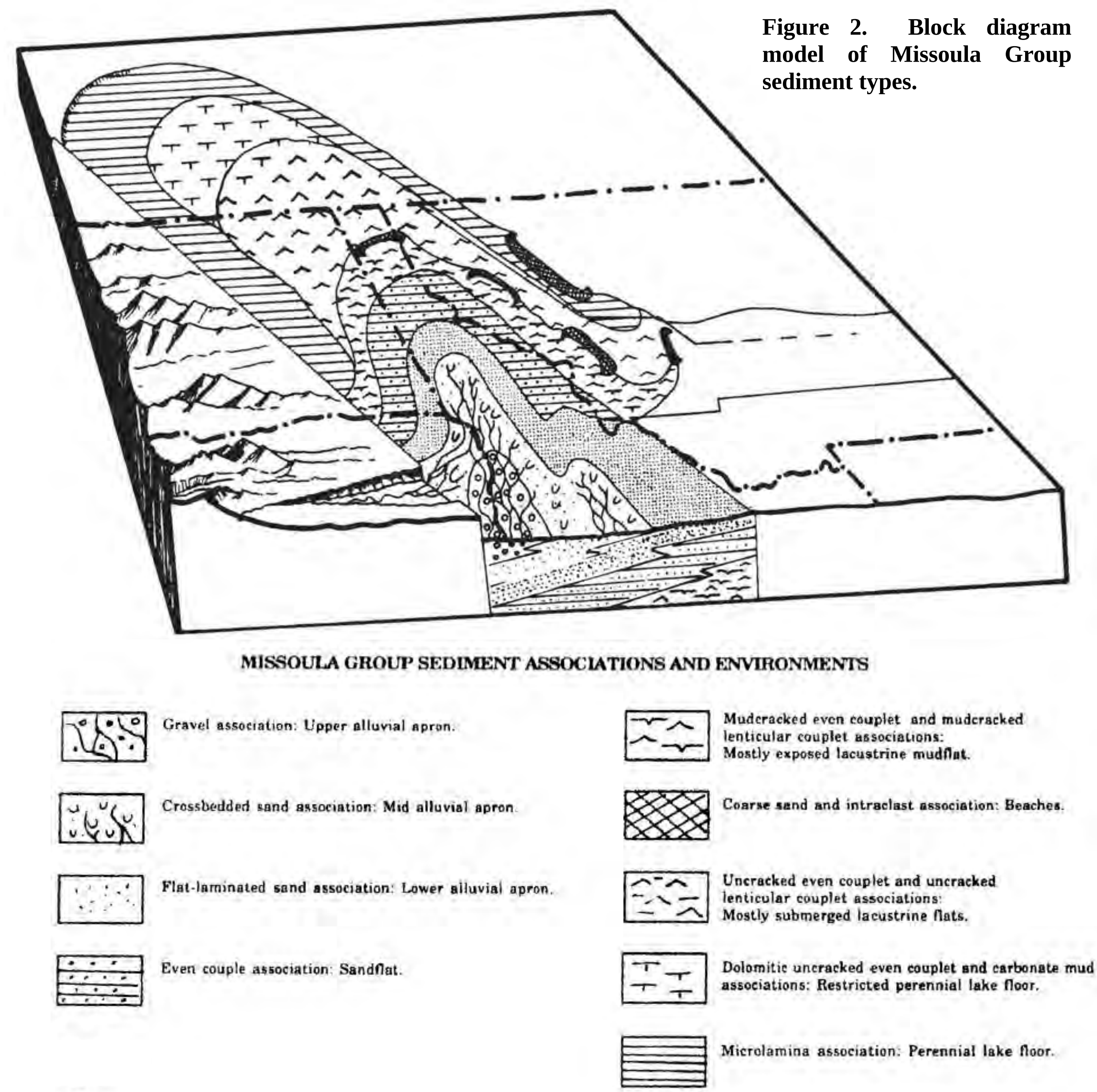


Figure 1. Cross section of Missoula Group formations from Missoula to Libby, showing the general northward fining of lithologies within the formations.

slip informal members 1, 3 and 5 that extend from Missoula to Glacier National Park. They represent northward advances of exposed mud-flat and sandflat deposits on an alluvial apron toe (Fig. 2). They are separated by two green argillite tongues with few mudcracks in which the iron has been reduced to the ferrous state under more subaqueous conditions (informal Snowslip members 2 and 4) and represent advances of lake margins. The redbed tongues pinch out into continuous non-desiccated green argillite in northwest Montana, indicating more perennial lake cover in this region (Lemoine and Winston, 1986).

Sharply overlying Snowslip member 5 is a black, thin-bedded argillite unit of Snowslip member 6 (Fig. 1). It marks expansion of a shallow organic-rich lake with hummocky crossbeds as far east as Glacier National Park. Mafic flows of the Purcell pillow lava flowed out into this lake floor across much of northern Montana and extend as far west as the Libby syncline. The upper part of Snowslip member 6 becomes lighter, greenish-gray, thin-bedded argillite. The field trip begins in black argillite of Snowslip member 6.

Figure 2. Block diagram model of Missoula Group sediment types.



Shepard Formation. Above the siliciclastic argillite of Snowslip member 6 is tan-weathering, thin-bedded dolomitic argillite of the Shepard Formation (Fig. 1). It contains greenish gray, even, undulating, and lenticular siliciclastic couplets like the Snowslip below, but clay in the upper muddy layers of the couplets is mixed with dolomite, which turns the outcrops tan on the weathered surface. Oscillation ripples of the lenticular couplets, occasional mudcracks and mudchip layers, and microcouplet intervals indicate that the floor of the Shepard water body was flat, shallow, and occasionally exposed. The Shepard was named in Glacier National Park (Willis, 1902) and extends south to Lincoln and Missoula. But south of Missoula on the Sapphire aulochthon it appears to interfinger with siliciclastic green and purple argillite. In northwestern Montana the dolomite of the lower Shepard is overlain by black argillite designated the upper part of the Shepard here in Montana and on the Sandpoint 1°x2° Quadrangle (Miller and others, 1999). However, in the Coeur d'Alene Mining District Ransome and Calkins (1908) placed the dolomite and overlying black argillite in the upper Wallace Formation, and they are so assigned by Lewis and others (2002) in the Coeur d'Alene quadrangle of Idaho. Although the Shepard has not been regionally studied, it is here provisionally interpreted to be a lake deposit based on similar sediment types and sediment type associations to other inferred Belt lacustrine deposits, particularly the Helena Formation. The lake waters were saline enough to form calcium, magnesium, carbonate mud, but apparently were not saline enough to form halite.

Mount Shields Formation. Overlying the Shepard is red and green siliciclastic argillite and arenite of the lower informal member of the Mount Shields Formation, Mount Shields member 1 (Fig. 1). It represents the return of the alluvial apron mudflats and sandflats that, based on regional facies relationships, prograded from the south, down the axis of the western part of the Belt basin (Slover and Winston, 1986) (Fig. 2). The argillite thins southward, and nearly pinches out beneath the overlying arenite of Mount Shields member 2 at Missoula.

The interbedded arenite and argillite of Mount Shields member 1 is overlain by continuous, tabular, mostly flat-laminated arenite beds of the informal Mount Shields member 2 (Fig. 1). In the section at Kootenai Falls the tabular beds also contain wavy laminae interpreted to be low antidunes deposited in the upper part of the upper flow regime. To the south the tabular beds become thicker, coarser, and locally trough crossbedded. The tabular, flat-laminted Mount Shields beds so closely resemble tabular flat-laminated arenite beds of the Revett that, in the Anaconda Range for example, the Revett has been mismapped as Mount Shields (Lonn and others, 2003). Like the Revett, the Mount Shields member 2 is interpreted to be a sheet-flood deposit in which flood waters flowed in the upper flow regime down across flat, unvegetated surfaces, producing the tabular beds that are separated by mud drapes at the tops of the sand beds. Unlike the Revett, however, the Mount Shields sand lithosome thickens to the south instead of the southwest, and, like the lower Mount Shields member, indicates flow down the northwest-trending axis of the western part of the Belt basin (Fig. 2).

The Mount Shields member 2 is sharply capped by oolite and stromatolite beds that mark the base of Mount Shields informal member 3, or the salt cast member (Fig. 1). At Kootenai Falls there are several oolite and stromatolite beds interleaved with arenite beds and rippled, mudcracked argillite beds. These extend northwestward to where U.S. Highway 2 crosses the Idaho-Washington state line (Winston and Woods, 1986). The lower stromatolite beds probably pinch out southward and eastward, so that only the uppermost stromatolite and oolite bed caps the Mount Shields member 2 from Glacier National Park to the Thompson River, and west to the Striped Peak Formation in the Coeur d'Alene Mining District. Farther south the bed is represented by thin dolomite layers north of Missoula and Helena and becomes a calc-silicate bed at Lost Creek in the Flint Creek Range north of Anaconda. Based on similarity with oolite sand flats and domal stromatolites of the Great Salt

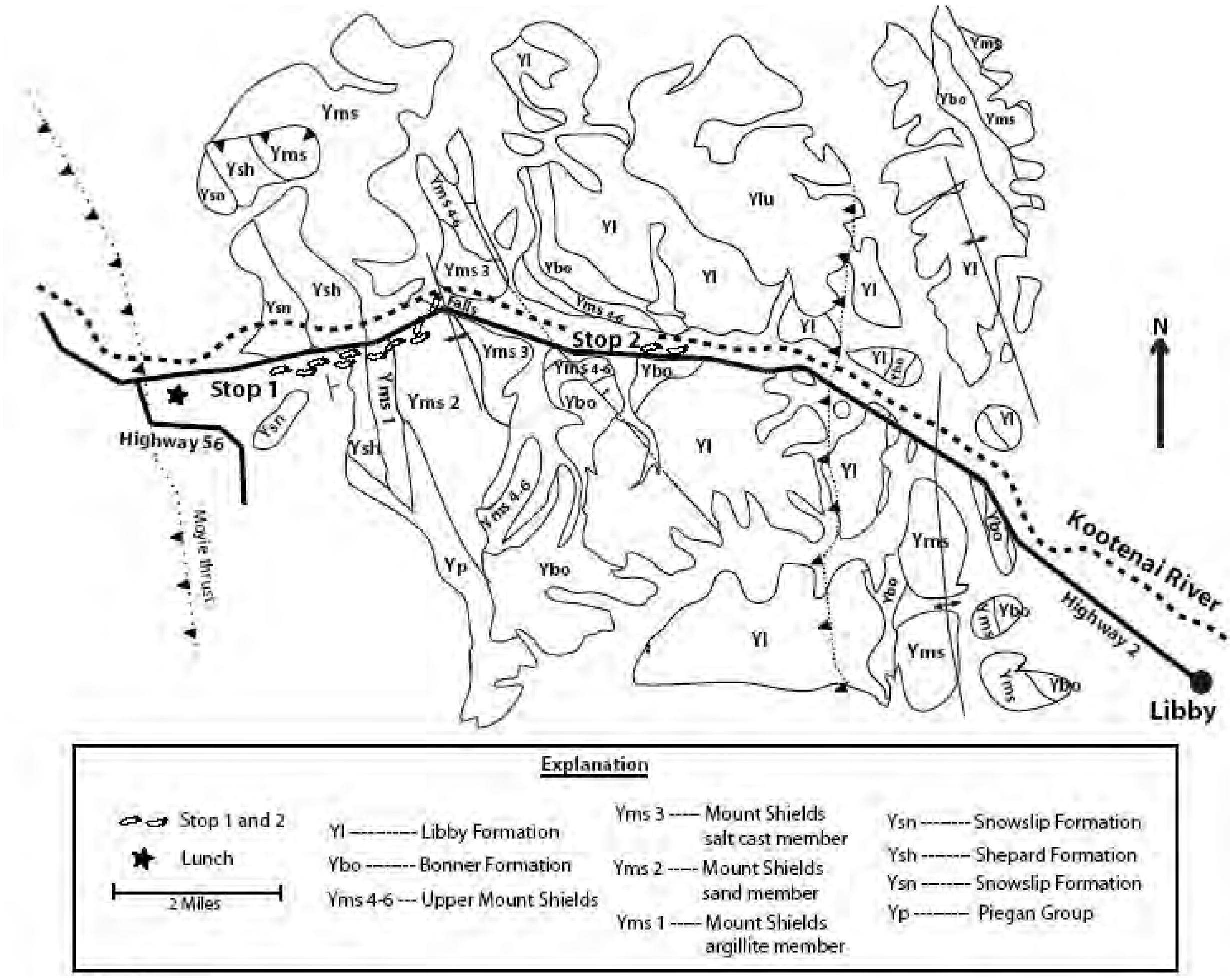


Figure 3. Field trip route from Libby to Kootenai Falls. Stop 1 is a two mile traverse from the top of Snowslip member 6 to Mount Shields member 3. Optional stop 2 is in the Bonner Formation.

Lake, these beds are interpreted to represent wind setup flats along the southward-advancing margin of the saline playa lake that deposited Mount Shields member 3. Coarse, round quartz grains in the centers of the ooliths are inferred to have come from the eastern margin of the Belt basin and to have been transported westward across the basin by longshore drift. Above the oolite and stromatolite beds are, oscillation rippled, mudcracked beds of Mount Shields member 3. The member is characterized by purple, mudcracked, lenticular to undulating silt-to-clay couplets with abundant halite casts. It extends eastward to Glacier National Park, southward to Philipsburg, Montana and southwestward to Striped Peak, in the Coeur d'Alene Mining District. The ripple-marks, salt casts, and mudcracks are interpreted to record deposition in a shallow, flat, saline, ephemeral playa complex. Bedding styles and interpreted environments compare closely with those of the saline Wilkins Peak Member of the Eocene Green River Formation of Wyoming (Smoot, 1983). Above the Mount Shields member 3 Harrison and others (1993) reported a succession of arenite, carbonate, and black argillite units they assigned to Mount Shields members 4, 5 and 6 (Fig. 1). They do not crop out well in the Kootenai canyon and will not be visited on the field trip.

Bonner Formation. Purple, tabular arenite and argillite beds of the Bonner Formation overlie the Mount Shields black argillite in the Kootenai Falls area (Fig. 1). They are well displayed at optional Stop 2 . The mostly 10 to 20 cm thick fine- to medium-grained feldspathic arenite beds are flat-laminated and interbedded with occasional trough crossbedded arenite layers. Both are capped by mud drapes. The argillite intervals are composed of even to lenticular couplets with light purple gray sand layers and bright purple desiccation cracked mud layers. To the south at the type area near Missoula, the Bonner becomes a coarse- to medium-grained, trough crossbedded arenite. (Winston and others, 1986a). Still farther south at Wise River the Bonner contains coarse rounded quartzite pebbles and angular microcline granules (Calbeck, 1975). The tabular, trough crossbedded arenite beds in the Bonner in the southern part of the basin record sheetfoods that flowed in the upper part of the lower flow regime in flood waters about a meter or more deep northward down the alluvial apron, forming the trough crossbeds (Winston, 2002) (Fig. 2). As the alluvial apron flattened out toward the sandflat toe, flow decelerated but shifted to the upper flow regime either because the flow became too shallow to form dunes or because the grain size became to small. As seen here, and in the Mount Shields member 2, sheetflood sand became interstratified with desiccated couplets in the more distal sandflats and mudflats of the alluvial apron toe.

Libby Formation. Interstratified greenish-gray even and undulating couplets and dark gray microcouplets of the lower part of the Libby Formation sharply overlie the tabular purple arenite beds of the Bonner (Fig. 1). Kidder (1998) shows that the Libby Formation contains two, sharply contrasting lithologies. The lower part of the Libby is composed of cherty, greenish gray argillite with scattered oolite and stromatolite beds. The upper Libby contains hummocky crossbedded micaceous arenite. Correlation of the Libby southward shows that the lower Libby passes to purple and green mudcracked argillite of the McNamara Formation, and the upper Libby represents the Garnet Range lithosome. The two may be separated by an unconformity (Bleiwas, 1977).

ROAD LOG

<u>Mile</u>

0.0
The road log begins at the intersection of Montana Highway 2 and Montana Highway 37 in Libby (Fig. 3). Drive west on Highway 2.

1.2
Cross Parmenter Creek.

2.5
On the south side of the highway are east-dipping beds of green argillite and siltite above dark gray argillite in the lower part of the Libby Formation. Here they are tightly folded over a small anticline with purple arenite beds of the Bonner Formation in the core.

3.0
East-dipping outcrops on south side of highway just west of the paved pullout nicely illustrate again the Libby-Bonner contact with dark microcouplet beds of the Libby overlying purple, tabular fine-grained arenite and siltite of the Bonner. East-dipping cliffs of the Bonner are in view on the north side of the Kootenai River and are on the east limb of a mile-wide anticline within the much larger Libby syncline.

4.4
Cross Cedar Creek and axis of the small anticline.

5.0
West-dipping beds in the roadcut on the south are on the west limb of the small anticline. The 10 to 20 cm-thick, tabular beds of fine-grained purple arenite interbedded with couplets of mudcracked purple argillite are in the uppermost part of the Bonner Formation. The Bonner is more fully exposed in railroad cuts north of the highway and was measured by Phil Jacob and Don Winston in 1977. More recent highway cuts ahead expose the contact of the Bonner with the lower part of the Libby Formation (McNamara lithosome). Hammer impacts on a cherty bed in the lowest Libby may mark the location of the detrital zircon sample dated by Evans and others (2000) at 1401 Ma. The lower beds of the Libby Formation are composed of intervals of dark gray microcouplets interstratified with intervals of cherty, mudcracked greenish-gray argillite couplets.

5.7
Cross the buried trace of a fault that Harrison

and others (1993) map as the northern extension of the major Showshoe fault farther south along the east side of the Cabinet Mountains. The Snowshoe fault is inferred to have been a Mesozoic thrust fault that was reactivated by Tertiary extension. On the hanging wall of this fault is a gentle syncline in the Libby Formation.

6.2
Road cuts on south are in west-dipping beds of the lower Libby Formation in the gentle syncline. The bedding flattens out in the axis of the syncline and becomes east-dipping. From this point on, beds dip eastward on the west limb of the Libby syncline, which is also the east limb of the Sylvanite anticline to the west. The field trip will begin in the uppermost Snowslip Formation in this east-dipping section and progress up into the Bonner Formation.

8.0
Highway cuts in purple arenite on the south side of the highway are near the top of the Bonner.

8.6
Beds of purple arenite and argillite in cuts on the south are in the Bonner Formation and may be more fully discussed in optional STOP 2.

10.5
Sign to the old Highway 2 trail on right.

11.2 GPS Coordinates N480 27.168', W 1150 46.166'

Parking lot for the Kootenai Falls County Park. Highway cuts in the syncline on the south side of the highway are low in the rippled, salt cast member of the Mount Shields Formation. We will end our two mile traverse here and walk down to Kootenai Falls.

12.0
Base of highway cuts on the south are in lower member I of the Mount Shields Formation and will be seen on the return traverse.

12.4
Highway cuts on the south are at the top of the lower carbonate member of the Shepard Formation and will be viewed on our traverse back to the Kootenai Falls parking lot.

12.8
End of the highway cuts on the south lie close to the base of the Shepard Formation

13.2. STOP I Snowslip informal member 6. GPS Coordinates N480 26.697', W 1150 48.451'

STOP 1

Pull off highway on the right opposite low outcrops of thin-bedded black argillite at the road level above railroad cuts beyond. From here we begin our two-mile traverse back to the Kootenai Falls parking lot. The lunch stop at the intersection of U.S. Highway 2 and Montana State Highway 56 is two miles beyond this point.

The thin-bedded black argillite in this outcrop contains thin interlaminae of dark greenish gray even siltite layers and lenses up to 5 mm thick capped by thinner black mudstone layers. Where the siltite and mudstone couplets are < 3 mm thick they are termed microlaminae or microcouplets. The fine grain size and thin laminae indicate silt and clay suspension settleout in quiet water. One would conjecture that they were deposited in deep water below the reach of waves. However, in most Belt rocks where facies relations can be established, these kinds of sediments turn out to have been deposited close to the lake margin in shallow calm water, which was protected from waves. Modern sediments like these have been described from shallow water of the Mackenzie Delta in the Beaufort Sea by Hill and Nedeau (1989).

If our correlations are correct, these rocks belong to Snowslip informal member 6 of Whipple (Whipple and others, 1984) (Fig. 1). In Glacier National Park (Whipple 1992) the unit is also composed of dark microcouplets, but also has hummocky fine-grained arenite

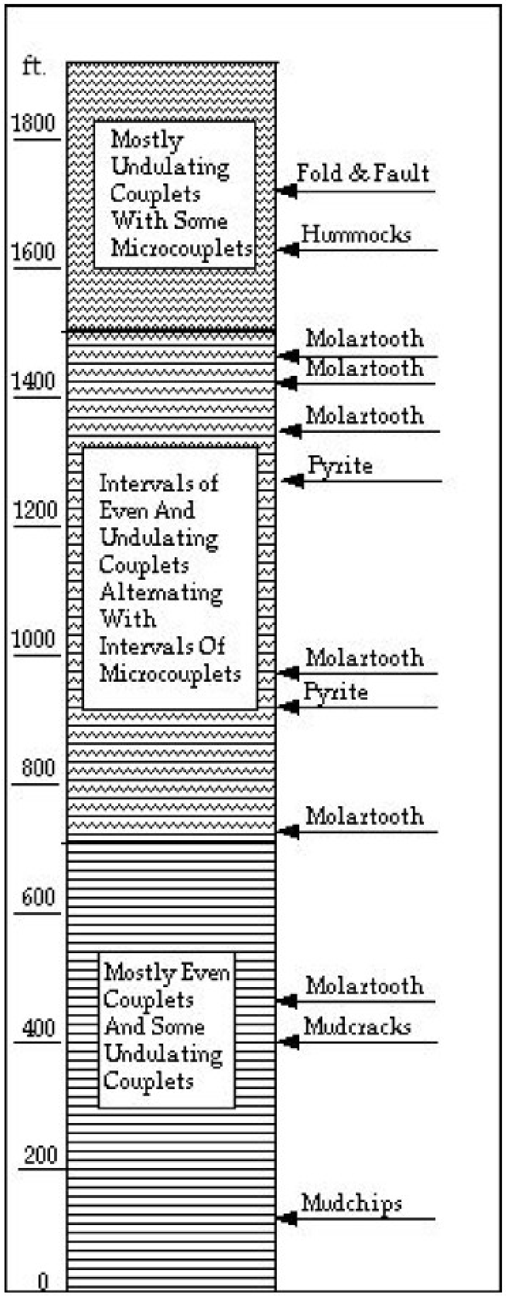


Figure 4. *(Left)* **Generalized measured stratigraphic section through the dolomitic interval of the Shepard Formtion in highway cuts at Stop 1.**

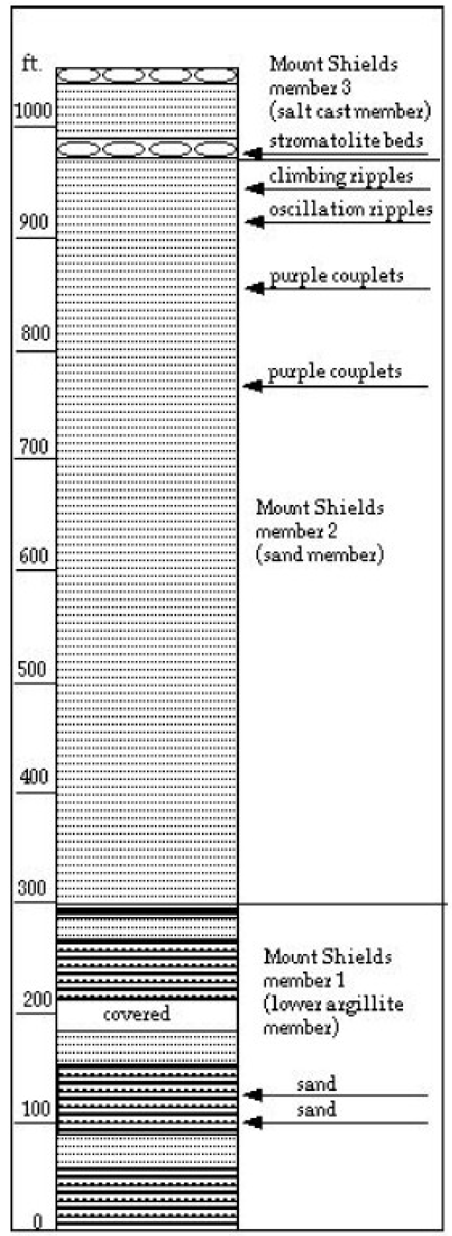
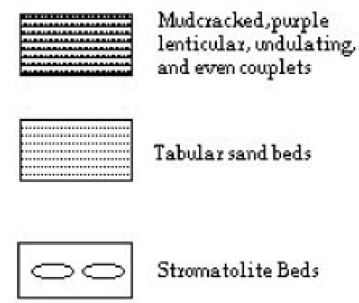


Figure 6 Generalized stratigraphic section through the upper part of Mount Shields member 1 and through the whole of Mount Shields member 2 in highway cuts at Stop 1



beds. The Purcell lava occurs within this unit and has been mapped discontinuously across northern Montana. It crops out on the north side of Surprise Gulch 2 miles north of this outcrop, but we have not found it here. Black thin-bedded argillite units in the Snowslip Formation pose a problem in correlating the Snowslip Formation of Montana with its homotaxial equivalent in Idaho, where it is assigned to the upper Wallace (Lewis and others, 2002). Snowslip member 6 may pinch out in Idaho and another black argillite unit may wedge in low in the section (Harrison and others, 1993). Walk east along the road for about 180 m and at the private road entrance cross the highway to low outcrops on the south side of the highway. Here are thin couplets with light-gray silt laminae and slightly greenish-gray mud caps. Some mud caps are cut by desiccation cracks and the dry mud polygons have been transported as mud chips. These beds probably mark the transition to the dolomitic Shepard above, but Harrison and others (1993) included them in the Snowslip. Continue east about 450 m across a covered interval to the highway cuts.

Base of section along highway cuts. **GPS Coordinates N480 26.885', W 1150 48.918'**

The highway cut exposes relatively fresh outcrops of the lower dolomitic part of the Shepard and was measured and briefly described by Winston and Wheeler in May, 2006 (Figs 4,5). The dark argillitic member of the Shepard is partly exposed above the highway cut. There is a general progression of siliciclastic couplet styles from low in this outcrop to the top. Fine, sandy even couplets are most abundant in the lower 700 ft. of the section. Mud caps of the couplets are thin, and some are desiccation cracked. Dry, desiccated polygons are locally transported and deposited as mud chips in sandy layers. Undulating couplets with more lenticular sandy couplet layers become more abundant in the upper part of this interval.

From about 700 ft. to about 1,500 ft. couplet intervals several meters thick become interstratified with intervals of dolomitic microcouplets that weather dark tan. Tan weathering in this interval has two origins. Dolomite weathers a light tan, whereas pyrite crystals and beds rich in pyrite weather a bright ocher. Large diagenetic pyrite cubes are exposed at 924 and 1275 feet. Beds with calcitic molartooth ribbons are scattered through this interval (Figure 3). Furniss and others (1993) interpreted molartooth ribbons to be gas expansion cracks in unconsolidated sediment that filled with vaterite, which rapidly inverted to calcite.

From about 1,500 ft to 1900 ft. at the top of the measured section, silt layers in the couplets become more lenticular, forming thicker undulating couplets. The progression from even couplets to undulating couplets probably reflects the progression from mostly suspension settleout low in the Shepard dolomite to wave reworking of the silt followed by suspension settleout of the dolomitic clay higher in the unit.

Continue above the highway cuts up onto the hill graded off by highway construction to scattered outcrops of the upper Shepard. They are composed of non-dolomitic dark gray to dark greenish gray couplets up to 2 cm thick that thin down to microcouplets. There are scattered mud cracked, and mudchip layers. Walk to the highest outcrop of even bedded arenite, which may mark the base of the Mount Shields Formation. Walk down to the highway and continue up to the next highway cut in the Mount Shields.

Base of Mount Shield highway cuts. **GPS Coordinates N480 26.885', W 1150 46.918'**

Highway cuts from here to the Kootenai Falls parking lot expose a spectacular section of the lower part of the Mount Shields Formation (Figure 6).

Mount Shields member 1

The lowest 296 ft. of the section are composed of alternating intervals of tabular arenite beds and purple argillite beds averaging 5 m. thick.

Figure 5. Highway cut through the upper part of the Shepard dolomite interval at Stop 1.

Figure 7. *(Left)* **Highway cut showing the lowest oolite and stromatolite bed (arrow) marking the base Mount Shields member 3 at the top of Mount Shields member 2.**

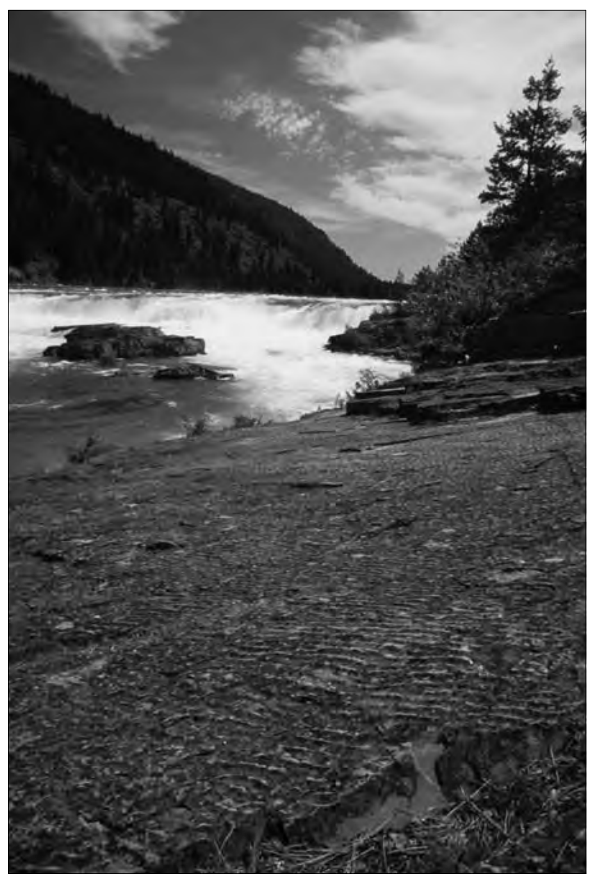


Figure 8. Oscillation rippled surface in the Mount Shields member 3 at Kootenai Falls.

The arenite intervals are composed of greenish gray, 10-40 cm.-thick tabular beds, that have flat to wavy internal laminae. Many arenite beds are separated by thin, desiccation-cracked mud drapes and some have oscillation ripples on their surfaces. Argillite intervals between the arenite intervals are composed of graded fine arenite-to-mud couplets, mostly 1-3 cm. thick. Dark greenish to purplish gray arenite layers of the lower half-couplets range from even, to undulating, to lenticular. Some purple mudcracked polygons have been transported and deposited as mud chips.

The flat tabular bedding records deposition across flat surfaces, and the flat to wavy internal laminae within the beds indicates deposition as upper flow regime plane beds or antidunes. These combine to indicate episodic, sheetflood deposition. Oscillation ripples that cap some beds reflect shallow puddles that formed on some sand surfaces after the floods, and the capping mud layers record deposition of mud drape during waning flood flow, followed by exposure and desiccation. Beds in the Mount Shields thicken and coarsen southward indicating the floods flowed from as far south as east-central Idaho and fanned out here on the distal sandflat toes of the vast alluvial apron. Couplets of the intervening purple argillite layers also record episodic deposition of thin muddy layers across flat surfaces. Even couplets may record deposition from suspension during decelerating flood flow, followed by exposure and desiccation. The lenticular couplets may indicate that the water ponded and was reworked by waves before the mud settled and was exposed and desiccated.

The interbedded arenite and argillite intervals indicate that the sheetflood sand flats at the toes of the alluvial aprons repeatedly prograded over the more distal mudflats and retreated before them (Fig. 2). This alternation is characteristic of the lower Mount Shields member, sometimes referred to as Mount Shields member 1. It thins southward, and passes into arenite beds of the Mount Shields member 2. but thickens northward across the Canadian border and eastward to Glacier National Park. In 1977 before the highway was widened, Phil Jacob and Don Winston measured 480 ft. of the lower Mount Shields from the river up to the highway. Tim Wheeler and Don Winston remeasured and briefly redescribed the highway cuts.

Mount Shields member 2 (sand member)

From 296 ft. to 967 ft. the tabular arenite facies, described below, takes over the section, resulting in stacked beds of tabular fine-grained flat- to wavy-laminated arenite, designated Mount Shields member 2, or sometimes called the sand member. Dolomitic stringers, rippled surfaces, and desiccated mud drapes carry upward as well. Based on the interpretations of the arenite intervals below, the Mount Shields member 2 is here interpreted to record long-term progradation of the alluvial apron toe northward across the northern distal reaches of the Belt basin. To the south, at Flint Creek Hill, south of Philipsburg, Montana, intervals of the Mount Shields sand become coarse grained, contain granite clasts, and contain trough crossbeds, indicating deeper flow and greater velocities farther up on the alluvial apron. The green color and dolomitic cement stringers probably record early diagenesis from fluid flow through porous sand, resulting in reduction of ferric iron to ferrous iron and carbonate precipitation. Fluids may have been in part ground water flow down the alluvial apron or induced by compaction of the sediment pile.

Mount Shields member 3 (salt cast member)

At 967 is the lowest of several light yellowish gray beds of oolitic quartz sandstone overlain by domal stromatolites, marking the base of Mount Shields member 3 , or the salt cast member (Fig. 1, 7). The ooliths record continual reworking across flat surfaces and are interpreted to have formed on wave worked wind setup flats, similar to modern wind setup flats of Great Salt Lake where periodic winds drive lake water across the exposed oolitic flats. The well rounded, medium, quartz sand grains in the oolith cores are unique to the eastern edge of the Belt basin and differ from the feldspathic coarse sand of the Mount Shields alluvial apron to the south (Winston and Lyons, 1997) and were probably driven by longshore drift out across the sand flats. The domal stromatolites, like those in the Great Salt Lake, also probably grew close to the water's edge. Above the lowest oolite and stromatolite are additional stromatolitic beds that are interstratified with tabular arenite intervals and mudcracked couplet intervals, like those of the lower Mount Shields member. These are also inferred to record repeated progradation of the alluvial apron followed by retreat and onlap of the oolitic sand flats and mudcracked mud flats at the distal toe of the Mount Shields sand apron. Walk 500 m up to the Kootenai Falls parking lot opposite the anticline-syncline pair in the highway cut that brings the stromatolite beds back up to the highway level.

Kootenai Falls County Park parking lot.
GPS Coordinates N480 27.168', W 1150 46.166'

Take the black-topped path past the restrooms, through the picnic area, and cross the footbridge over the railroad tracks. Take the right-hand trail to Kootenai Falls and follow it to the viewpoint on rippled surfaces of the Mount Shields member 3 salt cast unit (Fig. 8). These spectacular symmetric, wave oscillation ripples together with the halite casts and mudcracked couplets are inferred to record deposition in a shallow, flat, saline, periodically exposed playa lake complex. Ripples, salt casts, and mudcracks characterize this Mount Shields member across most of the Belt basin in western Montana and provide a sense of how broad this shallow lake was. Absence of tidal channels and unidirectional current ripples precludes this being a marine tidal flat deposit. Return to the parking lot and, if time permits, continue to the next stop by driving back east on Highway 2, 2.6 miles to outcrops of Bonner on the south side of the highway.

STOP 2

Mile 8.6 from Libby: Stop 2

GPS Coordinates N480 26.821', W 1150 42.533'

Beds of purple Bonner arenite crop out on the right. Walk east up through a short stratigraphic interval that illustrates the mostly fine-grained, tabular, flat-laminated arenite beds 10-20 cm thick that characterize the Bonner Formation of northwestern Montana, like the Mount Shields member 2 below, the Bonner here records upper flow sheetflood deposition on the lower part of the Bonner alluvial apron (Fig. 2). The tabular arenite beds form units a few meters thick and are interstratified with intervals of mudcracked lenticular and even couplets with light purplish gray fine-grained sand capped by purple, desiccation-cracked mud. Additional features in this outcrop further illustrate variation in the Bonner. A quartz-filled dike has apparently reduced the ordinarily purple hematitic beds of the Bonner to green argillite adjacent to the dike, which underscores the principal that the red-to-green coloration is dominantly a diagenetic product. Other greenish beds in the outcrop were probably also reduced to green, and in a small outcrop may be difficult to differentiate from greenish arenite beds of the Mount Shields member 2 sand. Higher in the outcrop are large trough crossbeds of a scale that might be mistaken for small channels. Large trough crossbeds like these characterize the Bonner near Missoula and their reduction illustrates the northward-fining and -thinning of the Bonner in the distal part of the alluvial apron. If the morning field trip group makes it this far, we will have lunch in the rest stop at the intersection of highways 2 and 56. If the afternoon group makes it this far, we will return to Libby.

REFERENCES

Bleiwas, D.I., 1977, The McNamara-Garnet Range transition (Missoula Group, [abstract]:

Geological Society of America Abstracts with Programs, v. 9, no. 6, p. 709-710.

Calbeck, J.M., 1975, Geology of the central Wise River Valley, Pioneer Mountains, Beaverhead County, Montana: unpub. M.S. thesis, University of Montana, 89 p.

Cressman, E.R., 1989, Reconnaissance stratigraphy of the Prichard Formation (Middle Proterozoic) and the early development of the Belt Basin, Washington, Idaho and Montana: U.S. Geological Survey Professional paper 1490, 80 p.

Evans, K.V., Aleinikoff, J.N., Obradovich, J.D., and Fanning, C.M., 2000, SHRIMP U-Pb geochronology of volcanic rocks, Belt Supergroup, western Montana: Evidence for rapid deposition of sedimentary strata: Canadian Journal of Earth Sciences, v. 37, p. 1287-1300.

Furniss, George, Rittel, J.F., and Winston, Don, 1998, Gas bubble and expansion crack origin of “Molar-Tooth” calcite structures in the Middle Proterozoic Belt Supergroup, western Montana: Journal of Sedimentary Research, v. 68, p. 104-114.

Harrison, J.E., and Cressman, E.R., 1993, Geology of the Libby thrust belt of northwestern Montana and its implications to regional tectonics: U.S. Geological Survey Professional paper 1524, 42 p.

Hill, P.R., and Nedeau, L.C., 1989, Storm-dominated sedimentation on the inner shelf of the Canadian Beaufort Sea: Journal of Sedimentary Petrology, v. 59, p. 455-468.

Kidder, D.L., 1988, Syntectonic sedimentation in the Proterozoic upper Belt Supergroup, northwestern Montana: Geology, v. 16, p. 658-661.

Lemoine, S.R., and Winston, Don, 1986, Correlation of the Snowslip and Shepard formations of the Cabinet Mountains with the upper Wallace rocks of the Coeur d’Alene Mountains, western Montana, *in* Roberts, S.M., ed., Belt Supergroup: A Guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 161-168.

Lewis, R.S., Burmester, R.F., Breckenridge, R.M., McFaddan, M.D., and Kauffman, J.D., 2002, Geologic Map of the Coeur d’Alene 30 X 60 Minute Quadrangle, Idaho: Idaho Geologic Survey Geologic Map 33, with 34 pp.

Lonn, Jeff, Lewis, R.S., and Winston, Don, 2003, Belt structure and stratigraphy of the Sapphire block, western Montana: 2003 Tobacco Root Geological Society Field Conference at Belt Symposium IV, Northwest Geology, v. 32, p. 17-28.

Miller, F.K., Burmester, R.F., Miller, D.M., Powell, R.E., and Derkey, P.D., 1999, Digital geologic map of the Sandpoint 1 x 2-degree quadrangle, Washington, Idaho, and Montana: U.S. Geological Survey Open-File report 99, scale 1:250,000.

Ransome, F. L., and Calkins, F. C., 1908, The geology and ore deposits of the Coeur d'Alene district, Idaho: U.S. Geological Survey Professional Paper 62, 203 p.

Sears, J.W., and Price, R.A., 2002, Hypothetical Mesoproterozoic supercontinent, Columbia: Implications of the Siberian-West Laurentian connection: Gondwana Research, v. 3, p. 35-39.

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

Smoot, J.P., 1983, Depositional subenvironments in an arid closed basin; the Wilkins Peak Member of the Green River Formation (Eocene), Wyoming, U.S.A.: Sedimentology, v. 30, p. 801-827.

Whipple, J.W., compiler, 1992, Geologic map of Glacier National Park, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1508-F, scale 1:100,000.

Whipple, J.W., and others, 1984, Preliminary report on the stratigraphy of the Belt Supergroup, Glacier National Park and adjacent Whitefish Range, Montana: Montana Geological Society 1984 Field Conference and Symposium, p. 33-50.

Willis, Bailey, 1902, Stratigraphy and structure, Lewis and Livingston ranges, Montana: Geological Society of America Bulletin, v. 13, p. 305-352.

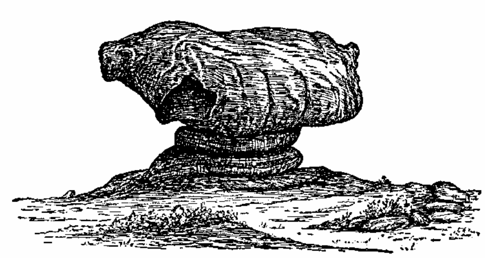
Winston, D., 2002, Unconfined sheetflood fluvial deposition in the Missoula Group, Middle Proterozoic Belt Supergroup, Montana: Geological Association of Canada, Abstracts, v. 27, p.124.

Winston, Don, and Link, P., 1993, Middle Proterozoic rocks of Montana, Idaho and eastern Washington: Belt Supergroup, *in* Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., and Ranking, D., eds., Precambrian: Conterminous U.S.: Boulder Colorado, The Geological Society of America, The Geology of North America, v. C-2, p. 487-517.

Winston, Don, and Lyons, T.W., 1993, Sedimentary cycles in the St. Regis, Empire and Helena formations of the Middle Proterozoic Belt Supergroup, northwestern Montana, *in* Link, P. K., ed., Geologic Guidebook to the Belt-Purcell Supergroup, Glacier National Park and vicinity, Montana and adjacent Canada: Belt Symposium III Field Trip Guidebook, Belt Association, Spokane, Washington, p. 21-51.

Winston, Don, McGee, David, and Quattlebaum, David, 1986, Stratigraphy and sedimentology of the Bonner Formation, middle Proterozoic Belt Supergroup, western Montana, *in* Roberts, S.M., ed., Belt Supergroup: A Guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 182-195.

Winston, Don, and Woods, Marvin, 1986, Road Log No. 3: A traverse across the northern Belt basin from East Glacier Park, Montana to Bonners Ferry Idaho, *in* Roberts, S.M., ed., Belt Supergroup: A Guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 47-68.



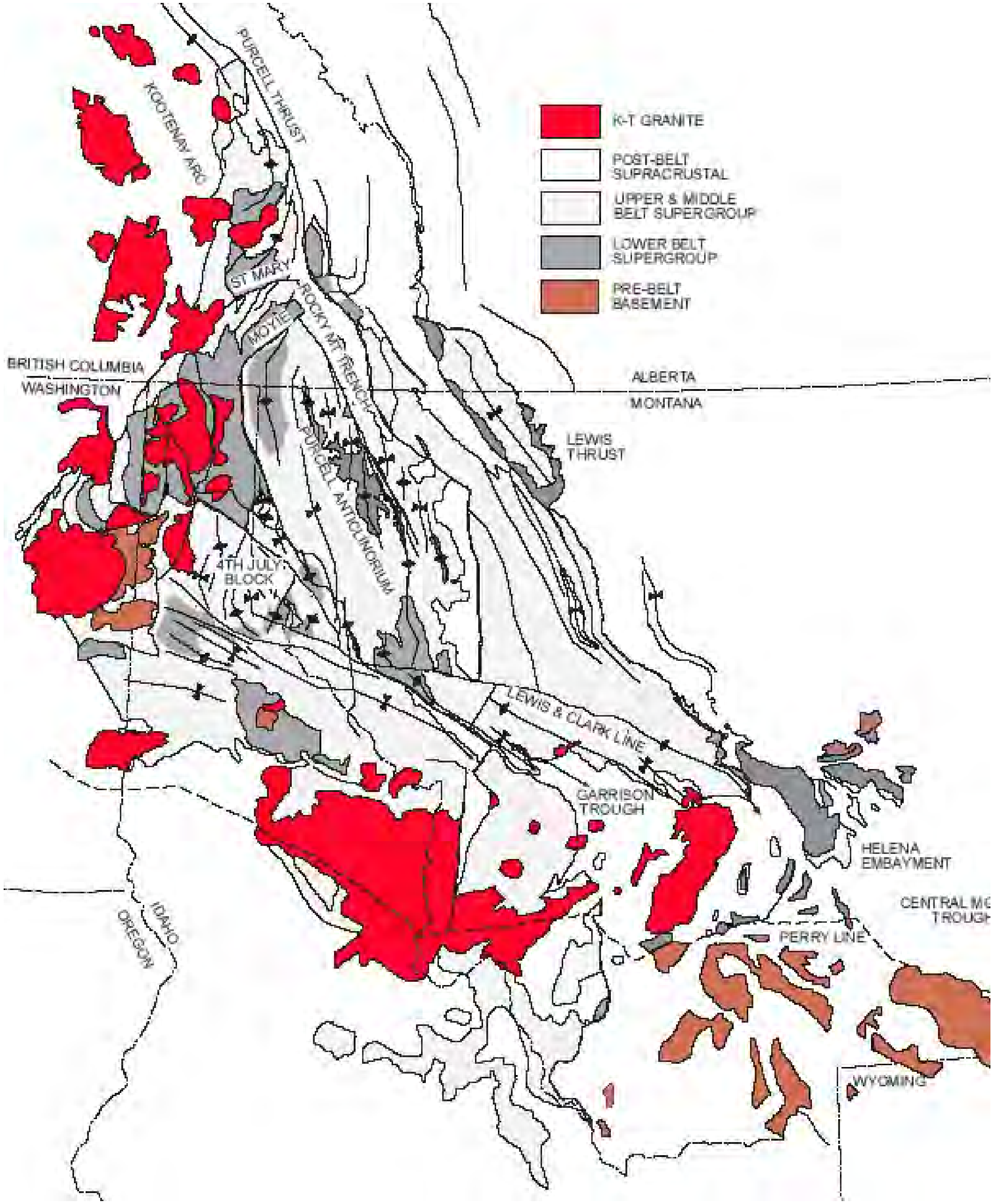


Figure 1. Tectonic map of Belt basin. Compiled from USGS 1X2 degree geologic maps and Price (1981), Link et al. (1993), and Reed et al. (1999).

BELT BASIN: A TRISKELE RIFT JUNCTION, ROCKY MOUNTAINS, CANADA AND USA

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ABSTRACT

A paleocontinental reconstruction that connects the Siberian craton to western North America predicts that the Mesoproterozoic Belt basin of the Rocky Mountains and the correlative Udzha basin of Siberia formed at a three-armed intracontinental rift. The three arms did not meet exactly at a point, but rather intersected one another to enclose a triangular rift basin resembling a surprisingly symmetrical, interlocking *triskele* junction. The intersections of the rift arms explain thickness variations in the Belt Supergroup. The *triskele* junction may be explained in terms of crack propagation on a brittle spherical shell. The *triskele* model does not require fracturing of a thermal dome and explains why the initial deposits of the Belt basin were rift-bound, deep-water turbidites engorged by syndepositional mafic sills.

INTRODUCTION

The Belt basin (Fig. 1) dominates the geology of the northern Rocky Mountains of Montana and parts of Idaho, Washington, British Columbia, and Alberta (Harrison, 1972; Winston, 1986; Lydon, 2000). The tectonic origin of this mineral-rich Mesoproterozoic basin has long been debated; it has been interpreted as a continental-margin miogeocline, a lake basin in an intracratonic rift, a mega-impact structure, a foreland basin, a paleo-hot spot, and an oceanic remnant basin (cf. Höy et al., 2000; Link, 1993). Here I suggest that the basin formed where three intracontinental rifts branched in a pattern resembling a *triskele*, an interlocking triangular design popular in Celtic folklore (Fig. 2 inset). It is like a three-armed rift, except that the rifts do not meet at a common central point, but rather, each rift abuts one of its neighbors, outlining a central triangular region. Such rift basins occur in modern settings, for example, where the East African rift intersects the Red Sea and Gulf of Aden in the Afar triangle.

SIBERIAN CONNECTION

Late Proterozoic to Early Cambrian rifts truncated the western edge of the Belt basin during the breakup of the Precambrian supercontinent Rodinia and opening of a passive continental margin along the western side of North America (Stewart, 1972; Hoffman, 1991; Burchfiel et al., 1992; Ross et al., 1992). Sears and Price (1978, 2003) proposed that the Siberian craton rifted from western North America, and that the Udzha-Khastakh basin of the northeastern Siberian craton represents the missing western continuation of the Belt basin. A detailed paleocontinental reconstruction by Sears et al. (2004) aligns the Udzha trough of Siberia with the restored Moyie fault of southern British Columbia and the Khastakh trough of Siberia with the restored Perry line (Fig. 2). The Udzha trough zig-zags across the eastern Siberian craton to the deep Sette-Daban trough of southeastern Siberia. The Khastakh trough abuts the Udzha trough in northeastern Siberia.

The Udzha trough may have captured sediment flow from a large, low relief continental region and shunted it into the Belt basin from the west (Sears, 2006). Cressman (1989) showed that the point source of sediment fans in the lower Belt Supergroup entered the Belt basin near Spokane from a missing continent; the position of that point source exactly matches the position of the Udzha trough in the reconstruction. Sears et al. (2004) proposed that rift tectonics shifted sediment flow from the Udzha to the Khastakh troughs to produce overlapping deltaic and alluvial fans in the Belt basin.

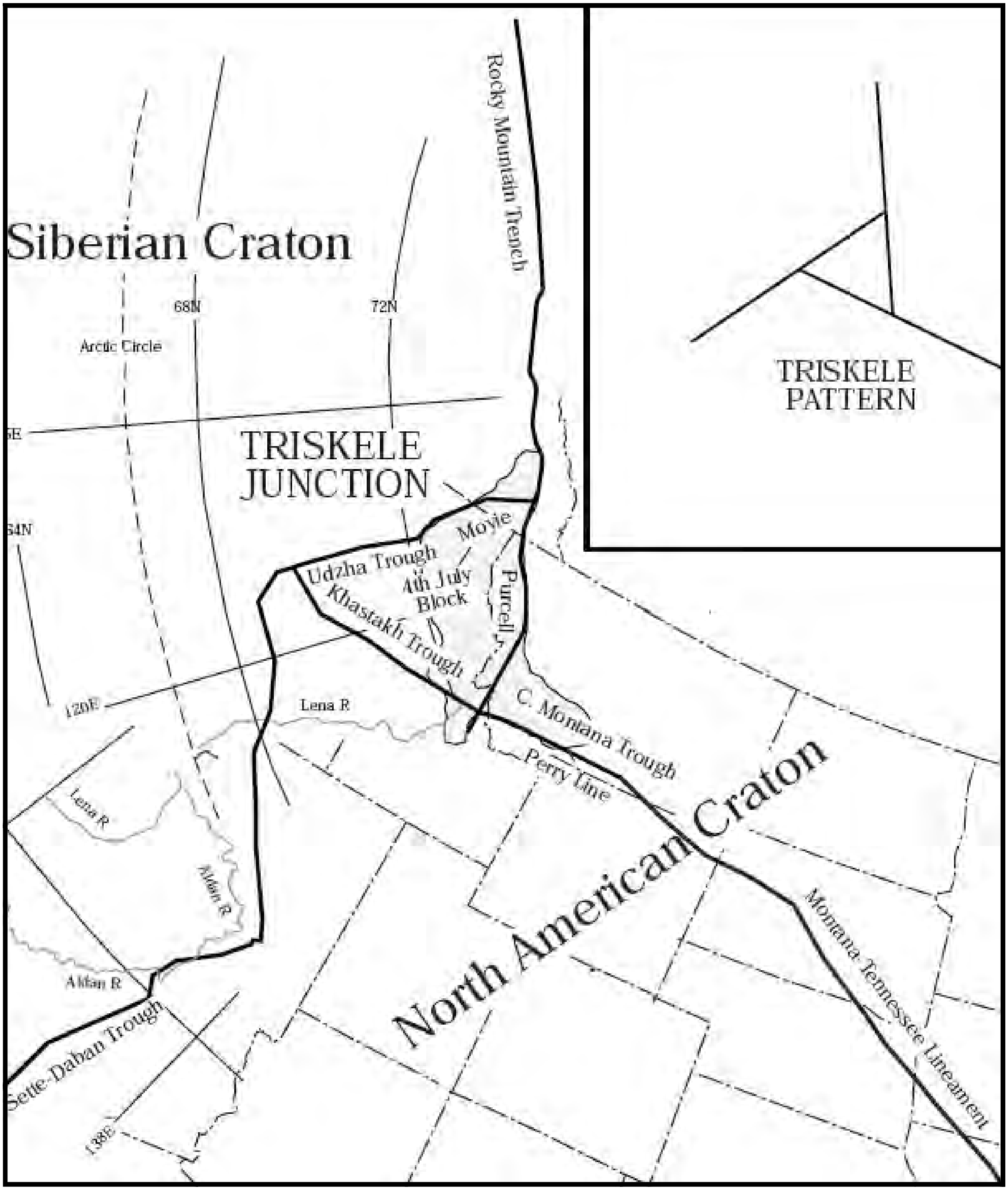


Figure 2. Siberian-North American paleocontinental reconstruction, after Sears and Price (1978, 2003) and Sears et al. (2005). Inset shows example of *triskele* pattern. Note that intersection of continental rift trends form a *triskele* junction in the Belt basin, with 4th of July block in center. See Figure 4 for more detail.

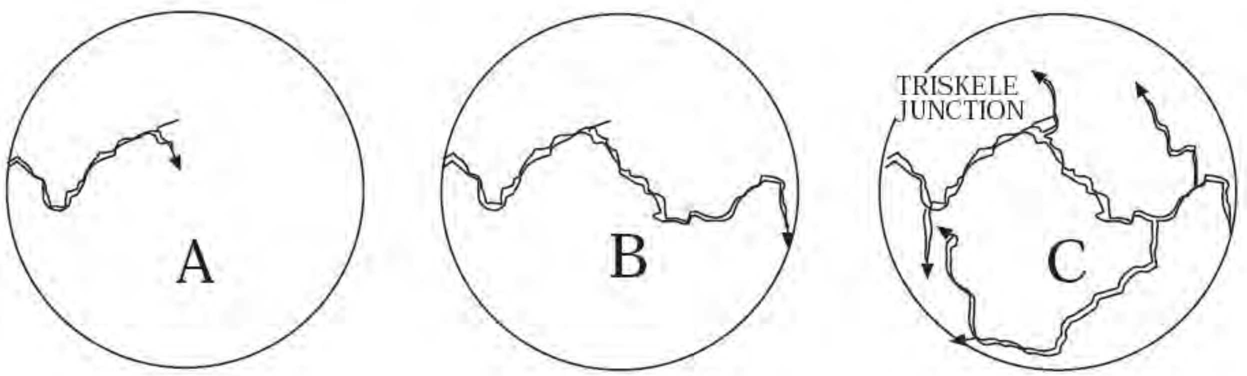


Figure 3. Line drawings of crack propagation on drying spherical clay shell. A&B: Master crack spontaneously zig-zags across shell with edge-lengths related to thickness and strength of clay shell. C:Branch cracks propagate from near bends in master crack. These also spontaneously bend to define polygons. Branch cracks may develop complex triangular *triskele* junctions very much like Belt basin.

Triskele junction

On the paleocontinental reconstruction, three continental-scale rift systems intersect one another orthogonally in a *triskele* pattern to outline the Belt basin. Each rift system is over 2000 km long. The Rocky Mountain trench is straight for 2600 km, from Yukon Territory to western Montana, where it intersects the Montana-Tennessee lineament near the intersection of Winston's (1986) Townsend and Perry lines. Cook and Van der Veldon (1993) showed that the trench coincides with a Proterozoic rift structure for much of its length in Canada. The Montana-Tennessee lineament (Hatcher et al., 1987; Paulsen and Marshak, 1994; Marshak et al, 2000) curves gently for 2600 km across the mid-continent from Tennessee to Montana and continues across the Siberian connection to the Khastakh trough, where it abuts the Udzha trough. The Sette-Daban-Udzha-Moyie rift parallels a Proterozoic basement structure for 2000 km from southeastern Siberia to northeastern Siberia (Kosygin and Parvenof, 1975) and along the Moyie fault to southeastern British Columbia, where it abuts the Rocky Mountain trench.

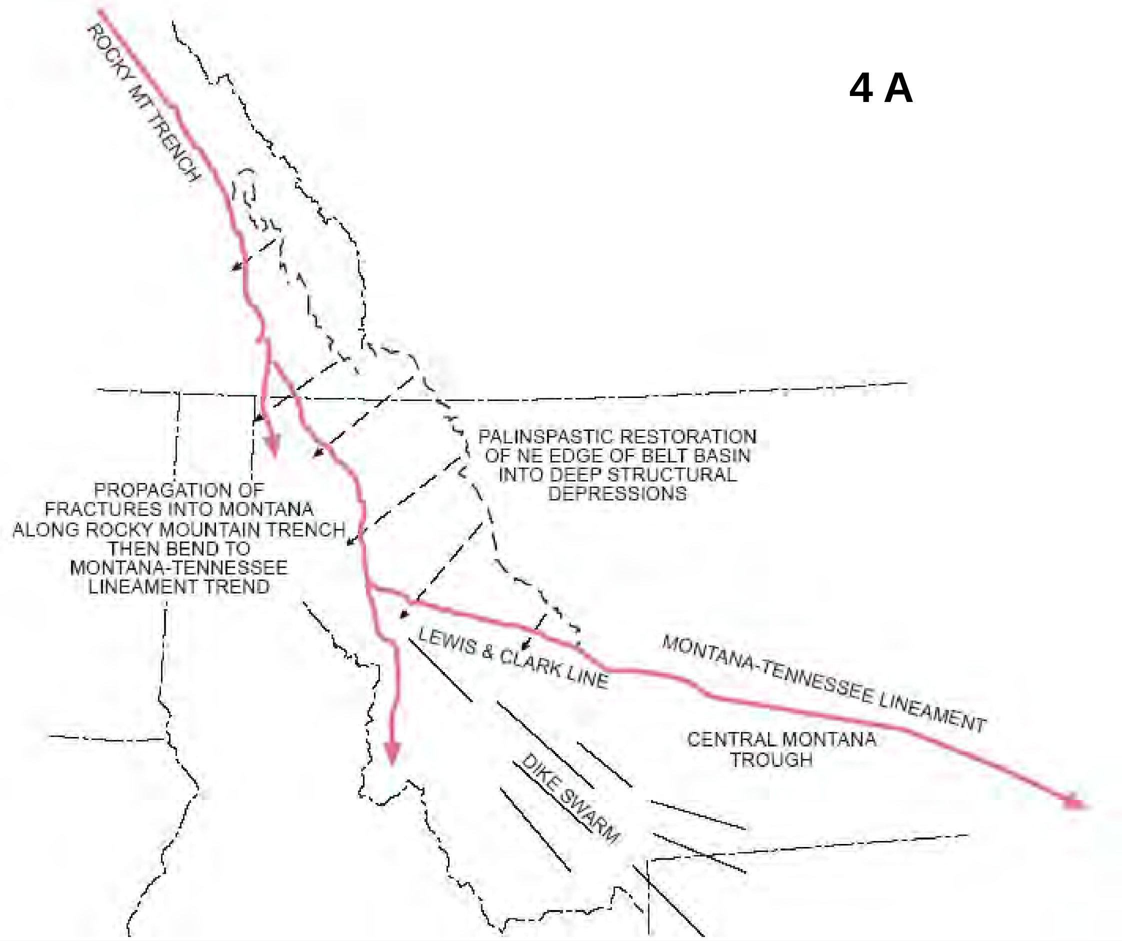
Experimental formation of *triskele* junctions

The mechanism typically invoked for a triple-rift junction calls for stretching over a broad crustal dome (Burke and Dewey, 1973). The dome is commonly inferred to develop above a rising mantle hot-spot plume (Ernst and Buchan, 2001). However, drainage would tend to flow away from such a dome; it seems, therefore, that it would be difficult for a rift basin on the crest of a dome to capture enough sediment to rapidly fill a deep Belt basin.

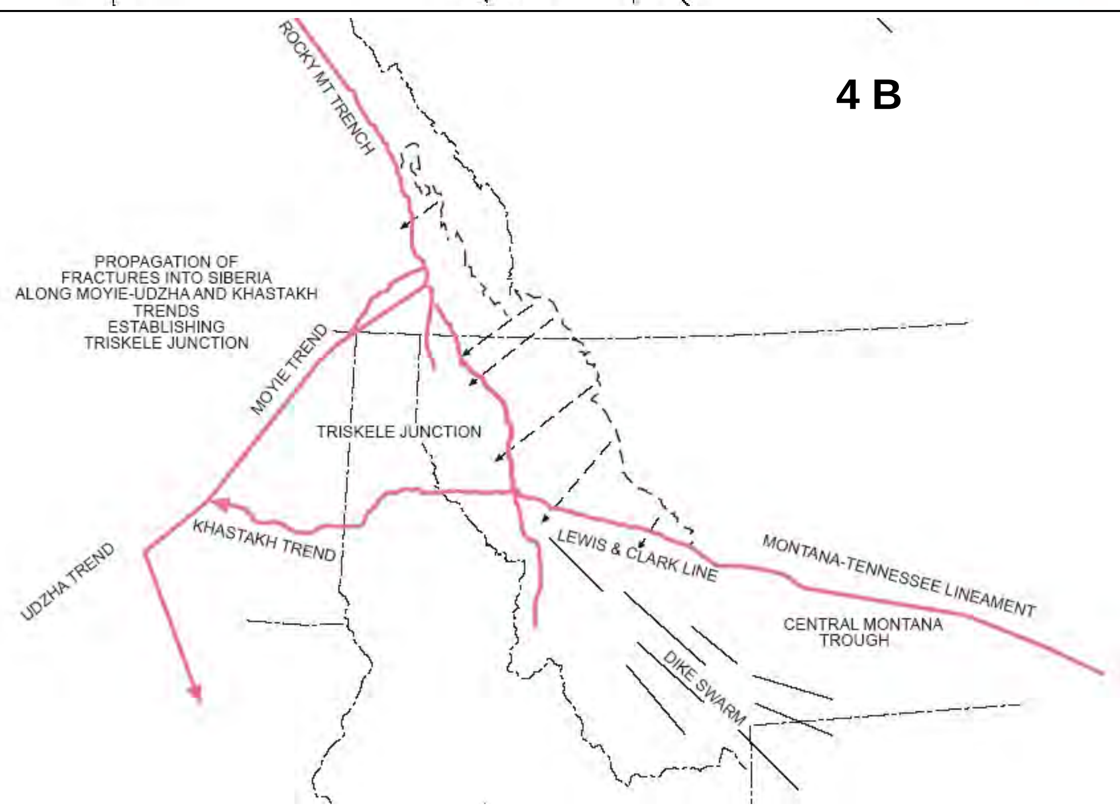
Experiments with drying clay shells provide a different concept for the formation of triple-rift junctions. A master crack will zig-zag across the shell in segments whose lengths are related to the thickness and strength of the clay (Fig. 3 A, B). Branch cracks will then propagate at the bends in the master crack to form triple-crack junctions. If a branch crack nucleates at some distance from a bend it may enclose a triangle in an interlocking *triskele* design. (Fig. 3 C).

The cracks form due to uniform tension in the drying clay shell. Stress is concentrated at the tip of the master crack, which enables it to propagate. As it propagates, it releases strain energy stored on either side of the crack. The tip bends so as to resolve strain that was not released along its initial trajectory and the crack continues to propagate. Stress then concentrates at the bends and initiates new cracks. Ideally, the new cracks would initiate exactly at the bends in the master crack, but if the segments of the master crack are somewhat irregular or the shell is not uniform, a new crack may miss the bend, and a complex triangular branch

4 A


ROCKY MT TRENCH
PALINSPASTIC RESTORATION OF NE EDGE OF BELT BASIN INTO DEEP STRUCTURAL DEPRESSIONS
PROPAGATION OF FRACTURES INTO MONTANA ALONG ROCKY MOUNTAIN TRENCH THEN BEND TO MONTANA-TENNESSEE LINEAMENT TREND
LEWIS & CLARK LINE
MONTANA-TENNESSEE LINEAMENT
CENTRAL MONTANA TROUGH
DIKE SWARM

4 B


ROCKY MT TRENCH
PROPAGATION OF FRACTURES INTO SIBERIA ALONG MOYIE-UDZHA AND KHASTAKH TRENDS ESTABLISHING TRISKELE JUNCTION
MOYIE TREND
TRISKELE JUNCTION
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UDZHA TREND
LEWIS & CLARK LINE
MONTANA-TENNESSEE LINEAMENT
CENTRAL MONTANA TROUGH
DIKE SWARM

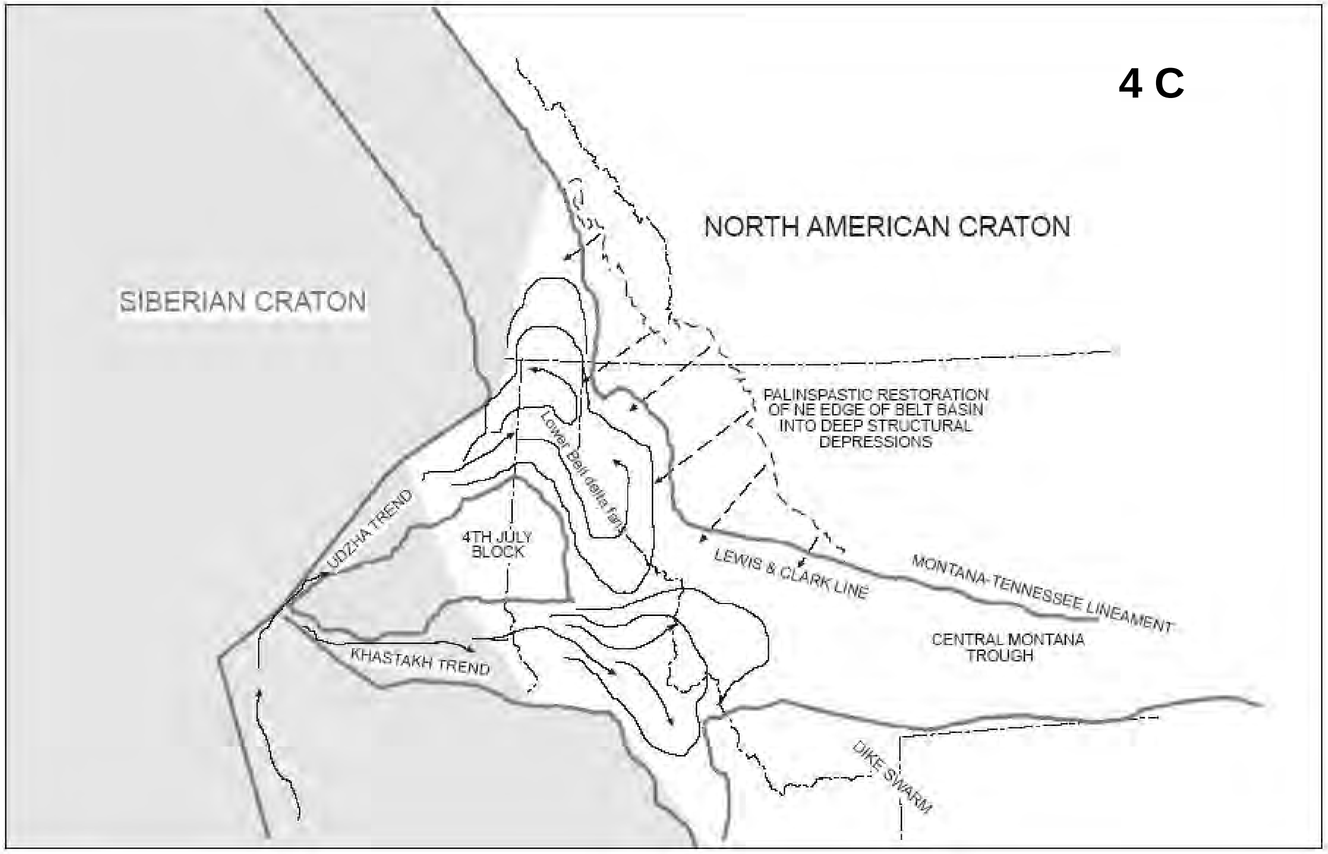


Figure 4. (opposite and above) Model for formation of Belt basin at *triskele* junction. Leading edge of Belt basin restored to deep structural depressions west of Rocky Mountain trench and south of Lewis and Clark line. See Price and Sears (2000) and text for more detail on restoration. A: Fracture propagates along Rocky Mountain trench to western Montana, then bifurcates into south trend and SSE trend along Montana-Tennessee lineament. Dike swarm intrudes SW Montana and adjacent Wyoming. B: Fracture branches to SW along Myie-Udzha trend, and from Lewis and Clark line west to Khastakh trend. Each pair of trends intersects orthogonally. At this stage, the fractures have not yet opened into rifts. C: Fractures open into rift grabens. Udzha and Khastakh troughs capture sediment flux from large continental region to input points in western Belt basin. Sediment fans split around Udzha-Khastakh interfluve and Fourth of July block. Siberian craton area shown in pink rifted away from North America in late Proterozoic to Early Cambrian.

will form a *triskele* junction. The cracks are tensile fractures; the new cracks must initiate orthogonally to the master crack because it constitutes a free surface - a principal stress plane – and tensile fractures parallel the principal stress direction, which must meet such a free surface orthogonally.

Formation of the Belt *triskele* junction

I suggest that the fractures that opened the Belt basin were lithospheric tension cracks that evolved into rift grabens. They are part of a continental-scale fracture tessellation of Mesoproterozoic age (Sears, 2001; Sears et al., 2005). In places, the fractures parallel dike swarms, which represent magma-filled tension cracks. The Belt fractures may therefore be analogous to the tension cracks in the drying clay shells. They may have resulted from uniform uplift and stretching of the lithosphere due to thermal expansion of insulated sub-lithospheric mantle (cf. Hoffman, 1989; Sears et al., 2005).

The Rocky Mountain trench, Montana-Tennesee lineament, and Moyie-Udzha trend comprise the three intersecting Belt fractures. Like the clay cracks, each fracture intersects its neighbors orthogonally. Figure 4 shows how they may have formed.

The Belt basin was displaced eastward in the Rocky Mountain overthrust belt from middle Jurassic through late Paleocene time. Price and Sears (2000) presented a map that restored the basin back to a possible pre-thrust position. That map was based on a dozen detailed balanced and restored structural cross-sections. Figure 4 modifies the Price and Sears (2000) reconstruction by removing the effects of large-scale Neoproterozoic and Early Cambrian rifting (cf. Price, 1981).

Figure 4A restores the leading northeastern edge of the Belt basin into deep structural depressions west of the Rocky Mountain trench and south of the Lewis and Clark line. The Lewis thrust plate now at the Canada-United States boundary restores to the deep Libby trough in northwestern Montana (Price and Sears, 2000).

The Rocky Mountain trench may represent the master crack that propagated SE into western Montana where it bifurcated into a crack that extended to the south and a radiating Mesoproterozoic dike swarm in southwestern Montana and adjacent Wyoming. The fracture may have then turned at about 120 degrees and propagated ESE along the Montana-Tennessee lineament. Later, the Moyie-Udzha crack may have branched orthogonally from the Rocky Mountain trench trend in southern British Columbia, to follow the older Vulcan-Hapshan basement suture (Fig. 4B).

After the cracks formed, they widened to form complex grabens (Fig. 4C). The deepest opened along the Rocky Mountain trench trend. Perhaps the Siberian craton block shifted relative to North America so that the Udzha acted as a transform fault. The Udzha trend may have delivered fine sediment from a large continental region into the Belt basin (cf. Price, 1964).

Opening of the grabens along the fracture trends could provide accommodation space for rapidly deposited Lower Belt Supergroup turbidite, and also provide pathways for injection of mafic sills from the upper mantle into the thick, unlithified sediments. The model does not require a hot-spot dome to initiate the process; it is not illogical to have transported sediment toward the opening basin while magma was being generated by decompression melting. However, the rift shoulders likely rose in response to isostatic unloading and to thermal expansion due to injection of the magma. This may have restricted sediment input to knick points in the Udzha and Khastakh troughs.

References cited

Burke, K., and Dewey, J.F, 1973, Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks: Journal of Geology, v. 81, p. 406-433.

Burchfiel, B.C., Cowan, D.S, and Davis, G.A., 1992, Tectonic overview of the Cordilleran orogen in the western United States, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen: Conterminous US: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-3, p. 407-478.

Cook, F.A., and Van der Velden, A.J., 1993, Proterozoic crustal transition beneath the Western Canada sedimentary basin: Geology, v. 21, p. 785-788.

Cressman, E. R., 1989, Reconnaissance stratigraphy of the Prichard Formation (Middle Proterozoic) near Plains, Sanders County, Montana: U.S. Geological Survey Professional Paper 1490, 80 p.

Ernst, R.E., and Buchan, K.L., 2001, large mafic magmatic events through time and links to mantle-plume heads, *in* Ernst, R.E., and Buchan, K.L., eds., Mantle plumes: Their identification through time: Geological Society of America, Special Paper 352, p. 483-566.

Harrison, J.E., 1972. Precambrian Belt basin of the northwestern United States, its geometry, sedimentation, and copper occurrences: Geological Society of America Bulletin 83, 1215-1240.

Hatcher, R.D., Jr., Zietz, I., and Litehiser, J.J., 1987, Crustal subdivisions of the eastern and central United States and a seismic boundary hypothesis for eastern seismicity: Geology, v. 15, p. 528-532.

Hoffman, P. J., 1991, Did the breakout of Laurentia turn Gondwanaland inside-out?: Science, v. 252, p. 1409-1412.

Hoffman, P.F., 1989, Speculations on Laurentia's first gigayear (2.0 to 1.0 Ga): Geology, v. 17, p. 135-139.

Höy, T., Anderson, D., Turner, R.J.W., and Leitch, C.H.B., 2000, Tectonic, magmatic, and metallogenic history of the early synrift phase of the Purcell basin, southeastern British Columbia, Chapter 4 *in* Lydon, J.W., Höy, T., Slack, J.F., and Knapp, M.E., eds., The Geological Environment of the Sullivan Deposit, British Columbia: Geological Association of Canada, Mineral Deposits Division Special Publication No. 1, p. 32-60.

Kosygin, Y. U., and Parvenof, L. M., 1975, Structural evolution of eastern Siberia and adjacent areas: American Journal of Science, v. 275-A.

Link, P. K., ed., 1993, Middle and Late Proterozoic stratified rocks of western US Cordillera, Colorado Plateau, Basin and Range province, *in* Reed, J. C., et al., eds., Precambrian: Continental U.S.: Boulder, Colorado, Geological Society of America, Geology of North America, v. C-2, p. 463-595.

Lydon, J.W., 2000, A synopsis of the current understanding of the geological environment of the Sullivan deposit, Chapter 3 *in* Lydon, J.W., Höy, T., Slack, J.F., and Knapp, M.E., eds., The Geological Environment of the Sullivan Deposit, British Columbia: Geological Association of Canada, Mineral Deposits Division Special Publication No. 1, p. 12-31.

Marshak, S., Karlstrom, K., and Timmons, J.M., 2000, Inversion of Proterozoic extensional faults: An explanation for the pattern of Laramide and ancestral Rockies intracratonic deformation, United States: Geology, v. 28, p. 735-738.

Paulsen, T., and Marshak, S., 1994, Cratonic weak zone in the U.S. continental interior: The Dakota-Carolina corridor: Geology, v. 22, p. 15-18.

Price, R.A., 1981. The Cordilleran thrust and fold belt in the southern Canadian Rocky Mountains, *in* McClay, K.R., and Price, N.J., eds., Thrust and nappe tectonics: Geological Society of London Special Publication 9, 427-448.

Price, R. A., 1964, The Precambrian Purcell system in the Rocky Mountains of southern Alberta and British Columbia: Bulletin of Canadian Petroleum Geology, v. 12, Special Issue, p. 399-426.

Price, R.A., and Sears, J.W., 2000, A preliminary palinspastic map of the Mesoproterozoic Belt-Purcell Supergroup, Canada and USA: Implications for the tectonic setting and structural evolution of the Purcell anticlinorium and the Sullivan deposit, Chapter 5 *in* Lydon, J.W., Höy, T., Slack, J.F., and Knapp, M.E., eds., The Geological Environment of the Sullivan Deposit, British Columbia: Geological Association of Canada, Mineral Deposits Division Special Publication No. 1, p. 61-81.

Ross, G. M., Parrish, R. R., and Winston, D., 1992, Provenance and U-Pb geochronology of the Mesoproterozoic Belt Supergroup (northwestern United States): Implications for age of deposition and pre-Panthalassa plate reconstructions: Earth and Planetary Science Letters, v. 113, p. 57-76.

Sears, J.W., 2006, Destabilization of a Proterozoic epi-continental pediment by rifting: A model for the Belt-Purcell basin, North America: *in* Link P.K., ed., Proceedings of Belt IV Symposium: SEPM Special Paper, in press

(June 2006).

Sears, J.W., 2001, Icosahedral fracture tessellation of early Mesoproterozoic Laurentia: Geology, v. 29, no. 4, p. 227-230.

Sears, J.W., and Price, R.A., 2003, Tightening the Siberian connection to western Laurentia: Geological Society of America Bulletin, v. 115, p. 943-953.

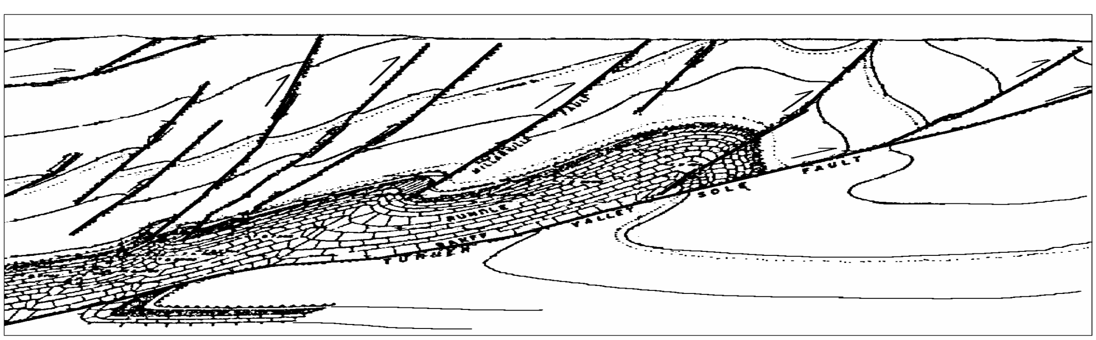
Sears, J.W., and Price, R.A., 1978, The Siberian connection: A case for the Precambrian separation of the North American and Siberian cratons: Geology, v. 6, p. 267-270.

Sears, J.W., St. George, G.M., and Winne, J.C., 2005, Continental rift systems and anorogenic magmatism: LITHOS.

Sears, J.W., Price, R.A., and Khudoley, A.K., 2004, Linking the Mesoproterozoic Belt-Purcell and Udzha basins across the west Laurentia-Siberia connection: Precambrian Research, v. 129, p. 291-308.

Stewart, J. H., 1972, Initial deposits of the Cordilleran geosyncline: Evidence of late Precambrian (<850 m.y.) continental separation: Geological Society of America Bulletin, v. 83, p. 1345-1360.

Winston, D., 1986. Stratigraphic correlation and nomenclature of the Middle Proterozoic Belt Supergroup, Montana, Idaho, and Washington, *in* Roberts, S.M., ed., Belt Supergroup: Montana Bureau Mines and Geology Special Paper 94, 69-84.



PLEISTOCENE GLACIAL DEPOSITS IN THE LIBBY AND LAKE RIVER VALLEY AREAS, LINCOLN COUNTY, MONTANA

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The glacial geology of the Kootenai River valley and its large tributaries in Lincoln County, Montana, has been studied in only a cursory manner. During the last glacial advance in the area, about 15,000—20,000 ^{14}C yr BP (16,300—22,000 cal. yr ago), the southern margin of the Cordilleran Ice Sheet was located near the southern end of the Cabinet Mountains (fig. 1). Valley glaciers in the Cabinet Mountains merged with the continental sheet. Although multiple glaciations are understood to have occurred regionally, the work in the area is not sufficient to show this. Glacial limits in the area are mostly based on field work by Alden (1953), which are shown with minor revisions by Richmond and others (1965), Richmond (1986), and Waitt and Thorson (1983). Different glacial limits, mostly more expanded, are shown by Locke and Smith (2004), based on map and aerial photo interpretation and unpublished student work at Montana State University, Bozeman. The ice extents shown on Figure 1 are modified from those of Alden (1953) and Locke and Smith (2004). The ice extent and glacier history are known only in a general sense. Because the mapping of valley glaciers and nunataks is especially sketchy, their depiction by a stippled pattern in Figure 1 is only diagrammatic.

The topography along the semi-circular route of the Kootenai River valley, the intervening Cabinet Mountains, and the north-flowing Lake and Libby Creeks affected glacier flow directions. The east Kootenai glacier of the Cordilleran ice sheet flowed south-southwest down the Kootenai River from the north-northeast to 15-20 miles south of Libby, into the Libby Creek drainage. The west Kootenai glacier flowed south-southeast, up the Kootenai River valley near Troy, up the Lake Creek valley, across the divide into the Bull River valley, into glacial Lake Missoula. The topography of the Cabinet Mountains and the area south and southeast of Libby encouraged ponding of small glacial lakes along the southern margin of the ice sheet during both glacial advance and glacial retreat. Terminal and lateral moraines from the valley glaciers are not extensive. Apparently most of the valley glaciers merged with the Cordilleran ice sheet during the last glacial stage, so prominent terminal moraines were not formed. Although till does exist throughout the area, most deposits are thin, a few to a few tens of feet. The continental ice sheet deposits in Lincoln County are thin compared to valleys containing the Purcell Trench lobe (Figure 1) or the Flathead lobe in the Flathead Valley, where tills reach thicknesses greater than 200 feet.

For his classic work on the glacial geology of western Montana published in 1953, the USGS geologist W. C. Alden visited many localities during 1938 in the Kootenai River, Fischer River, Bull River, and Lake Creek drainages in Montana and part of the Lake Pend Oreille drainage in Idaho. Alden (1953) described some of the valley fills as containing thick glaciolacustrine sequences (Figure 2). The sequences include glacial lake deposits apparently overridden by advancing glaciers, till, overlying glaciolacustrine sediments deposited during retreat, and post-glacial alluvium. One of the most striking landforms in the Libby, Pipe, and Lake Creek valleys, and from Troy to Bonners Ferry along the Kootenai River, is the glaciolacustrine deposit-cored bench near the altitude of about 2,450—2,500 feet. Alden (1953) recognized these as deposits of a "glacial Lake Kootenai." Other early workers in the Lake Creek and Bull River valleys also

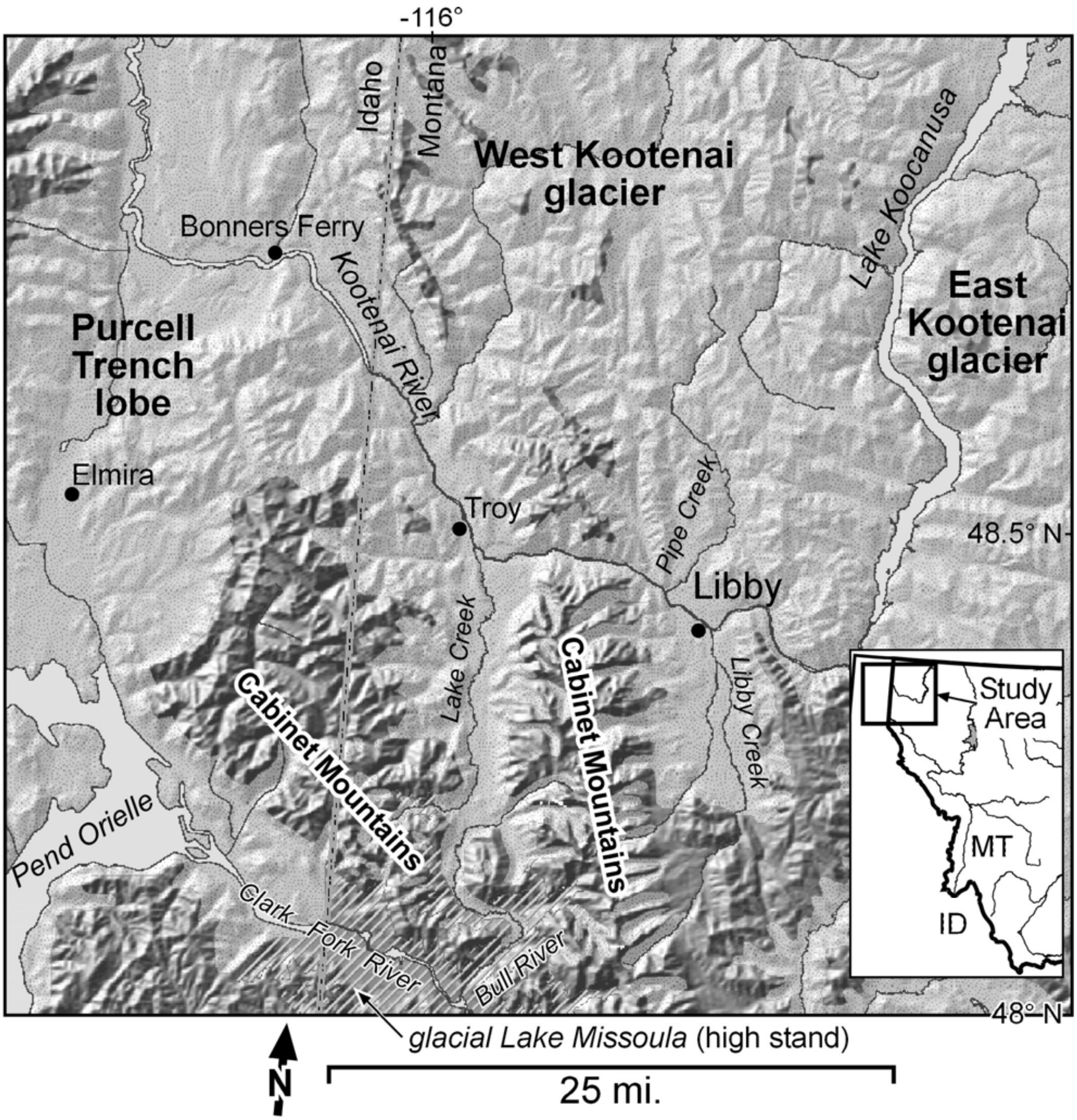


Figure 1. Location map of the study area showing approximate last-glacial maximum extent (stippled area) of the Pleistocene glaciers (modified from Alden, 1953, and Locke and Smith, 2004).

recognized the thick deposits of glaciolacustrine silt, clay, sand, and minor gravel exposed in many roadcuts and stream banks (Adkinson, 1942; English, 1942). Johns (1970) also reported on glacial Lake Kootenai.

Outcrops and well logs in the Libby and Troy areas display great thicknesses of glaciolacustrine silts; a cursory sampling shows greater than 300 feet of silty deposits in some locations. Silty sediments are interbedded with silty gravel and permeable sand and gravel, suggesting the presence of coarse water-worked deposits and till in some sections. The silt and sandy sediments are thin- to thick-bedded and do not have clay and silt couplets characteristic of strongly seasonal (varve) sediments (Alden, 1953). The irregular bed thicknesses and sandy to gravelly interbeds suggest deposition in glaciolacustrine environments proximal to sedi-

Figure 2. Photograph looking east of thin to thick beds of glaciolacustrine silt and fine sand in the Lake Creek valley; 5’ 2”-tall Vanna White imitator for scale; location is west of Schoolhouse Lake in T. 31 N., R. 33 W., Section 29, about 3 mi SSE of Troy.

ment inputs. Many wells in the valley produce water from interbeds of sand and gravel and from sand and gravel directly overlying bedrock, possibly representing interglacial alluvium or outwash deposited in front of the advancing glaciers.

Alden (1953) described the evidence for an ice- or sediment-dammed glacial Lake Kootenai that spilled water into the Bull River drainage (Figure 3). The lake stood for a significant time, as evidenced by the thick accumulation of glaciolacustrine sediments, dammed along the Kootenai River near Bonners Ferry, Idaho. Alden noted that it stood much lower than glacial Lake Missoula (which had a maximum altitude of about 4,200 feet), and must have been more recent, as its outlet would have been lower than the larger lake to the south. The lake was likely impounded by ice of the Purcell Trench lobe of the Cordilleran ice sheet. As the Purcell Trench lobe retreated northward from the Lake Pend Oreille area, the site of the glacial Lake Missoula dam, water in the Kootenai drainage could not flow northward, and may have spilled across the divide near Bull Lake into the Clark Fork River. Another southern route from the lake would be near Elmira, Idaho (Figure 3). Johns (1970) thought that Lake Kootenai did not drain catastrophically, suggesting that it lowered by the erosion of its sill through glacial till.

REFERENCES

Adkinson, B.W., 1942, The alpine glacial history and post-glacial adjustments of a section of the Cabinet Mountains, Montana: Ph.D. dissertation, Clark University, 115 p.

Alden, W. C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geological Survey Professional Paper 231, 200 p.

English, V.H., 1942, Cordilleran glaciation in a section of the Cabinet Mountains, Montana: Ph.D. dissertation, Clark University, 123 p.

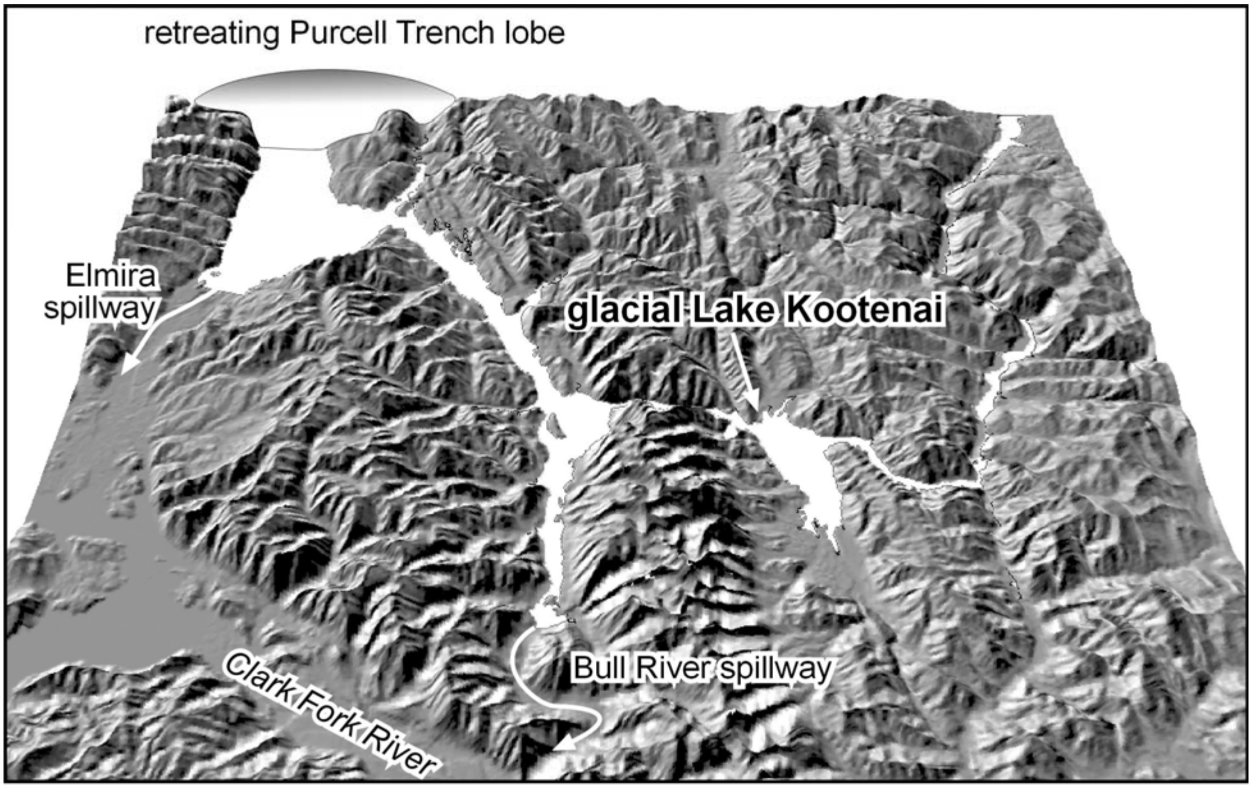


Figure 3. Perspective diagram showing topography of the area with glacial Lake Kootenai shown at an altitude of 2,500 feet.

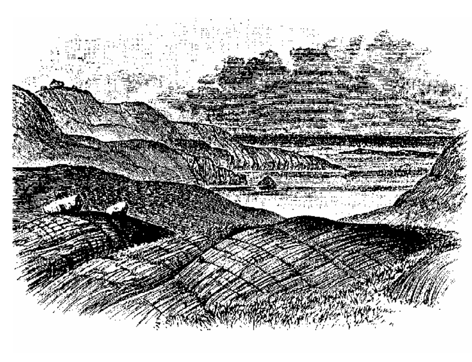
Johns, W. M., 1970, Geology and mineral deposits of Lincoln and Flathead counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p.

Locke, W., and Smith, L.N., 2004, Pleistocene mountain glaciation in Montana, USA: *in* Ehlers, J., and Gibbard, P. L., eds., Extent and Chronology of Glaciations: Elsevier, Amsterdam, p. 117–121.

Richmond, G. M., 1986, Tentative correlation of deposits of the Cordilleran ice-sheet in the northern Rocky Mountains: Quaternary Science Reviews, v. 5, p. 129–144.

Richmond G.M., Fryxell, R., Neff, G.E., and Weis, P.L., 1965, The Cordilleran ice sheet of the Northern Rocky Mountains, and related Quaternary history of the Columbia Plateau: *in* Wright, H.E., Jr., and Frey, D.G., eds., The Quaternary of the United States: Princeton University Press, Princeton, New Jersey, p. 231-254.

Waitt, R.B., and Thorson, R.M., 1983, The Cordilleran Ice Sheet in Washington, Idaho, and Montana: *in* Porter, S.C., ed., Late-Quaternary Environments of the United States 1, The Late Pleistocene: University of Minnesota Press, Minneapolis, Minnesota, p. 53–70.



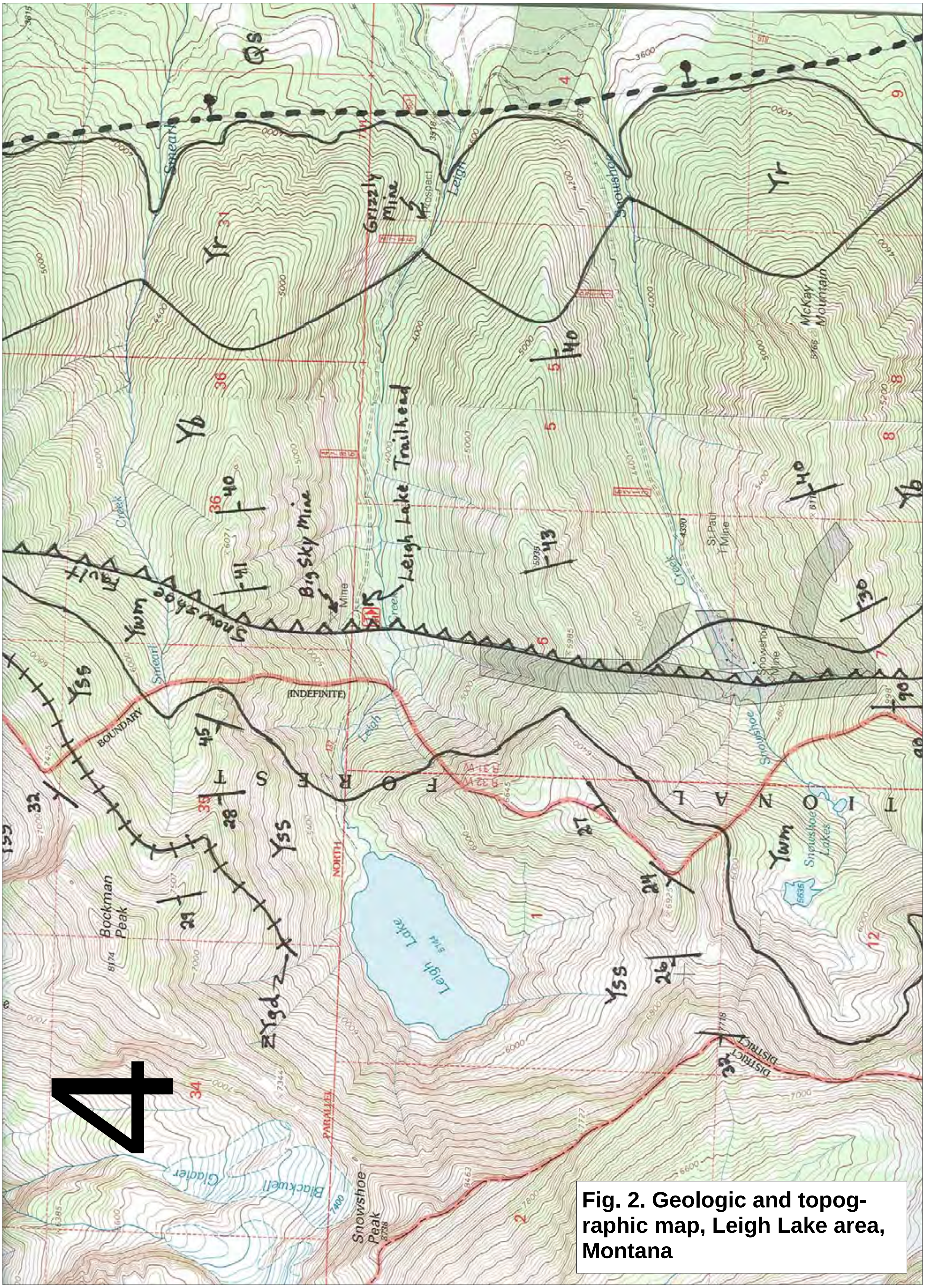


Fig. 2. Geologic and topographic map, Leigh Lake area, Montana

THE TRIP TO LEIGH LAKE: BELT ROCKS, BIG FAULTS AND SMALL MINES IN THE HIGH CABINETS, NORTHWEST MONTANA

Phyllis Hargrave, Bruce Cox, Jeff Lonn
Geologists, Butte and Missoula, Montana

Rumor, innuendo and cursory review of the geologic literature together suggest that the Leigh Creek valley of northwestern Montana affords a variety of unusual geologic features in a spectacular alpine setting. In the spirit of many TRGS field trips, the excursion outlined below is intended to be leaderless, i.e. the organizers have assembled the geology from previous workers, the roads and trails are well-marked and the rocks should provide lots for discussion.

Leigh Creek tumbles from high glacial terrain at the northern end of the Cabinet Mountains and flows into Cherry Creek, a major tributary of the Kootenai River. Leigh Lake occupies a deep cirque basin at the head of the valley and is surrounded by the highest peaks in the Cabinets.

As you travel up the Leigh Creek valley you are traversing down section through north-striking, east-dipping Ravalli Group rocks (Yr), first through the Revett Formation and then into the Burke Formation. The Revett is divided into 3 informal members: two quartzite intervals separated by a finer-grained siltite and argillite unit. The quartzite is feldspathic, medium-grained, thick-bedded, and purplish-gray, and contains both flat laminations and trough cross beds. The quartzite members host the famous stratabound copper-silver deposits of Spar Lake, Rock Creek, and Montanore. Total thickness of the Revett is about 2000 feet. The underlying Burke Formation forms the prominent cliffs above the trailhead. The Burke is finer-grained than the Revett, containing mostly green and purple siltite to argillite couplets with abundant ripple marks and mud cracks, and greenish-gray fine-grained quartzite and siltite. Total thickness of the Burke Formation is about 4000 feet (descriptions from Harrison and Cressman, 1993).

Near the Leigh Lake trailhead, the Burke Formation is separated from the younger carbonate-bearing metasediments of the Wallace Formation (Yw) by the north-trending Snowshoe fault. The Snowshoe fault was originally mapped as a west-dipping, younger-over-older thrust fault (Wells et al., 1981; Harrison and Cressman, 1993). However, more recently, Fillipone and Yin (1994) showed that the Snowshoe fault dips east, contains steep ENE-plunging lineations, and is associated with west-verging overturned folds, and they therefore reinterpreted it as a west-directed, older-over-younger, reverse fault. This north-striking fault and several northwest-striking splays host sulfide-carbonate-quartz veins that were mined periodically through the 1960s.

Road & Trail Log

Incremental Miles	Total Miles	Refer to Figure 1

0.0 **0.0** The trip begins in the center of Libby at the junction of US Highway 2 and State Highway 37. Take Highway 2 southeast toward Kalispell.

8.0 **8.0** Cherry Creek Road 278 - turn right (southwest). Alluvium in Cherry Creek is reworked from a thick sequence of glacial outwash deposits.

3.0 **11.0** Road 867. Turn right (west). Leaving the valley floor of Cherry Creek, Road 867 traverses down-section through the Ravalli Group.

4.4 **15.4** Road 4786. Turn right (west) on the road toward Leigh Lake.

0.4 **15.8** Grizzly mine.

0.3 **16.4** Road crosses east-dipping Proterozoic sill.

1.6 **17.0** Leigh Lake trailhead. Road ends here.

Trail Miles	Elevation	Refer to Figure 2

0.0 **4200 ft.** Begin walking traverse. The Leigh Lake trail is 1.2 miles long and climbs 900 feet elevation.

0.1 **4350 ft.** Second switchback. Approximate trace of the Snowshoe fault which strikes N-S, dips steeply E and places Yr against Yw (reverse displacement). The Big Sky mine is located along the fault, 100-200 feet elevation above and northward from this switchback. Look for quartz-sulfide vein float. The trail traverses north-striking, west-dipping Wallace Formation rocks from this point westward, and you will be going upsection. The rocks immediately west of the Snowshoe fault are part of the informal middle member of the Wallace, and they are characterized by pinch and swell couplets and couples of tan-weathering dolomitic siltite and fine sand that grade upward into black argillite.

0.3 **4440 ft.** Cross into Cabinet Wilderness.

1.0 **5160 ft.** Cross lip of cirque basin. In the Cabinet Mountains, published mapping does not divide the informal middle Wallace from the upper Wallace, which Montanans would call Snowslip and Shepard Formations. But in the vicinity of the lake outlet, the distinctive pinch and swell beds of the middle Wallace give way upsection to very thinly laminated black argillite beds (Don Winston, written communication, 2005) that most Belt mappers would place in the upper Wallace member (if from Idaho) or the Snowslip Formation (if from Montana).

1.2 **5144 ft.** Shore of Leigh Lake. We can't comment on the fishing, but we will comment on the setting. Leigh Lake lies in a spectacular cirque, with Snowshoe Peak, the highest in the Cabinet Range at 8700 feet, towering 3500 feet above the lake. The dramatic alpine scenery at such low elevations is due in large part to the prodigious amounts of precipitation the Cabinet Mountains receive, which resulted in very extensive glaciation during the ice ages. Abundant snowfall continues into modern times, ensuring that frequent avalanches trim the trees that otherwise might obscure the sweeping views.

On the cirque wall on the north side of Leigh Lake, are green siltite to argillite couplets that are stratigraphically higher than the rocks at the outlet (Don Winston, written communication, 2005); this sediment type is common in the Snowslip Formation (upper Wallace). We have not yet examined the rocks further upsection, at the top of Snowshoe Peak—are they Shepard Formation equivalents? Resolution will have to wait for the next field trip.

Selected References

Fillipone, J.A., and Yin, An, 1994, Age and regional tectonic implications of Late Cretaceous thrusting and Eocene extension, Cabinet Mountains, northwest Montana and northern Idaho: Geological Society of America Bulletin, v. 106, p. 1017-1032.

Johns, W.M., 1970, Geology and Mineral Deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geol. Bull. 79, 182 pp.

Kleinkopf, M. Dean, Harrison, Jack E., And Zartman, Robert E., 1972, Aeromagnetic and Geologic Map of Part of Northwestern Montana and Northern Idaho: U.S. Geological Survey Geophysical Investigations Map GP-830, 5 pp.

REFERENCES (Cont'd. from previous page)

Wells, J.D., Lindsey, D.A., and Van Loenan, R.E., 1981, Geology of the Cabinet Mountains Wilderness, Lincoln and Sanders Counties, Montana: U.S. Geological Survey Bulletin 1501-A, p. 9-19, map scale 1:62,500.

Harrison, J.E., and Cressman, E.R., 1993, Geology of the Libby thrust belt of northwestern Montana and its implications to regional tectonics: U.S. Geological Survey Professional Paper 1524, 42 p., map scale 1:125,000.

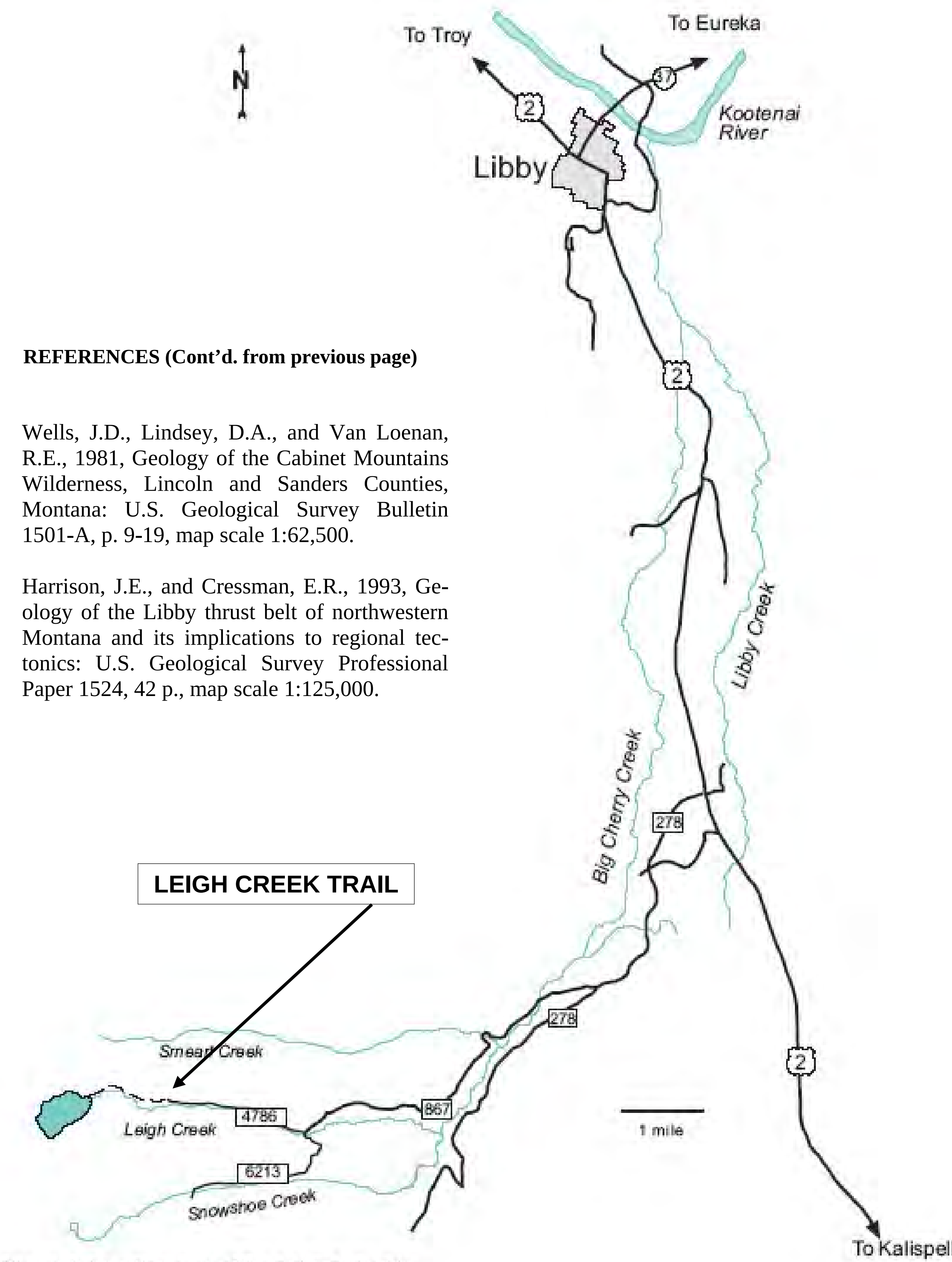
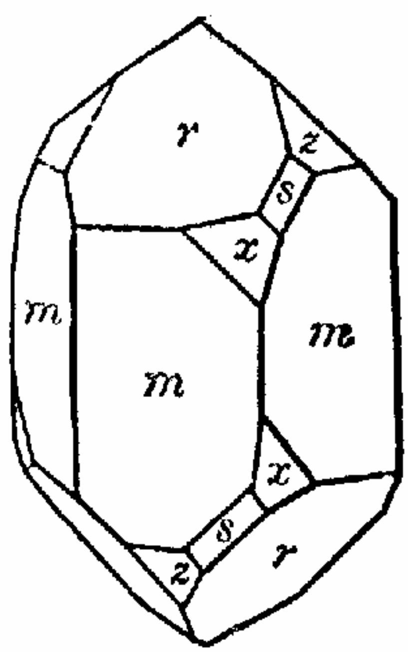


Figure 1. Location map of the Leigh Lake trip.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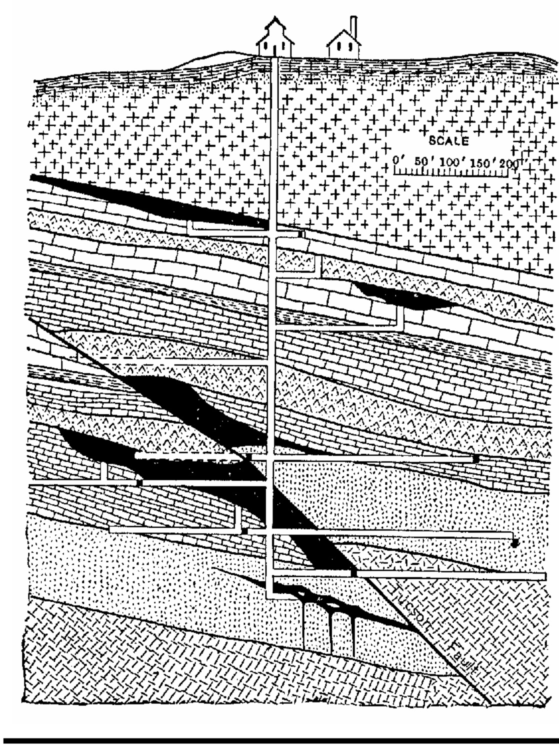
CABINET MINING DISTRICT, LINCOLN COUNTY, MONTANA
Historic Mining District Narrative

Montana State Department of Environmental Quality

HISTORIC CONTEXT

The Cabinet district, also known as West Fisher or Fisher River, is located on the eastern slope of the Cabinet Mountains near the headwaters of West Fisher Creek. Initial mineral discoveries in this remote and rugged area were an offshoot of placer mining in the neighboring Libby district to the north.

Prospectors sampled many streams along the Libby Creek valley in the early 1860s, but there was no general excitement until the summer of 1867. The camp grew quickly to 500-600 miners, then dwindled nearly as fast. By the early 1870s the town on Libby Creek was virtually deserted. It revived in 1885, however, and placering continued in the Libby district, at times sporadically, for more than 50 years (Renk, 1994).



Prospectors fanned out from the placer mines to search for lode deposits. One of the first discoveries in the Cabinet/West Fisher district was the Blacktail group, located by Don Schanck and Henry Bramlett in 1892 on Bramlett Creek. Other discoveries included the Brick and Branigan mine on Bramlett Creek and the American Kootenai mine on West Fisher Creek. Both were in operation by 1899 (Renk, 1994; Kalispell Bee, 1901).

Sedimentary rocks of the Belt series underlie most of the Cabinet/West Fisher district. Diorite sills intruded into these rocks during Precambrian or Paleozoic time, after which the rocks were uplifted and slightly deformed. Extensive mountain building occurred during late Mesozoic or early Tertiary time, with the rocks folded and cut with thrust faults. At the close of this period, magma invaded the rocks, forming dikes that cut both stocks and sedimentary rocks (Gibson, 1933, 1948).

The majority of the gold lode mines are found near the head of West Fisher Creek and near two tributaries, Bramlett and Standard creeks. Most gold-quartz veins are located in the Prichard formation; exceptions include the Midas and Montezuma mines where the veins are found in Wallace strata. "Gold-quartz veins in the Prichard Formation parallel bedding planes, and most ore is produced near high-angle crosscutting faults." Scheelite, or tungsten ore, occurs in white quartz veins; it is associated with native gold in the Midas mine (Johns, 1970).

Mines in the Cabinet district got off to a slow start. Following the discovery of the early mines, A. B. Johnson packed 6,300 pounds of selected ore out for a smelter test. The results were disappointing, however, showing values of $43 in gold and $2 in silver and lead, and owners were then unable to raise capital for development work and milling equipment. Operators conducted only assessment work for several years (Libby News, 1900).

Finally, in 1899 the West Fisher Mining Co. organized with stated aims of operating the Brick and Branigan mine, building a wagon road and erecting a 10-stamp mill. A year later, owners of the American Kootenai mine built a 10 stamp mill, and the two mines employed a total of 60 men. Several other mines were in operation during the early 1900s, including the Illinois and Montana, Mustang, Wayup, and Midas. Most closed after a few years, however, and nearly all activity ended around 1910. The American Kootenai mine closed that year after a snowslide destroyed much of the mill, and while operators attempted to restart operations, the mine did not reopen (Libby News, 1900; Renk, 1994; Johns, 1970).

Most activity during the next decade centered around the Midas mine where geologists discovered tungsten, a key ingredient for steel, during World War I. The mine produced $27,000 in tungsten and gold from 1916-1918. The Midas also produced well during the early 1930s. Other mines, including the Little Annie, Brick and Branigan, Montezuma, and Wayup, operated intermittently during the 1930s and 1940s, with activity at the Wayup continuing into the following decade (Johns, 1970).

The Cabinet/West Fisher district was almost entirely a gold lode district, with the exception of the Midas mine that produced both gold and tungsten. Unlike the neighboring Libby district, placering was unimportant in the Cabinet area. The Spokane Placer Mining Co. organized late in 1904 to mine 1280 acres of land along Standard Creek. Promoters claimed that the ground would yield $.41 per yard, but it is doubtful that any work was done on the project. A similarly large project was proposed during the 1930s when O. V. Miller and P. Church claimed 1200 acres along West Fisher Creek, south of Teeters Peak. They later dropped all but one 20 acre claim which they developed with a 100-foot shaft and a churn drill hole 110 feet deep. The men recovered only $.12 to $.16 per yard and reported no production (Western News, 1904; Johns, 1970).

BOUNDARIES OF THE DISTRICT

MacDonald (1909) places the Cabinet district "in the Cabinet Mountains, about 20 miles southeast of the Snowshoe mine." He credits the district with mines both on Silver Butte Mountain and on the headwaters of the Fisher River, just north of Silver Butte. Most subsequent writers deleted the first group of claims, placing them within the Silver Butte district. According to Sahinen (1935), the Cabinet district is centered around the headwaters of the Fisher River; while there are several branches of the Fisher River, it is probable that Sahinen was referring to West Fisher Creek. Other authors include primarily the mines that cluster at the headwaters of West Fisher Creek, and at least one historical map bears out this definition of boundaries (Johns, 1970; Gibson, 1948; Clapp, c. 1905).

HISTORIES OF SELECTED MINES

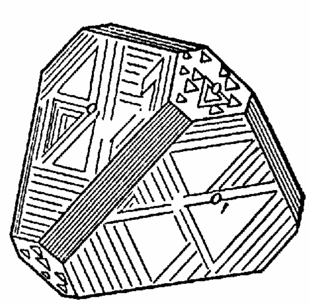
American Kootenai

The American Kootenai encompasses five patented claims (Jim Blaine, Gold Den, Gold King, Gold Bug, and Gold Bug millsite) on the south side of West Fisher Creek. Discovered in the 1890s, the mine was worked very little until

1900 when the American Kootenai Mining and Milling Co. erected a 10 stamp mill that ran on water power, with a backup boiler and engine. The company evidently utilized a 2,240 foot aerial tram to carry ore from the mine to the mill, although it is unclear when and if this facility was actually built. By 1901, 40 men worked at the mine, using electric power to operate the drilling equipment. The mine closed for a time around 1905-1906 when a stockholder disagreement held up operations. Production stopped again in 1910 when a snowslide destroyed most of the mill. Crews were repairing the mill a year later when the company was working two claims, and manager J. A. Town announced large development plans. These may not have materialized since no mention is made of the mine after this date. Workings include 3 adits with a total length of 600 feet (Johns, 1970; Libby News, 1900; Kalispell Bee, 1901; Byrne, 1901; Walsh and Orem, 1906, 1910, 1912; Rowe, 1911).

Blacktail (Jumbo, Tip Top, New Deal)

The Blacktail group includes several claims on the north side of Bramlett Creek. Don Schanck and Henry Bramlett located the claims in the spring of 1892 and began development work. Bad luck struck soon. They bonded the mine just before the price of silver dropped on the national market, the purchaser then defaulted, and an Anaconda geologist filed a conflicting claim. Although Schanck and Bramlett won their case, the attorneys ended up holding 51 percent of the stock. They organized a new company around 1899 and within two years had constructed a 10 stamp mill and a 3,000 foot surface tramway at the mine. A sample shipment of ore tested at $30 in gold per ton (Schanck, c. 1919; Kalispell Bee, 1901).



The Blacktail group operated sporadically during the twentieth century, often under different names. The mine was active in 1909 and 1911. The Tip Top reported production from 1928-1931, milling 100 tons of ore in 1930 and about 50 tons in 1931. Operating under the New Deal name, the mine produced gold ore in 1934, 1937-1938, and 1940-1941; during the last year, operators milled 25 tons of ore. There are no reports of production after this date. Mine workings included cuts, trenches, and adits (Johns, 1970).

Brick and Branigan

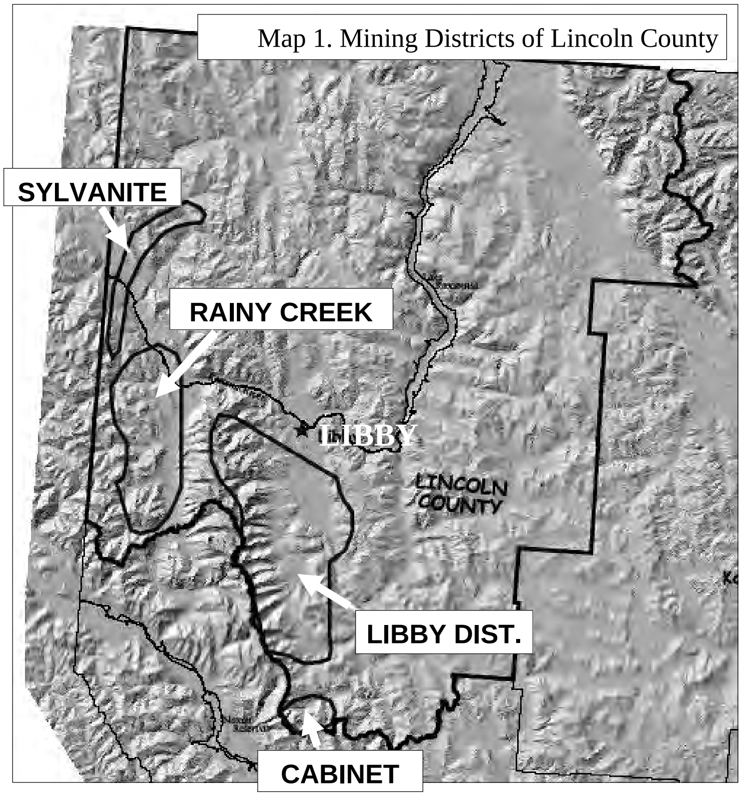
Located in 1892, the Brick and Branigan grew to include eight patented claims on Bramlett Creek. A group of Iowa capitalists organized the Fisher Creek Mining Co. in 1899 to operate the mine, build a wagon road, erect a mill, and install an 1,150 foot bucket tram. The 25 ton mill contained either 10 or 15 stamps, two vanners, and two California bumping tables. It was powered by steam in 1900, but owners altered it within a year to run on water power. The mine produced 18,000 tons of ore from 1901-1903, netting the owners $150,000. After this initial activity, the mine evidently operated only sporadically until the late 1930s. Lessees ran a test on 1,450 tons of ore in 1938. Twenty-five men worked in the mine, producing 24,239 tons of ore in 1940-1941 and 1950. The mine included nearly one mile of underground workings, with 10 tunnels up to 700 feet in length. Total production up to 1947 was estimated at $300,000 (Johns, 1970; Libby News, 1899b, 1900; Kalispell Bee, 1901; Byrne, 1901; WPA, 1940).

Illinois and Montana

The Illinois and Montana mine made a brief splash around 1903 and then faded from public view, perhaps because it did not turn out as well as its promoters had hoped. The company owned four claims along the same vein, extending around the mountain from Fourth of July Creek to Lake Creek. Contractors worked all winter to drive 200 feet of tunnels to reach the ore vein. Assays supposedly showed values of hundreds of dollars per ton in free milling gold. Despite the glowing reports, the mine apparently did not pan out (Press, c. 1903; Western News, 1903a).

Little Annie (Gloria)

This property is located on the north side of the



Map 1. Mining Districts of Lincoln County

creek, near the headwaters of West Fisher Creek. Operated by the Golden West Mining Co., the mine sat 1200 feet above the company camp on the valley floor; the camp, which included several large cabins, also served the company's New mine across the creek. The Little Annie had two nearly parallel adits connected by a crosscut, making 300 feet of workings. A shipment of 39 tons of ore in the early 1930s averaged 3.874 ounces of gold and 1.05 ounces of silver per ton, while other small shipments were richer. The mine shipped ore in 1939 and then apparently did not operate much after that (Johns, 1970; Gibson, 1948).

Midas

The Midas was discovered in 1905, at which time it was known as the Rose Consolidated. It includes eight lode claims and one placer located one mile southeast of Howard Lake. The mine initially produced gold ore, but interest was sparked during World War I when geologists found that the ore contained tungsten as well. From 1916-1918 the Midas produced $27,000 worth of gold bullion and tungsten concentrates. After a period of quiet, the Midas reported production in 1927 and then ran a test on 1000 tons of ore the following year; the results yielded 317.14 ounces of gold; 503 ounces of silver; 77 pounds of copper; and 1,029 pounds of lead and netted $6,034. Operators made $20,962 from 1932-1933 with ore that contained 990.79 ounces of gold. The mine continued operations on a sporadic basis at least through the 1950s. The physical plant included a 75-ton mill with jaw and cone crushers, ball mill, sampler, Dorr classifier, flotation equipment, concentrating tables, and cyanide tanks. The underground workings contained two shafts and 3000 feet of drifts, crosscuts, and raises. Total production from the mine up to 1933 was $59,000 (Johns, 1970; Gibson, 1948; WPA, 1941).

Montezuma

The Montezuma mine consists of six unpatented claims on the east side of West Fisher Creek, about two miles southeast of the Midas mine. Olson and Bolyard operated the prospect sporadically during the 1930s, and there has been little work since. The underground workings include two adits (lower one 385 feet and upper one 90 feet), a 30-foot inclined shaft, and a number of pits and trenches. Although the mine has reported no production, assay values range widely from $6.40 to $76 in gold and silver (Johns, 1970).

Mustang

Located on the south side of Standard Creek, the Mustang property includes four unpatented lode claims. Like many other mines, it caused a brief excitement and then faded from sight. Herman Hildebrandt and A. Himes sold the group of claims to the Mustang Consolidated Gold Mining Co. late in 1902. At that time, assay values from the Mayflower claim averaged $15.40 in gold, with one as high as $45.60 and the Alabama No. 1 claim averaged $20.60 in gold. Mine buildings included a cook house, bunkhouses, root cellar, blacksmith shop, and powder house. Six months later, the mine manager suspended work because of water in the Alabama tunnel, despite the fact that they were "undoubtedly within a few feet of one of the ledges they expected to strike...." Success may have eluded the owners since little else is known about the mine. There is no reported production (Western News, 1902b, 1903b; Johns, 1970).

Wayup

The Wayup property includes two patented and ten unpatented claims on the north side of West Fisher Creek. Located in the 1890s, the mine was bonded to James Higgins around 1896. He undertook extensive development work, investing $10,000 on the Wayup claim in over 350 feet of underground workings, open cuts, cabins, and trails. Higgins and partners purchased the property two years later, organizing the Montana-Kootenai Gold Mining Co. in 1899 to operate the mine. By 1902, the company reported that underground developments had reached 800 feet and opened up a good section of ore that averaged $20 in gold per ton. After years of inactivity, the Wayup was reopened in 1937, with additional activity from 1948-1949 and again in the 1950s. There is no reported production from the mine (Libby News, 1899a; Western News, 1902a; Johns, 1970).

Others

Other mines of lesser importance in the Cabinet district include the Betty Mae, Diamond John, Great Northern, Hannegan, Irish Boy, Mother Lode, Standard, Union, and Williams.

REFERENCES

Abandoned Mine Reclamation Bureau (AMRB), 1994, Mining districts of Montana, Maps 1:100,000 and Map #94-NRIS-129, Compiled and edited by Joel Chavez: Prepared by Montana State Library Natural Resource Information System (NRIS) for Montana Department of State Lands, Helena.

Byrne, John, and Frank Hunter, 1898, Ninth Report of the Inspector of Mines of the State of Montana: State Publishing Company, Helena.

-------, 1901, Annual Report of Inspector of Mines of the State of Montana: State Publishing Company, Helena.

Calderhead, J. H., 1898, Montana Bureau of Agriculture, Labor, and Industry, 6th Annual Report.

Calkins, Frank Cathcart, 1909, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, U. S. Geological Survey, Bull. 384, pp. 7-112.

Clapp, Lewis A., c. 1905, Map of Libby and West Fisher Mining Districts, Montana: Copy on file, Libby Ranger Station, Kootenai National Forest.

Gibson, Russell, 1931, Gold-Quartz Veins South of Libby, Montana, U. S. Geological Survey, Circ. 7, 1934; Dept. of Interior, Memo. for the Press, 1931.

-------, 1948, Geology and ore deposits of the Libby Quadrangle, Montana: U.S.G.S. Bulletin 956.

Gibson, Russell, Jenks, William F., and Campbell, Ian, 1938, Stratigraphy of the Belt Series in Libby and Trout Creek Quadrangles, Northwestern Montana and Northern Idaho: Geol. Soc. America Bull., Vol. 52, pp. 363-380, 1941; (abst.) Geol. Soc. America Proc., 1937, p. 83, 1938.

Johns, Willis M., 1970, Geology and Mineral Deposits of Lincoln and Flathead Counties, Montana: Bulletin 79, Montana College of Mineral Science and Technology, Butte.

Kalispell Bee, 1901, Flathead Mining Industry: 18 December, page 13.

Libby News, 1899a, To Work the Way-Up Mine: 16 February.

-------, 1899b, Fisher Creek Mining Co: 21 December, page 3.

-------, 1900, A Promising Gold Camp: 16 August, page 3.

MacDonald, D. F., 1909, Notes on the Economic Geology, *in* A Geological Reconnaissance in Northern Idaho and Northwestern Montana, by F. C. Calkins: U.S.G.S. Bulletin 384.

Press, c. 1903, Mines and Miners of Montana: Undated article on file, Mining #42, Montana files, Flathead County Library, Kalispell.

Renk, Nancy F., 1994, Mining, *in* Historic Overview of the Kootenai National Forest, Vol. 1, edited by Christian J. Miss: Northwest Archaeological Associates, Inc., Seattle.

Rowe, Jesse Perry, 1911, Gold Quartz Mining in Western Montana: Mining World, Vol. 34, No. 20, pp. 1033-1034.

Sahinen, Uuno Mathias, 1935, Mining Districts of Montana: Unpublished Master's thesis, Department of Geology, Montana School of Mines, Butte.

Schanck, Don E., c. 1919, Wandering Feet: Manuscript. on file, Montana Historical Society Archives, Helena.

Walsh, William, and William Orem, 1906, Biennial Report of the Inspector of Mines of the State of Montana for the Years 1905-6: Independent Publishing Company, Helena.

-------, 1910, Biennial Report of the Inspector of Mines of the State of Montana for the Years 1909-10: Independent Publishing Company, Helena.

-------, 1912, Biennial Report of the Inspector of Mines of the State of Montana for the Years 1911-1912: Independent Publishing Company, Helena.

Western News, 1902a, The Way-Up Is In Ore: 25 September, page 3.

-------, 1902b, Mustang Buys Alabama Group: 18 December, page 2.

-------, 1903a, Illinois and Montana: 16 April, page 3.

-------, 1903b, In the West Fisher District: 4 June, page 2.

-------, 1904, A Placer Company Organized: 17 November, page 3.

Work Projects Administration (WPA), Mineral Resources Survey, 1940, Directory of Montana Mining Properties: Memoir No. 20, Montana School of Mines, Butte.

-------, 1941, Montana Mine Index, An Alphabetical Index Arranged by Counties, Districts and Mines of Information on Montana Mines from 1867-1940: Montana School of Mines, Butte.

DEEP CRUSTAL STRUCTURE REVEALED BY MAGNETO-TELLURIC TRANSECT BETWEEN THE SELKIRK CREST, IDAHO AND THE WHITEFISH RANGE, MONTANA

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ABSTRACT

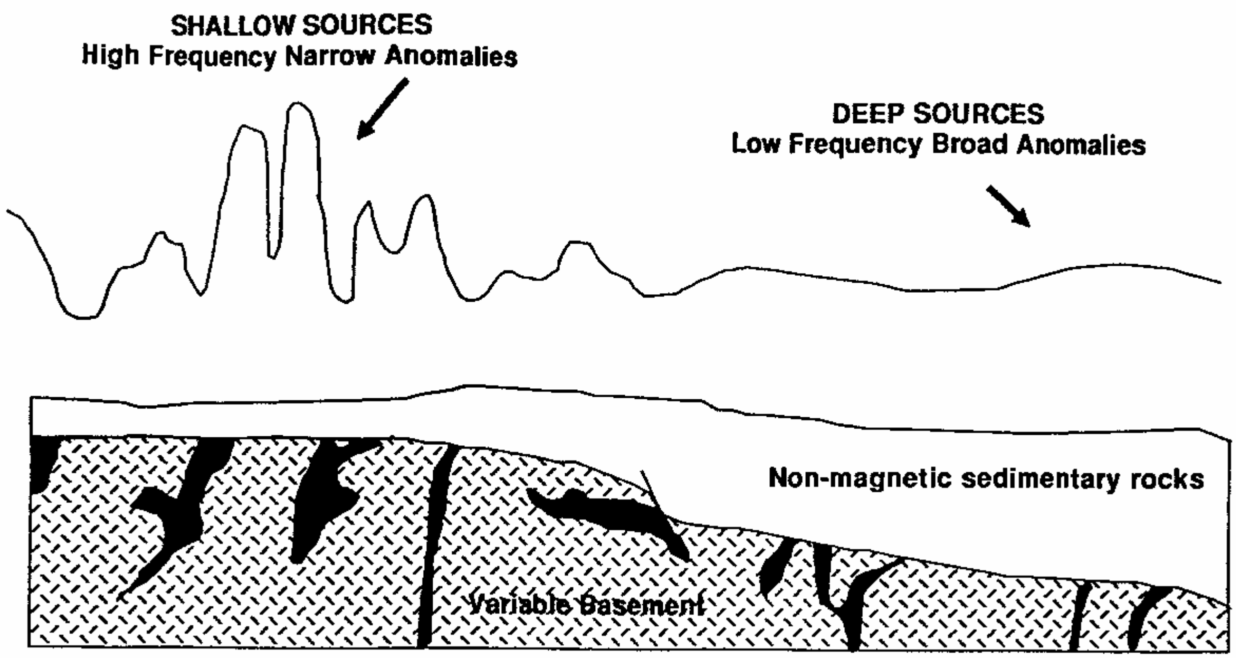
Long-period (deep crustal) magnetotelluric (MT) data were collected along a 140 km transect in August and September, 2005. Broadband (shallow crustal) data were previously collected for the eastern half of the transect in the 1980s, and new broadband data was collected on the western half in 2005. A portion of the transect is overlapped by two deep crustal seismic reflection profiles (COCORP lines MT-2 and ID-2) collected in the 1980s. The data generally confirm the NW strike of the Sylvanite anticline and Purcell anticlinorium and the more northerly strike of the Libby Thrust Belt.

A best-fit, two-dimensional (2D) resistivity model was generated from the MT data down to 50 km. The model is characterized by two subhorizontal, highly conductive horizons. A shallower horizon at 10-15 km depth begins 10 km west of the Whitefish Range front and continues to the west for 60 km to an abrupt end beneath the Sylvanite anticline. A deeper highly conductive, concave-up layer occurs at 25-35 km depth from just west of southern Lake Koocanusa to an abrupt end about 20 km east of the Purcell trench. From that point west to the Selkirk Crest, the entire crust is very resistive. A crude resisitivity stratigraphy is delineated: highly resistive middle and upper Belt Supergroup (above the Prichard Fm.), moderately conductive Prichard Fm. (to the present depth of exposure), a highly conductive sub-Prichard layer (below the lowest Prichard unit mapped at the surface), and moderately to highly resistive pre-Belt crystalline basement.

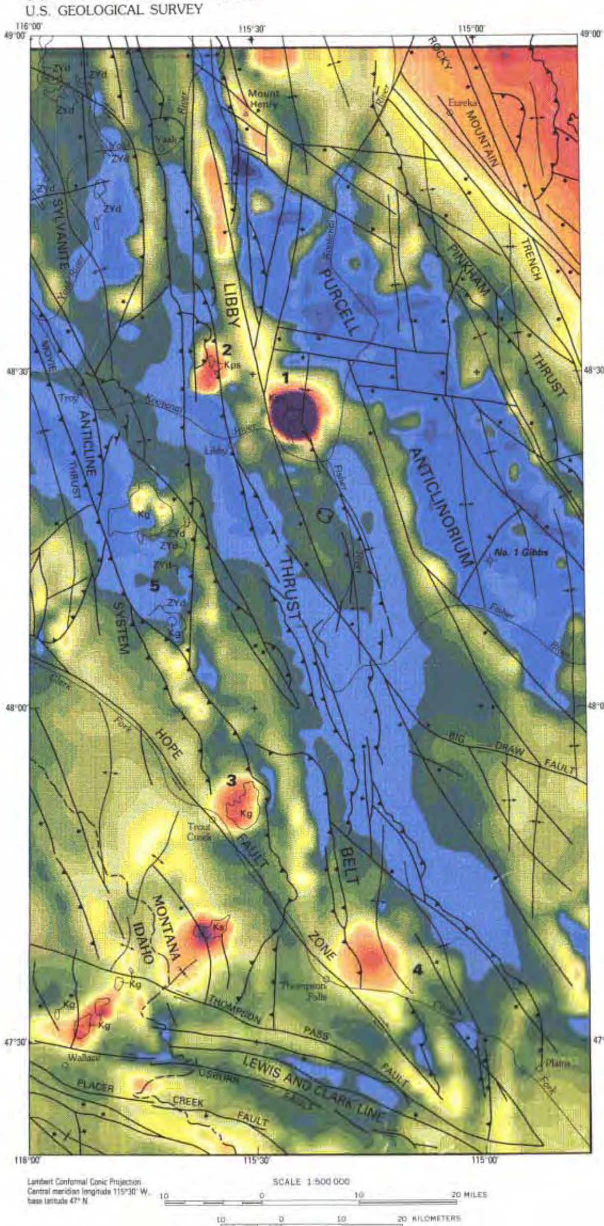
The Eocene Purcell trench detachment fault can be traced dipping 25-30^{o} east down to about 20 km depth, flattening along the abrupt base of the shallower conductive layer to its eastern end, fully 100 km east of the surface trace of the fault. Realignment of the eastern edges of the shallow and deep conductive layers connects those edges into a single west-dipping horizon and suggests about 35 km of Eocene top-to-the-east offset on the northern Purcell trench detachment fault. Reversal of that displacement reveals the crustal structure as it existed at the end of late Mesozoic Cordilleran thrusting.

A major thrust decollement at 10-12 km, well-defined below the Sylvanite anticline, occurs below the deepest exposed Prichard units but above the shallower highly conductive layer. The shallower highly conductive layer is interpreted as sub-Prichard sedimentary strata with disseminated carbonaceous matter or sulfide grains rendered interconnected (and thus conductive) by shearing. The shallow and deep conductive layers are suggested to be thrust repetitions of a single original layer. The highly resistive horizon separating the two conductive layers is inferred to be a thrust imbricate of Archean crystalline basement, 35 km wide and 5-8 km thick, with the top at 20 km and centered below the Sylvanite anticline.

Total Cordilleran thrust shortening of 150-200 km is indicated.



Frequency-Depth Relationship for magnetic anomalies (provided by Dick Gibson)



MAP *A*. RESIDUAL TOTAL-INTENSITY AEROMAGNETIC ANOMALIES AND STRUCTURAL FEATURES

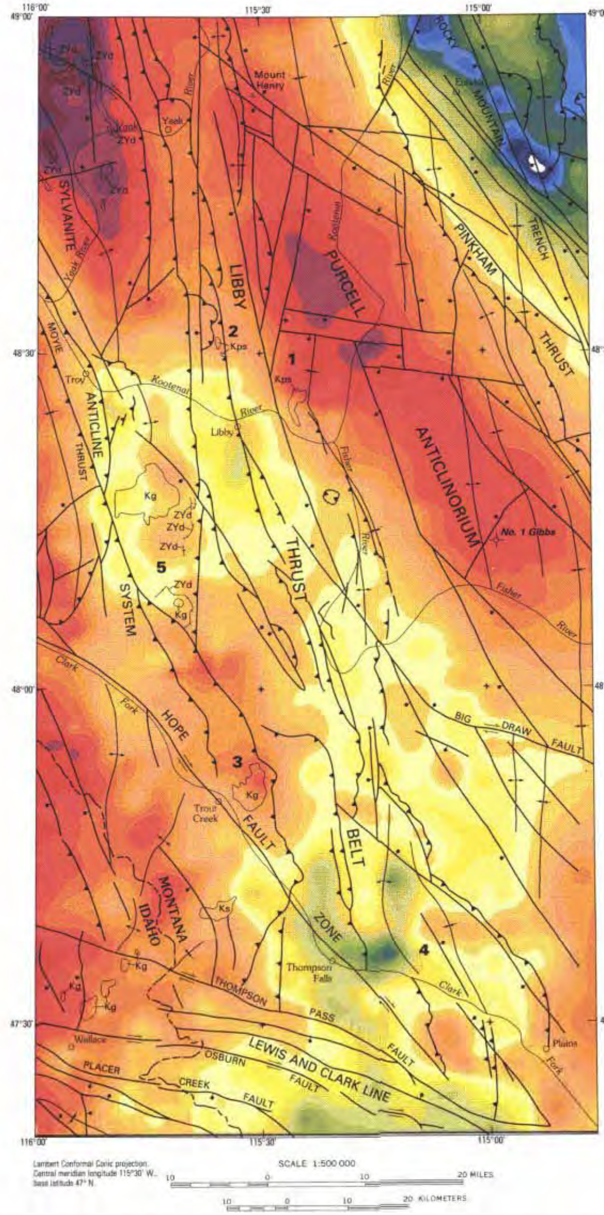
EXPLANATION FOR MAPS *A* AND *B*

Kg	Felsic intrusive rocks (Cretaceous)
Ks	Syenite (Cretaceous)
Kps	Pyroxenite and syenite (Cretaceous)
ZYd	Sill (Late and Middle Proterozoic)
	Fault
	Normal fault—Bar and ball on downthrown side
	Thrust fault—Sawteeth on upper plate
	Tear fault—Arrows show direction of horizontal movement
	Anticline—Showing crestline and dips of limbs
	Syncline—Showing troughline and dips of limbs
4	Aeromagnetic anomaly referred to by number in text
	Location of Atlantic Richfield-Marathon Oil No. 1 Gibbs borehole, NE1/4 sec. 2, T. 28 N., R. 27 W., Flathead County, Montana

Color bar showing residual total-intensity aeromagnetic intensity in 10, 20, and 30 nT intervals

440.0, 410.0, 380.0, 350.0, 320.0, 290.0, 260.0, 230.0, 200.0, 170.0, 140.0, 110.0, 90.0, 80.0, 70.0, 60.0, 50.0, 40.0, 30.0, 20.0, 10.0, 0.0, −10.0, −20.0, −30.0, −40.0, −50.0, −70.0, −100.0, −130.0, −160.0

INDEX SHOWING LOCATION OF MAPPED AREA



MAP *B*. COMPLETE BOUGUER GRAVITY ANOMALIES AND STRUCTURAL FEATURES

Color bar showing complete Bouguer gravity intensity in 2-mGal intervals

−110.0, −112.0, −114.0, −116.0, −118.0, −120.0, −122.0, −124.0, −126.0, −128.0, −130.0, −132.0, −134.0, −136.0, −138.0, −140.0, −142.0, −144.0, −146.0, −148.0, −150.0, −152.0, −154.0, −156.0, −158.0, −160.0, −162.0, −164.0, −166.0, −168.0, −170.0, −172.0

MAPS SHOWING RESIDUAL TOTAL-INTENSITY AEROMAGNETIC ANOMALIES, COMPLETE BOUGUER GRAVITY ANOMALIES, GEOLOGY, AND STRUCTURAL FEATURES, LIBBY THRUST BELT, NORTHWESTERN MONTANA AND NORTHEASTERN IDAHO

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GEOPHYSICAL INTERPRETATIONS OF THE LIBBY THRUST BELT, NORTHWESTERN MONTANA

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ABSTRACT

Interpretations of gravity and aeromagnetic anomaly data, as well as results from two seismic reflection profiles and five magnetotelluric soundings, were used to study buried structure and lithology of the Libby thrust belt of northwestern Montana. Gravity modeling, supplemented by structural data from the seismic reflection profiles and geologic contraints derived from projection of surface geology, measured sections, and lateral consistency of sills, leads to the interpretation that thrust slices of folded crystalline basement form the core of the Purcell anticlinorium and Sylvanite anticline, which consist mainly of rocks

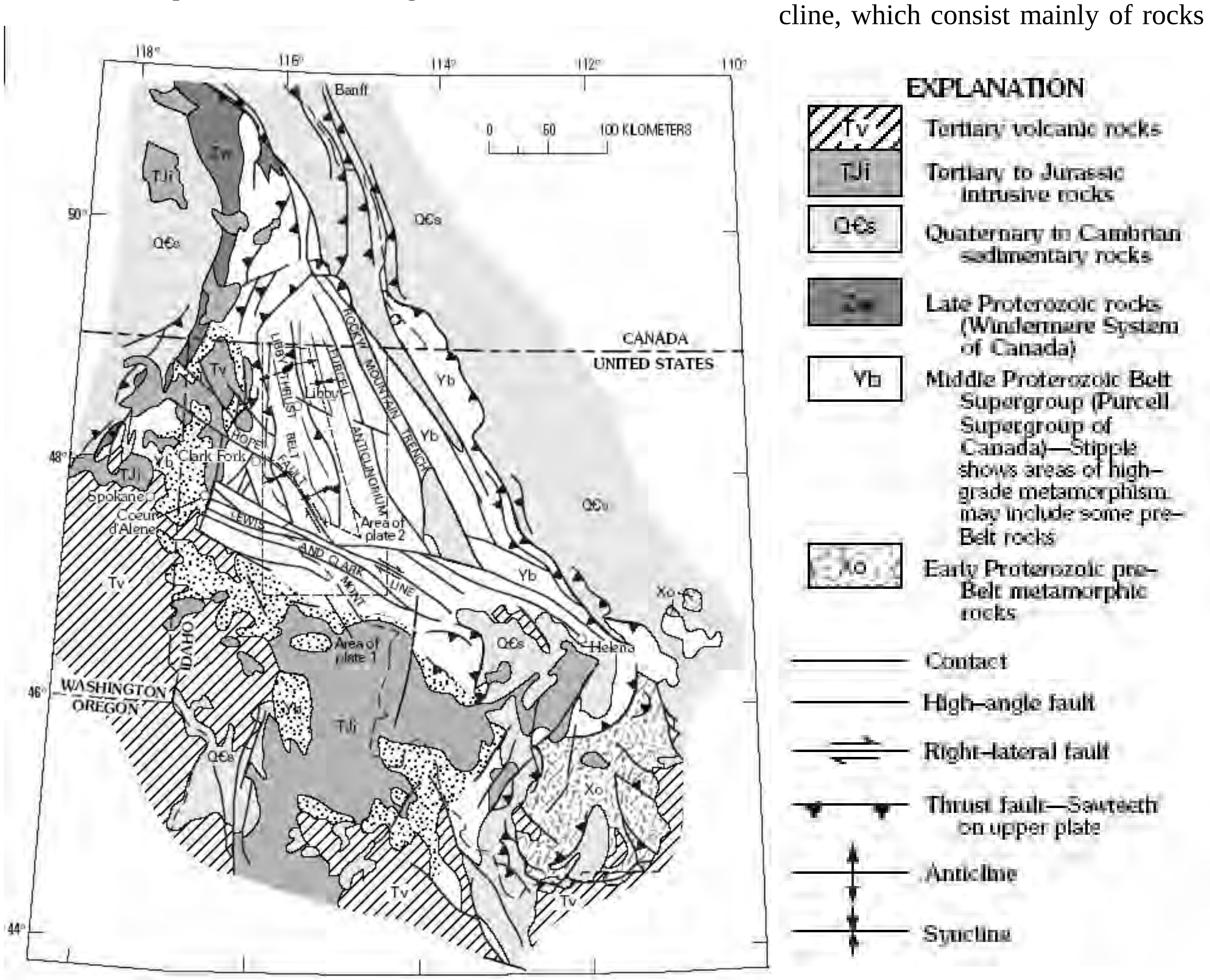

Figure 1. Map showing generalized geology of the Belt terrane in the region of the Libby thrust belt, northwestern Montana and surrounding area. Modified from King (1969) and Harrison and Cressman (1993).

of the Middle Proterozoic Belt Supergroup.

Gravity anomaly data show marked correlation with major structure of the area. The Purcell anticlinorium exhibits positive anomalies in excess of 20 mGal and the Sylvanite anticline anomalies in excess of 10 mGal. In the northern part of the study area, a distinct northwest-trending high-gradient zone suggests that a buried crustal shear zone may be present just north of Libby. The Rainy Creek and Bobtail Creek stocks, which show distinct positive magnetic anomalies, lie along this trend, and their emplacement may have been influenced by the postulated zone of deformation.

The most distinct magnetic anomalies in the principal study area are five positive anomalies associated with Cretaceous or younger cupolas and stocks that either are exposed or are known from drillholes to be present in the near-surface. Amplitudes range from 100 to more than 3,000 nT. Short-wavelength anomalies are associated with outcrops of magnetite-bearing sedimentary rocks of the Ravalli Group of the Belt Supergroup. A strip of high magnetic gradient correlates with the Hope fault zone. Modeling of the magnetic anomaly data was not done because of the absence of long-wavelength magnetic anomalies having likely sources in deeply buried Proterozoic crystalline basement. The mafic sills of dioritic to gabbroic composition show little or no magnetic response in outcrop, probably because the magnetite content in the sills was reduced by chemical processes related to interaction of hydrothermal fluids with cooling magmas of the intrusions.

Evidence from the magnetic and gravity anomaly data suggests that the Cabinet Mountains Wilderness is underlain by a major batholith of felsic composition that extends from north of the Dry Creek stock south almost to the Vermilion River stock. Along this trend are a number of small high-amplitude positive anomalies of 60–100 nT in areas of outcrops of the Wallace Formation of the Belt Supergroup and, in a few cases, the Ravalli Group. In the case of the Ravalli

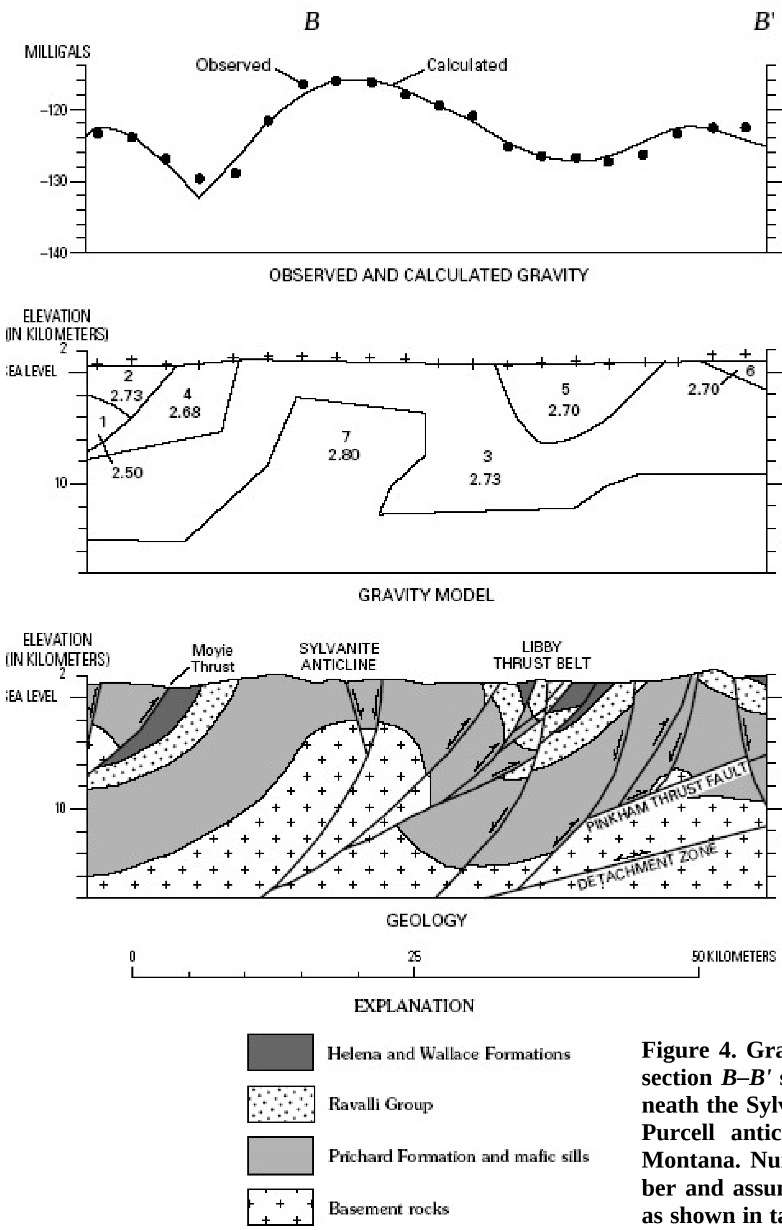

Figure 4. Gravity block model of extended geologic cross section *B–B'* showing inferred lithology and structure beneath the Sylvanite anticline and northwestern part of the Purcell anticlinorium, Libby thrust belt, northwestern Montana. Numbers on gravity model refer to body number and assumed density (in grams per cubic centimeter) as shown in table 1; for example, for body 2, the density is 2.73 g/cm3.

rocks, the highs probably are not related to outcrops of magnetite-bearing Ravalli group rocks that in other places cause linear magnetic highs along ridge tops; instead, because of their equidimensional shape on the map, they may indicate near-surface sources related to granitic intrusions or cupolas of a larger batholith mass at a few kilometers depth beneath the Cabinet Mountains Wilderness.

A basal surface of detachment is inferred from a series of seismic reflections. Depth to the basal surface is 9–18 km, and this surface dips about 15° in inferred crystalline basement rocks. Strong reflections at and below 4 seconds are attributed to stratification in the basement such as layered gneiss or mylonite along the detachment zone for the older tectonic folding. No seismic reflection is present for the Belt-crystalline basement contact. Just below the Pinkham thrust fault, strong reflections attributed to stratification in crystalline basement rocks image relief in the basement on the western flank of the Purcell anticline.

Interpretation of the magnetotelluric data suggests a thick conductive section that is incompatible with a crystalline basement composed of granitic gneiss, mafic intrusive rocks, and high-grade metasedimentary rocks considered typical for the region. Thus, there are major differences between the deep crustal model developed from the magnetotelluric data and the model obtained from the gravity and seismic data. This heterogeneous type of crust is generally not low in resistivity unless partial melting has occurred. Low resistivities may be possible in granitic rocks at depths of 10–15 km and temperatures of 500°C –600°C if 1–3 percent free water is present; however, there is no evidence in the study area for these levels of temperature. A thermally related basement conductive zone could possibly be present now at depth where a low-resistivity (3–5 ohm-m) zone forms the bottom layer in the western part of the magnetotelluric profile. This zone corresponds approximately with the interpreted basal surface of detachment that separates basement rocks from the Prichard Formation of the Belt Supergroup. Some of the low resistivities observed likely are caused by pre-Prichard crystalline rocks (metamorphic (metasedimentary) or igneous) that are conductive because they contain large amounts of metallic minerals. The striking variations in observed resistivities in the Prichard Formation of from 0.6 to more than 400 ohm-meters probably reflect the percentage and continuity of iron-sulfide-rich zones. Another possible line of thermal evidence is the absence of magnetic sources in pre-Belt crystalline rocks at depths of 10–15 km. The lack of magnetic anomalies may relate to shallow Curie-point temperatures, above which magnetism does not exist.

The magnetotelluric data have limitations in structural analysis because resistivities are mostly controlled by the percentages of metallic minerals and not by lithology. Accuracy of the interfaces obtained from the magnetotelluric data is not great, both because of the widely spaced sounding locations and because of the very large contrasts in resistivity between unmineralized and mineralized zones in the Belt Supergroup.