Sedimentation, Stratabound Cu-Ag Mineralization, and Syndepositional Tectonics in the Revett Formation, Flathead Indian Reservation, Western Montana

Peter C. Ryan[1] and Steve Buckley[2]

Abstract

The Revett Formation on the Flathead Indian Reservation is a northward-thinning clastic wedge that ranges from 3,200 to 5,300 ft thick (970 to 1,610 m) over a distance of 40 mi (60 km). Revett Formation isopachs strike east-west, and paleoflow direction was downslope to the present-day north and northeast. Revett Formation quartzite on the southern end of the reservation was deposited in the upper flow regime (transitional) by periodic north- and northeast-directed sheetfloods on a large alluvial-fan complex. To the north, sediment was mainly deposited under lower flow regime conditions by braided streams with less-frequent sheetfloods at the toe of the alluvial-fan complex. On the southern end of the reservation, an abrupt 1,000-ft (300-m) thinning of the lower Revett Formation is evidence for down-to-the-south syndepositional faulting along the west-trending Jocko line, a proposed Proterozoic syndepositional growth fault.

Stratabound Cu-Ag mineralization occurs in two west-trending belts in the Revett Formation on the Flathead Indian Reservation. The mineralized belts coincide with the Jocko line and the Big Draw fault, proposed west-trending Proterozoic syndepositional faults. The spatial association of faults and mineralized Cu-Ag belts, combined with the presence of mineral zonation and vertically stacked deposits, indicates that syndepositional faults controlled stratabound Cu-Ag mineralization. The mineralization is similar in grade and character to stratabound Cu-Ag deposits hosted by the Revett Formation in the western Montana copper belt.

Introduction

The Revett Formation (Ravalli Group) is host to large stratabound Cu-Ag deposits of the western Montana copper belt (WMCB). The Flathead Indian Reservation is located 40 mi (60 km) east of the WMCB and contains abundant exposures of the Revett Formation. Although previous studies have documented a few isolated stratabound Cu-Ag occurrences in the Ravalli Group on the reservation (Harrison *et al.* 1977, Earhart *et al.* 1980), no study to date has mapped these rocks in detail. Much of the Revett Formation on the reservation has been previously mapped as Burke and Spokane formations (Mauk 1983, Cronin 1988), and because it is unknown whether these formations contain significant Cu-Ag mineralization, the Flathead Indian Reservation has not been seriously considered for Revett-type stratabound Cu-Ag deposits.

At least three stratigraphic classifications have been used to map 10,000–13,000 ft (3,000–4,000 m) of interbedded quartzite, siltite, and argillite of the Ravalli Group on the Flathead Indian Reservation. Wells (1974) mapped a thick Burke Formation overlain by a thin Revett Formation on the southern end of the reservation, and Harrison *et al.* (1986) indicated that repeated argillite-rich and quartzite-rich units of the Burke and Revett formations were produced by normal faulting. These authors (Buckley and Ryan 1991) and others (Jacobson 1981, Mikelsons and Dunlavy 1982, Mauk 1983, Cronin 1988) have mapped Ravalli Group rocks on the reservation according to the stratigraphic classification established for Ravalli Group rocks in the Coeur d'Alene district by White *et al.* (1977).

The purposes of this study are to determine 1) the extent and grade of stratabound Cu-Ag mineralization on the Flathead Indian Reservation, 2) mechanisms responsible for Cu-Ag mineralization, 3) a consistent Ravalli Group stratigraphic classification for the reservation, and 4) Revett Formation depositional environment.

Regional Geology

The 1.2-million-acre Flathead Indian Reservation is located in western Montana and is dominated by exposures of the Proterozoic Belt Supergroup (figures 1,2). Ravalli Group rocks outcrop throughout the reservation. The underlying Prichard Formation outcrops extensively in the southwest part of the reservation and the overlying middle Belt carbonate and Missoula Group are found in the eastern part of the reservation. Tertiary and Quaternary sediment are localized in Cenozoic valleys, and the Hog Heaven volcanic field is on the northern reservation boundary (figure 2).

[1]Salish-Kootenai College, Pablo, MT 59855, [2]Watershed Consulting, Polson, MT

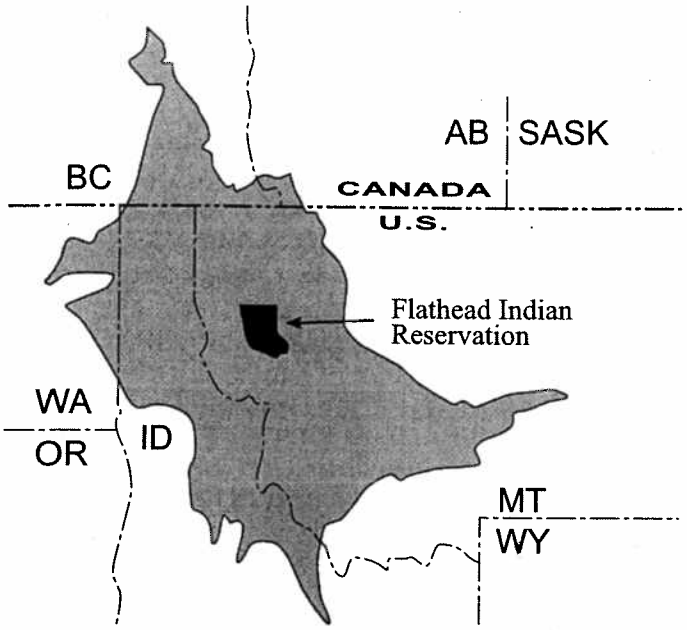

Figure 1. Location of the Flathead Indian Reservation and extent of the Belt basin, shown by stippled pattern.

Ravalli Group Stratigraphy

The Ravalli Group in western Montana and northern Idaho is subdivided from oldest to youngest into the Burke, Revett, St. Regis, and Empire formations (Harrison *et al.* 1974). The Burke Formation mainly consists of interbedded gray sericitic quartzite, green siltite and argillite, and minor vitreous quartzite. The overlying Revett Formation is predominantly lavender vitreous quartzite with interbedded argillite and siltite. The St. Regis Formation contains interbedded siltite, argillite, and fine-grained quartzite beds, and the Empire Formation is a distinctive green calcareous argillite that is transitional between the overlying middle Belt carbonate and the underlying St. Regis Formation.

Revett Formation Stratigraphy and Depositional Environment

White *et al.* (1977) divide the Revett Formation in the Couer d'Alene district of northern Idaho into three informal members. The lower and upper members are predominantly vitreous white-gray quartzite characterized by flat laminations and crossbedding, whereas the middle Revett mainly consists of argillite and siltite. Subsequent studies have extended these subdivisions northward to the Cabinet Mountains (Young and Winston 1990) and eastward to the Swan Range (Cronin 1988).

The depositional environment of the Revett Formation has been interpreted by previous workers in several ways. Hrabar (1971, 1973) concluded that the Revett Formation was deposited as a turbidite complex, and Harrison *et al.* (1974) suggested that the Revett Formation was deposited into a marine basin along a passive continental margin. Bowden (1977) indicated that Revett Formation sediment was deposited as a braided river complex, and recent studies advocate sheet-flood deposition of sediment on an alluvial-fan complex (Alleman 1983, Mauk 1987, Kuhn 1987, Cronin 1988, Young and Winston 1990).

Structural Setting

The structural geology of the reservation is characterized by Late Cretaceous anticline/syncline pairs broken by steep range-bounding Cenozoic normal faults such as the Mission fault and the Pistol Creek fault (figure 2).

A major west-trending structural lineament occurs 3–4 mi (4.9–6.4 km) south of the Flathead River on the southern end of the reservation (figure 2). North of the river, rocks are mildly cleaved and folds are broad and strike north-south. South of the river, folds are tighter, plunge to the southeast, and are locally overturned, and the rocks are characterized by intense southeast plunging cleavage. This major structural lineament is part of a regional plunge change proposed by Sears (1988) to be the result of compressional deformation over a transverse basement ramp. It also parallels and is proximal to the Jocko line, a proposed Proterozoic syndepositional growth fault that was active during Revett Formation deposition (Winston 1986).

In the southern part of the reservation, the large southeast-plunging Purcell anticlinorium exposes rocks from the lowest exposed part of the Prichard Formation up through the Missoula Group (figure 2). Stratabound Cu-Ag deposits similar to those in the Western Montana copper belt (figure 3, Harrison 1972) are found in the Ravalli Group on the limbs of this fold.

On the northern part of the reservation, the Big Draw fault is a Phanerozoic strike-slip fault (Harrison *et al.* 1986). The occurrence of stratabound Cu-Ag deposits in the Revett Formation along the trace of the Big Draw fault west of the reservation in the Thompson River drainage led Jon Thorson (written communication 1994) to suggest that the fault may have been active during Revett deposition and responsible for the Cu-Ag mineralization.

Stratabound Cu-Ag Deposits

The WMCB, hosted in clastic rocks of the Revett Formation, is well known for stratabound Cu-Ag deposits, most notably the world class Spar Lake (Troy mine), Rock Lake (Montanore project), and Rock Creek deposits—all located in the Cabinet Mountains of northwest Montana (figure 3).

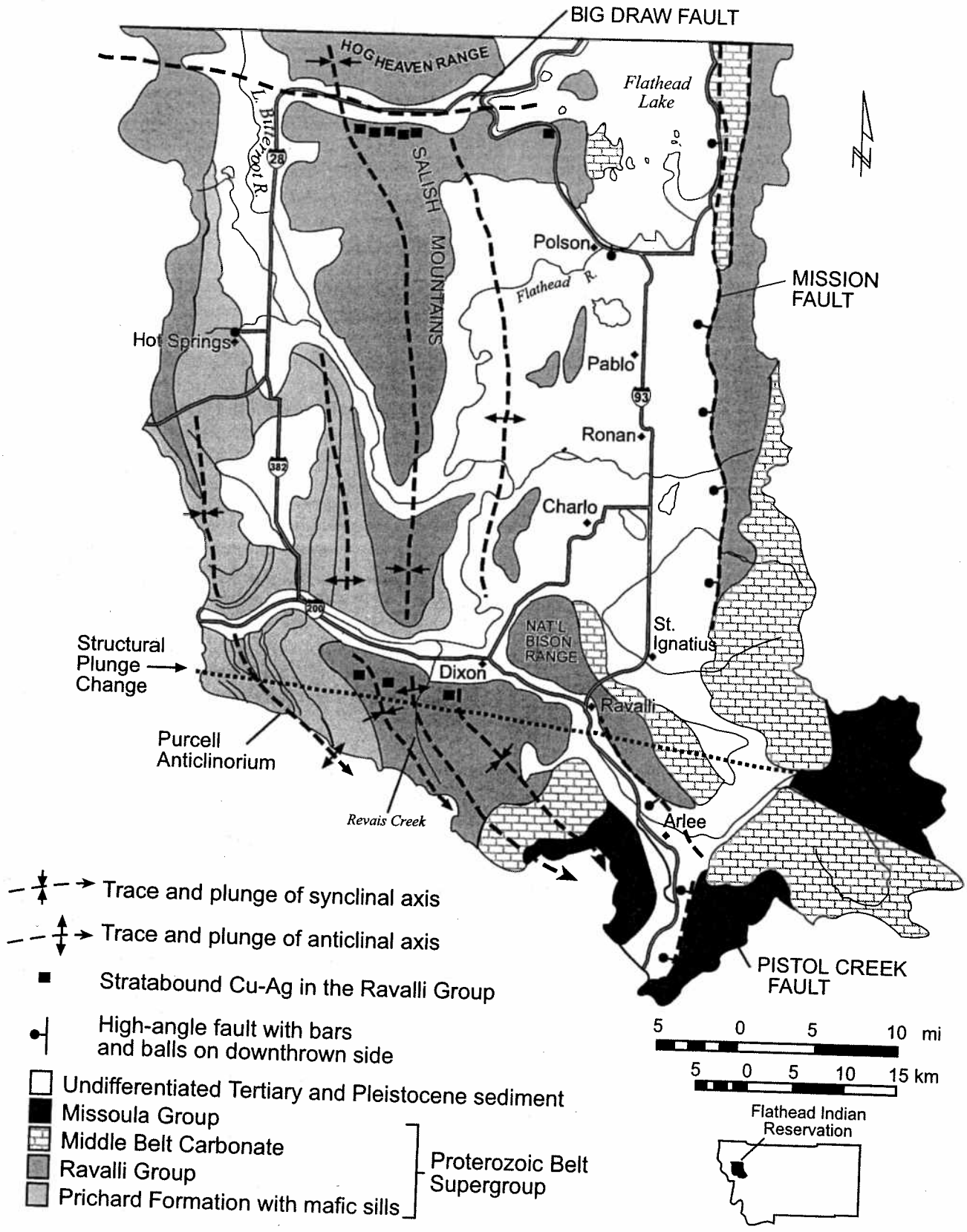

Figure 2. Generalized geologic map of the Flathead Indian Reservation (modified from *Harrison et al. 1986*).

The ore body at the Troy mine is in quartzite and siltite of the upper Revett Formation, whereas ore at Montanore and Rock Creek is in quartzite and siltite of the lower Revett Formation. Mineralization primarily occurs as disseminated bornite and chalcocite interstitial to detrital grains, often concentrated along bedding planes in coarse, permeable units (Hayes and Einaudi 1986). Reserves at the Troy mine were 58 million metric tons averaging 0.7% copper and 1.5 opt silver over 40 stratigraphic feet (12 m) (Hayes and Einaudi 1986), and preliminary reserves at the Rock Creek deposit are estimated at 144 million metric tons of 0.68% copper (Balla 1998).

While the highest grade deposits tend to occur in quartzite, several deposits exist in finer grained siltite and argillite (as well as quartzite) south and east of the Cabinet Mountains. The easternmost reported occurrences of stratabound Revett-type Cu-Ag mineralization are in the WMCB outcrop east of Trout Creek, Montana, 40 mi (60 km) west of the Flathead Indian Reservation (figure 3).

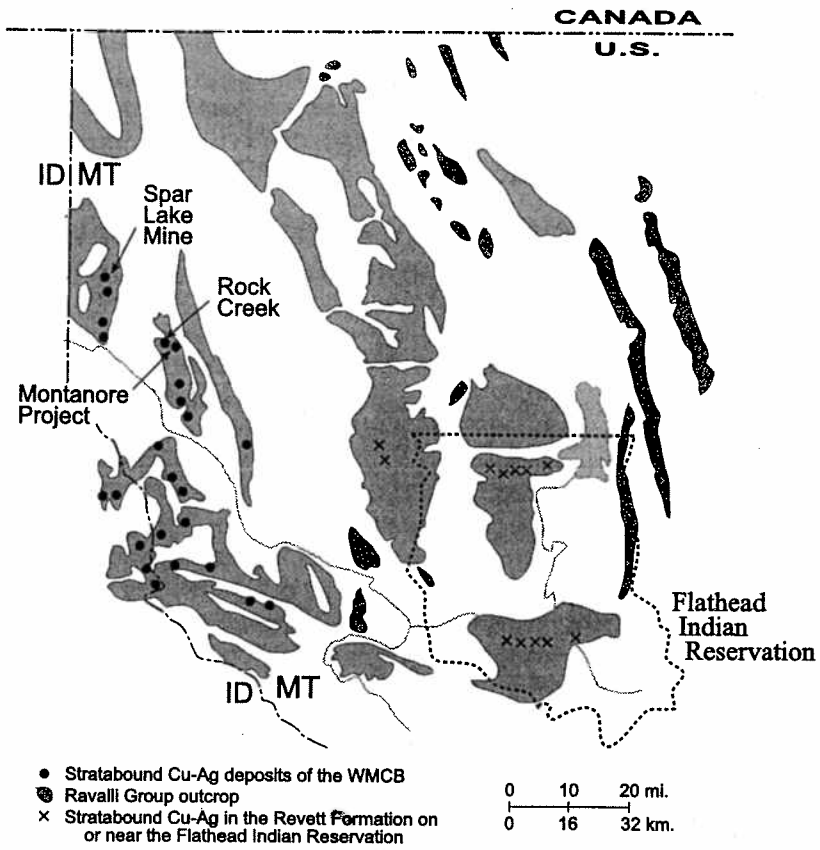

Figure 3. Western Montana copper belt (WMCB), Ravalli Group exposures in western Montana, and stratabound Cu-Ag occurrences in the Revett Formation on the Flathead Indian Reservation (modified from *Lange and Sherry 1983*).

Lange (1975) proposed that Cu-Ag mineralizing fluids originated in oxidized sediment and migrated laterally. Mineral deposits subsequently formed when the migrating fluids encountered bacterially reduced sediment. Lange and Sherry (1983) proposed that these deposits may have formed when oxidized metal-bearing fluids migrated upward along syndepositional faults and into permeable reduced beds. Hayes and Einaudi (1986) studied mineral zonations at the Troy mine and suggested that alteration proximal to the ore-bounding East fault was unrelated to syndepositional faulting.

Numerous greenbed-type copper occurrences are found in green argillite throughout the Belt basin (Harrison *et al.* 1977). Trammell (1975) indicated that greenbed copper occurrences result from sediment dewatering and sulfide accumulation at redox boundaries, while Lange *et al.* (1986) proposed that syndepositional structures controlled Cu-Ag mineralization in green argillite and carbonate of the Ravalli Group near Helena.

Ravalli Group Stratigraphy on the Flathead Indian Reservation

Early workers mapping the Belt Supergroup on the southern end of the Flathead Indian Reservation included a thick sequence of interbedded gray to lavender quartzite, siltite and argillite in the Burke Formation (Wells 1974, Harrison *et al.* 1986), whereas on the northern end of the reservation, Harrison *et al.* (1986) included interbedded lavender quartzite and purple argillite in the Spokane Formation. Mauk (1983), Cronin (1988), and Buckley and Ryan (1991), however, identified the same sequences of rocks as lower, middle, and upper members of the Revett Formation because of similarities with Revett Formation members in the Coeur d'Alene district (White *et al.* 1977). In this study, the authors have mapped all Ravalli Group rocks on the reservation according to the classification White *et al.* (1977) established in the Coeur d'Alene district.

Methods

All Ravalli Group rocks on the reservation were mapped at the 1:24,000 scale, and detailed maps were made of areas where the Revett Formation is well exposed. Geologic maps (1:10,000 scale) were made of the Revais Creek and Ravalli Hill areas on the southern end of the reservation and of the Big Draw area and northern Mission Mountains on the northern end of the reservation. Stream and soil geochemi-

cal surveys were used to explore for stratabound Cu-Ag deposits in the Ravalli Group throughout the reservation. Sulfide and alteration minerals were determined by thin section and X-ray diffraction analyses.

Results

Revett Formation Stratigraphy Southern Part of the Reservation

The lower, middle, and upper members of the Revett Formation (White *et al.* 1977) have been recognized and mapped in a thick section exposed in the Revais Creek area on the southern end of the Flathead Reservation (figure 4). The Revett Formation (5,300 ft [1,610 m]) conformably overlies the Burke Formation (3,530 ft [1,070 m]). The change is gradational, with the proportion of vitreous quartzite progressively increasing upsection in the Burke Formation. The uppermost Burke Formation is defined by interbedded green siltite and medium-bedded sericitic and vitreous quartzite, whereas the base of the lower Revett Formation consists of thick-bedded, vitreous, lavender quartzite separated by thin argillite interbeds.

The most common sedimentary structures in the lower Revett Formation (2400 ft [730 m]) are sets of tabular flat-laminated quartzite that pass upward into climbing ripple cross-laminated quartzite commonly capped by desiccation cracked argillite. Locally, flat-laminated quartzite is underlain by massive quartzite. Less-common sedimentary features include planar cross-beds with tangential and planar toes, lenticular quartzite beds, massive siltite beds, and argillite beds with abundant desiccation cracks.

The middle Revett Formation (1,600 ft [485 m]) mainly consists of purple, green, and gray coupleted argillite with abundant dessication cracks and interbedded massive siltite. Less-common features include intervals of vitreous quartzite, sericitic quartzite, and discontinuous quartz-argillite and siltite-argillite layers.

The upper Revett Formation (1,300 ft [395 m]) is lithologically similar to the lower Revett but contains a greater proportion of lenticular quartzite beds and localized cosets of trough cross-beds.

Thicknesses of the Revett Formation members gradually thin northward throughout the southern part of the reservation with one noteworthy exception. In the Revais Creek drainage immediately south of the previously mentioned structural lineament (Sears 1988); the lower Revett Formation is 2,400 ft thick (730 m). However, 3 mi (1.9 km) north of the structural change, near the town of Dixon, the lower Revett is only 1,800 ft thick (545 m), and 10 mi (15 km) east near the town of Ravalli; the lower Revett is only 1,400 ft thick (425 m) north of the structural lineament (figure 5). This abrupt thinning occurs across the structural lineament and the trace of the Jocko line. In addition, on the northern end of the reservation, the lower Revett Formation thins northward across the Jocko line from 1,200 to 1,020 ft (365 to 309 m) over a distance of 4 mi (6 km).

The St. Regis Formation conformably overlies the Revett Formation, and the contact is sharp. The lowermost St. Regis Formation contains dessication cracked, purple, coupleted argillite and interbedded green coupleted argillite, siltite, and fine-grained quartzite, whereas the uppermost Revett consists of lavender, flat-laminated quartzite with minor siltite and coupleted argillite.

Northern Part of the Reservation

The authors have extended the Ravalli Group stratigraphy throughout the northern part of the reservation. Recognition of the three Revett Formation members on the northern end of the reservation at Big Draw indicates that the total formation thickness is 3,200 ft (970 m), including 1,200 ft (365 m) of lower Revett quartzite, 1,500 ft (455 m) of middle Revett siltite-argillite, and 495 ft (150 m) of upper Revett quartzite (figure 6). Correlation of the lower, middle, and upper members of the Revett Formation across the reservation reveals that the Revett Formation gradually thins northward from 5,300 ft (1,610 m) in the Revais Creek area to 3,200 ft (970 m) at Big Draw, a distance of 40 mi (60 km) (figure 7). The only exception is the abrupt stratigraphic thickness change near Revais Creek. Average grain size also decreases northward (figure 6).

Relatively thin Revett Formation sections (3,200 ft [970 m]) on the north end of the reservation are characterized by climbing ripple cross-beds, scoured beds, cut and fill structures, troughs, megaripples, lenticular quartzite beds, and abundant siltite and argillite interbeds with abundant dessication cracks. The middle Revett at Big Draw is almost entirely purple-couplet argillite and siltite. Sets of tabular flat-laminated quartzite passing upward into climbing ripple cross-laminated quartzite and capped by dessication cracked argillite are present locally in the lower and upper Revett at Big Draw but do not dominate the section. Commonly, flat-laminated quartzite, climbing ripple cross-bedded quartzite, or argillite is scoured and overlain by megaripples and trough cross-beds. These commonly pass upward into climbing ripple cross-bedded quartzite capped by dessication cracked argillite. Individual channels are observed locally.

In the northern Mission Mountains on the northeast part of the reservation, the Revett Formation is 3,400 ft thick (1,030 m). It is lithologically similar to the Revett Formation at Big Draw farther west, but it also contains local thin beds (≤2–3 cm) of white, coarse-grained, red mudchip bearing quartzite characteristic of the northern and eastern correlative, the Grinnell Formation (Whipple 1992, Cronin 1988).

Paleocurrents obtained from Revett Formation climbing ripple cross-bedded quartzite throughout the Reservation

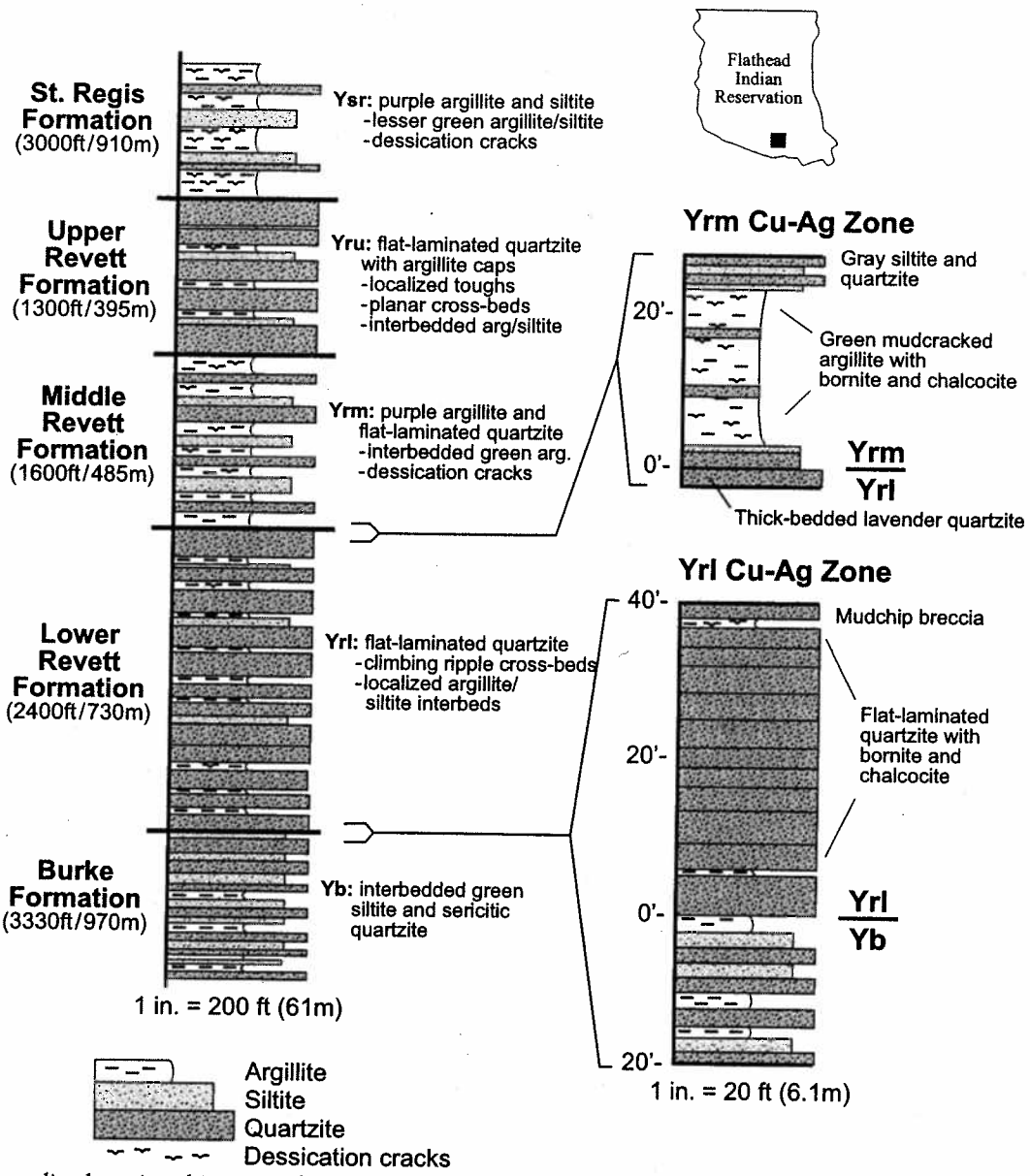

Figure 4. Generalized stratigraphic section showing sediment type and stratabound Cu-Ag in the Revett Formation, Revais Creek, southern Flathead Indian Reservation.

indicate that paleocurrents primarily flowed to the north and northeast. This observation supports data compiled by Hrabar (1973), Bowden (1977), Mauk (1983) and Cronin (1988) showing that the dominant Revett Formation paleocurrent direction was to the north-northeast.

Stratabound Cu-Ag Mineralization South Zone

Stratabound Cu-Ag mineralization occurs at two distinct stratigraphic intervals in the Revett Formation on the southern end of the reservation: 1) in vitreous quartzite of the lower Revett, and 2) in green siltite and mudcracked green-coupleted argillite of the middle Revett (figure 4). Mineralized rock occurs in a 2 x 14-mi (3 x 20-km), west-striking band south of the towns of Dixon and Ravalli and is spatially associated with the structural grain change south of the Flathead River (figure 8). North of the structural change, cleavage is not intense, and folds are broad and strike north-south; south of the structural change, cleavage is intense and folds are tight, plunge to the southeast, and are locally overturned. The mineralized band also coincides with the Jocko line, a proposed syndepositional growth fault (Winston 1986).

Cu-Ag mineralization at the base of the lower Revett Formation primarily occurs as bornite and chalcocite interstitial to detrital quartz grains and as malachite on fractures. The mineralized beds are typically thick-bedded, flat-laminated quartzite beds that locally contain planar cross-beds. The mineralized zone in the lower Revett is approximately 45 ft thick (14 m), with surface grab samples containing 0.3% copper and 0.2 opt silver. The zone is capped by one meter of argillite.

Cu-Ag mineralization at the base of the middle Revett Formation primarily occurs as disseminated bornite and chalcocite (figure 4). Covellite and malachite have been remobilized along Late Cretaceous cleavage planes (Sears 1988). The mineralized zone is at least 20 ft (6 m) thick and surface grab samples contain up to 1.0% copper and 0.5 opt silver and average 0.6% copper and 0.25 opt silver.

Mineral zonation occurs in stratigraphic intervals (figure 9). 3.7 mi (6 km) southwest of the mineralized quartzite in the lower Revett, stratigraphically equivalent quartzite beds are oxidized and contain hematite and iron-rich carbonate. Six tenths of a mile (1 km) northeast of the mineralized zone, stratigraphically equivalent quartzite beds are reduced and contain disseminated euhedral (2 mm) and anhedral pyrite (3 mm diameter). The Cu-Ag mineralization occurs in reduced quartzite at the interface between oxidized and reduced beds. This relationship is most evident southwest and southeast of the town of Ravalli.

Thin section analyses indicate that the middle Revett Cu-Ag zone is characterized by chalcocite replacement of bornite; although, the chalcocite may be the result of supergene alteration. X-ray diffraction patterns of the <2μm fraction indicate that mineralized beds contain abundant iron-rich chlorite, whereas the μm fraction of unmineralized beds at the same stratigraphic level north and south of the mineralized zone are illite rich and contain only traces of chlorite. The mineralized rock is hosted by green, reduced argillite, whereas north and south of the mineralized zone, stratigraphically equivalent argillite beds are oxidized purple argillite.

North Zone

At Big Draw, at least five distinct 9 ft (3 m) thick stratabound Cu-Ag zones occur in reduced green siltite and green-couplet argillite of the uppermost Burke, lower Revett, and middle Revett formations. No mineralization was found in thick-bedded quartzite. The mineralization is exposed in a 3 x 12 mi (5 x 19 km) west-striking band immediately south of the Big Draw fault (figure 2), along a possible syndepositional fault (Thorson, written communication 1994). Surface grab samples contain up to 0.5% copper and 0.5 opt silver.

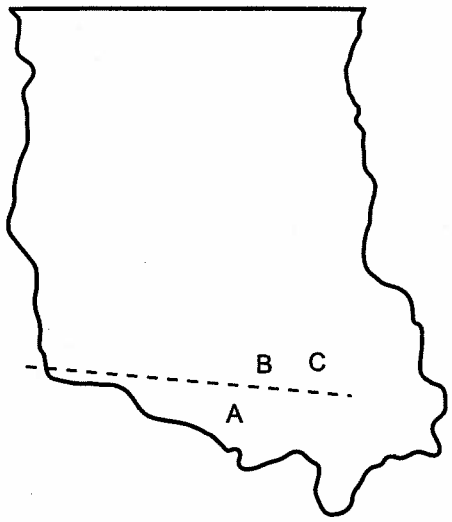

Figure 5. Lower Revett Formation thickness changes across the structural lineament on the southern end of the reservation. This lineament coincides with the Jocko line, a Proterozoic syndepositional growth fault (Winston 1986).

Cu-Ag mineralized green argillite is bounded on all sides by purple argillite.

Detailed geologic mapping and soil and stream geochemistry suggest that no stratabound Cu-Ag mineralization occurs between Revais Creek and the Big Draw. All known stratabound Cu-Ag mineralization on the Flathead Indian Reservation is contained within two west-trending belts, one on the southern end of the reservation (Revais Creek) and one on the northern end of the reservation (Big Draw).

Discussion

Stratigraphy

On the Flathead Indian Reservation, the Revett Formation is a northward-thinning clastic wedge, ranging from 5,300 ft (1,610 m) on the southern end (Revais Creek) to 3,200 ft (970 m) at the northern end (Big Draw). Grain size progressively decreases northward, consistent with a sediment source to the south and northward sediment transport. Climbing ripple cross-beds indicate that paleocurrents flowed downslope to the north and northeast (figure 10).

The occurrence of thick (5,300 ft [1,610 m]) Revett Formation sections on the southern end of the reservation indicates that Revett Formation isopachs strike east-west between the Coeur d'Alene district and Ravalli (figure 10). In this reconstruction, effects of Cretaceous-Tertiary deformation are minor except for complications in the Coeur d'Alene district. There also may be complications in the northwest corner of Montana, where the Revett Formation appears to thicken northeastward between Troy and Lake Koocanusa, possibly in response to syn-depositional tectonics (B. White, Personal Communication 1993).

The authors concur with the work of Mikelsons and Dunlavy (1982), Mauk (1983), and Cronin (1988) that the stratigraphic sequence: Burke Formation to lower, middle, and upper Revett Formation to St. Regis Formation to Empire Formation is mappable and should be applied throughout the reservation.

Revett Formation Sedimentology and Depositional Environment

On the southern end of the reservation, thick Revett Formation sections (5,300 ft [1,610 m]) are dominated by sets of flat-laminated quartzite that pass upward into climbing ripple cross-bedded quartzite commonly capped by dessication cracked argillite (figure 6). This sedimentary sequence is similar to the Bouma sequence observed in turbidites (Bouma 1962), but unlike marine turbidites, the Bouma-like sequences in the Revett Formation are commonly capped by dessication cracked argillite, indicating frequent subaerial exposure.

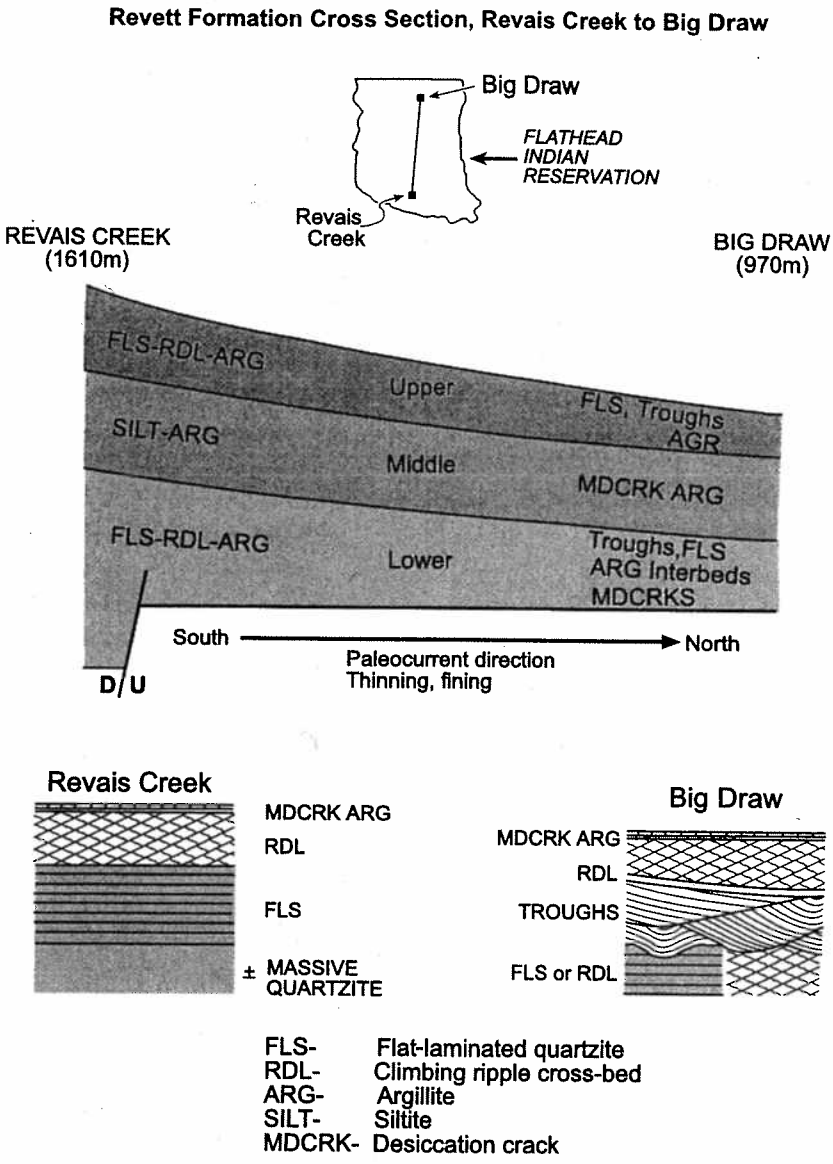

Figure 6. Change in sedimentary facies and thicknesses of Revett Formation members from Revais Creek to the Big Draw. Average grain size decreases northward.

With this in mind, the authors believe the Revett Formation at the southern end of the reservation was deposited by periodic high-energy sheetfloods on a large alluvial-fan complex. Currents flowed in the lower part of the upper flow regime (transitional) and deposited sand from traction load, producing flat-laminated sand beds. As flow velocity decreased, currents passed from upper to lower flow regime and ripple cross-bedded sand was deposited over flat-laminated sand. Finally, fine-grained silt and clay settled out of suspension, resulting in coupleted argillite caps over the ripple cross-beds. Subsequent subaerial exposure formed dessication cracks on the argillite caps. This interpretation is consistent with depositional environments elsewhere in the Revett Formation (Alleman 1983, Mauk, 1983, Kuhn 1987, Cronin 1988, Young and Winston 1990).

At times, upper flow regime sheet floods reached the north end of the reservation and deposited Bouma-like sequences. More often, however, currents moving in the upper flow regime (transitional) at Revais Creek had passed into lower flow regime by Big Draw, causing scouring of existing sediment. The authors believe that the scoured, trough cross-bedded and climbing ripple cross-bedded sequences at Big Draw represent braided stream

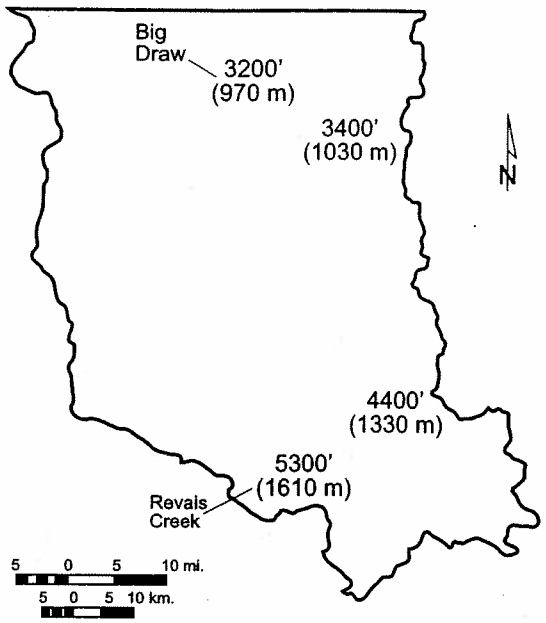

Figure 7. Revett Formation thicknesses on the Flathead Indian Reservation.

deposits at the toe of a large alluvial fan complex. Bowden (1977) also proposed that the Revett Formation farther to the west was deposited by braided streams.

Evidence for Syndepositional Faulting

Jocko Line

The abrupt 1,000-ft (300-m) decrease in stratigraphic thickness in the lower Revett Formation near Revais Creek (figure 5) is consistent with down-to-the-south syndepositional faulting along the Jocko line. The fault motion is consistent with similar motion along the Jocko line documented by Alleman (1983) and Winston (1986) in the Revett Formation 31.1–62.2 mi (50–100 km) west. The west-striking syndepositional Jocko line fault also coincides with a major structural lineament/plunge change, implying that the Proterozoic Jocko line and the Cretaceous structural plunge change were manifested along a long-lived basement weakness that has been periodically reactivated since at least Proterozoic time.

The Jocko line parallels Revett Formation isopachs on the southern end of the reservation (figure 10), suggesting that syndepositional faulting along the Jocko line influenced basin morphology during Revett deposition. Also, west of the reservation near the western Montana copper belt, Revett Formation isopachs are subparallel to proposed west- and north northwest–trending syndepositional faults (figure 10), thus lending further support to a fault-controlled basin during Revett deposition (Lange and Sherry 1983, Winston 1986).

Big Draw Fault

The lower Revett Formation thins from 1,200 to 1,020 ft (365–309 m) across the Big Draw fault, possibly reflecting down-to-the-south syndepositional faulting during lower Revett deposition. However, the thickness change is less than that observed across the Jocko line, and it also appears to be compatible with the progressive northward thinning of the Revett alluvial apron. Middle and upper Revett Formation members are not well exposed on both sides of the fault, making it difficult to determine whether or not the Big Draw fault was active during middle and upper Revett deposition. Further detailed mapping and section measuring, possibly west of the reservation, need to be conducted to determine whether there was syndepositional movement along the Big Draw fault during Revett Formation deposition.

Stratabound Cu-Ag

The location of Cu-Ag mineralization in reduced beds near a redox boundary indicates that oxidized Cu-Ag-bearing fluids flowed through oxidized sediment and deposited sulfides upon encountering reduced zones (Lange 1975, Hayes and Einaudi 1986). The spatial arrangement of reduced pyritic beds to the north and oxidized hematitic beds to the

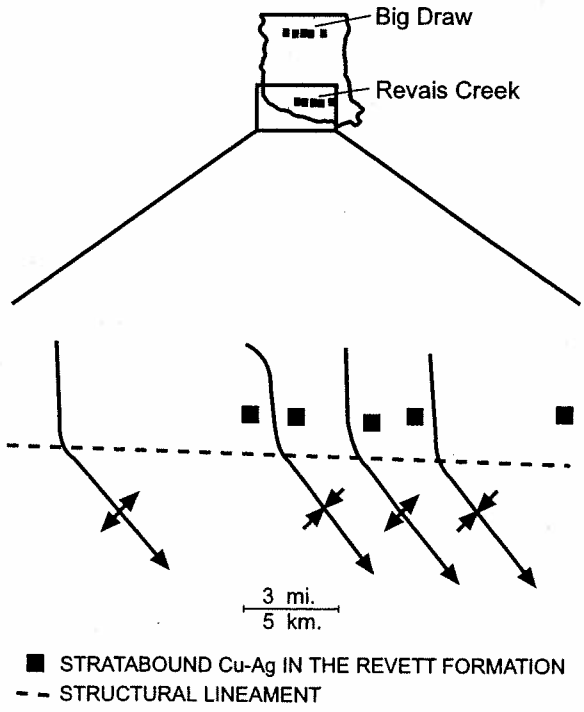

Figure 8. The spatial association of stratabound Cu-Ag mineralization in the Revett Formation and the prominent structural lineament/syndepositional growth fault (Jocko line) (Winston 1986).

south of the mineralized zone indicate that oxidized fluids migrated northward (downdip and basinward). Bornite and chalcocite clots within the mineralized zone and similar size pyrite clots in reduced beds outside the mineralized zone indicate that oxidized mineralizing fluids reacted with pre-existing pyrite to form Cu-Ag sulfides (Lange and Sherry 1983).

Stratabound Cu-Ag mineralization in the lower and middle Revett Formation at Big Draw occurs in green and gray siltite as well as reduced, chlorite-rich green argillite bounded on all sides by oxidized purple argillite. These occurrences are compatible with diagenetic metal-rich fluids migrating through oxidized red beds during basin dewatering and precipitating sulfides upon encountering reduced green beds (Trammell 1975).

Tectonic Influence on Cu-Ag Mineralization

The two known groups of stratabound Cu-Ag occurrences on the Flathead Indian Reservation have an east-west alignment (figure 8). Deposits in lower Revett quartzite and middle Revett siltite/argillite in the Revais Creek area occur along an east-west trend 2.5–3.7 mi (4–6 km) north of both the major east-west striking structural lineament (figure 8) and the east-west striking Jocko line (Winston 1986). The spatial association of lineated Cu-Ag occurrences with a basement weakness/syndepositional fault (Jocko line) is evidence for fault-controlled mineralization, and the mineral zonation at Revais Creek is consistent with the migration of metal-bearing fluids out of the fault and basinward (northward) into reduced beds.

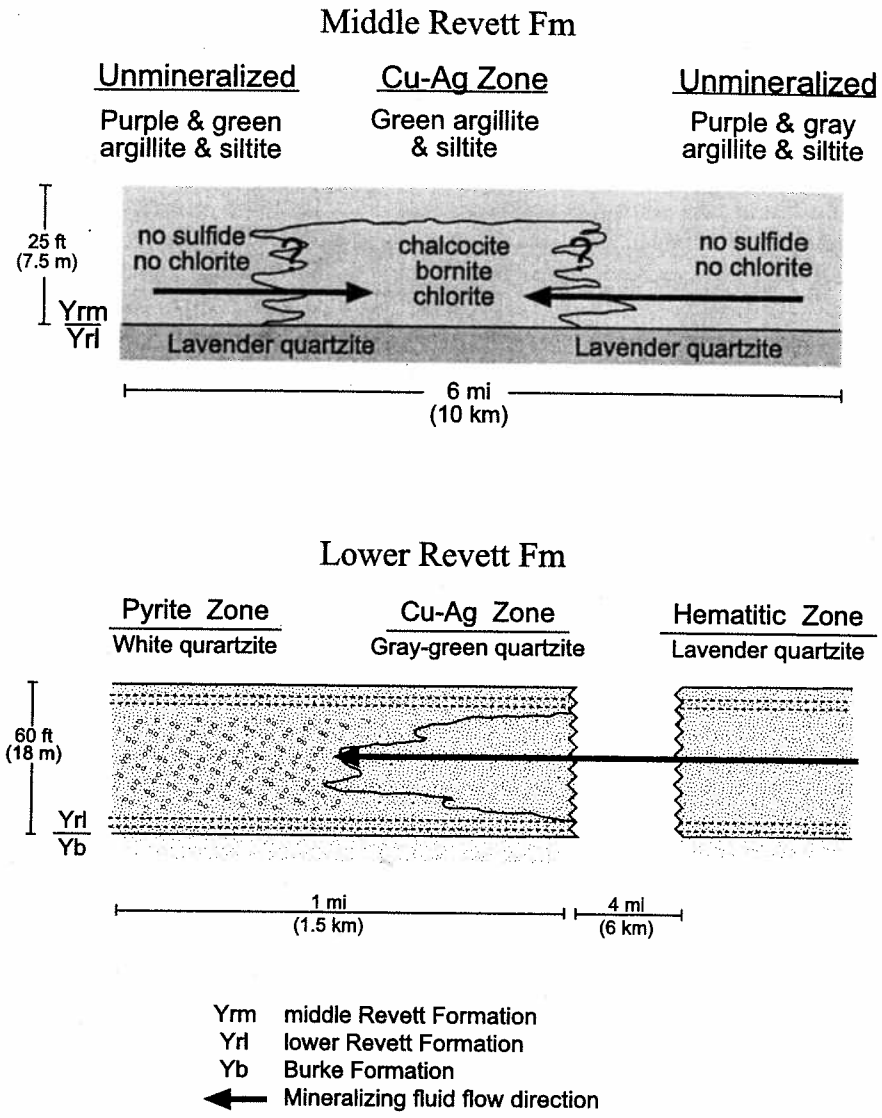

Figure 9. Mineral zonations and the direction of metal-bearing fluid migration in the Revett Formation on the southern end of the reservation.

There is currently no convincing stratigraphic evidence for syndepositional motion along the Big Draw fault, but the alignment of Cu-Ag occurrences along the fault on the reservation and to the west (J. Thorson, written communication 1994) suggests that the fault controlled Cu-Ag mineralization. Further evidence for fault-controlled mineralization is 1) the vertical stacking of mineralized beds at Revais Creek and Big Draw (Lange and Sherry 1983), 2) the lack of Cu-Ag mineralization between the Jocko line and the Big Draw fault, and 3) the association of nearly all stratabound Cu-Ag deposits in western Montana with proposed west- and north-northwest-trending syndepositional faults (Lange and Sherry 1983, Winston 1986).

The formation of stratabound Cu-Ag deposits in both reduced quartzite and green argillite on the reservation may have occurred by one of two methods: 1) oxidized metal-rich fluids may have migrated along syndepositional faults, and on encountering permeable beds, migrated laterally until they encountered reduced zones, where sulfides precipitated (Lange and Sherry 1983); or 2) reduced fluids migrating upward through faults may have migrated laterally into permeable beds, causing vertically stacked reduced zones. Metals, which had been carried into the basin during sedimentation, subsequently migrated through oxidized permeable beds

during diagenesis and dewatering. When these metal-bearing oxidized fluids encountered the west-trending reduced zones, Cu-Ag reacted with pre-existing reduced sulfur and formed sulfides. The northward migration of metal-bearing fluids as indicated by the mineral zonation at Revais Creek is consistent with either model.

Summary

1. The lower, middle, and upper informal Revett Formation members are identifiable and mappable across the reservation.
2. The Revett Formation is a northward thinning clastic wedge. Paleocurrents flowed downslope to the north and northeast and grain size decreases to the north to reflect a dominant south-to-southwest sediment source.
3. Revett Formation sediment was deposited on an alluvial-fan complex by periodic high-energy sheet floods high on the fan and by braided streams near the toe of the fan.
4. An abrupt stratigraphic thickness change proximal to a prominent basement weakness on the southern end of the reservation is evidence for down-to-the-south faulting along the Jocko line during Revett deposition.
5. Oxidized metal-bearing fluids flowed northward (downdip) through oxidized, permeable beds and deposited Cu-Ag sulfides in reduced beds near redox boundaries.
6. Mineralization in the two west-trending stratabound Cu-Ag mineralized belts in the Revett Formation was controlled by fluid migration along two structures, the syndepositional Jocko line and the possibly syndepositional Big Draw faults.

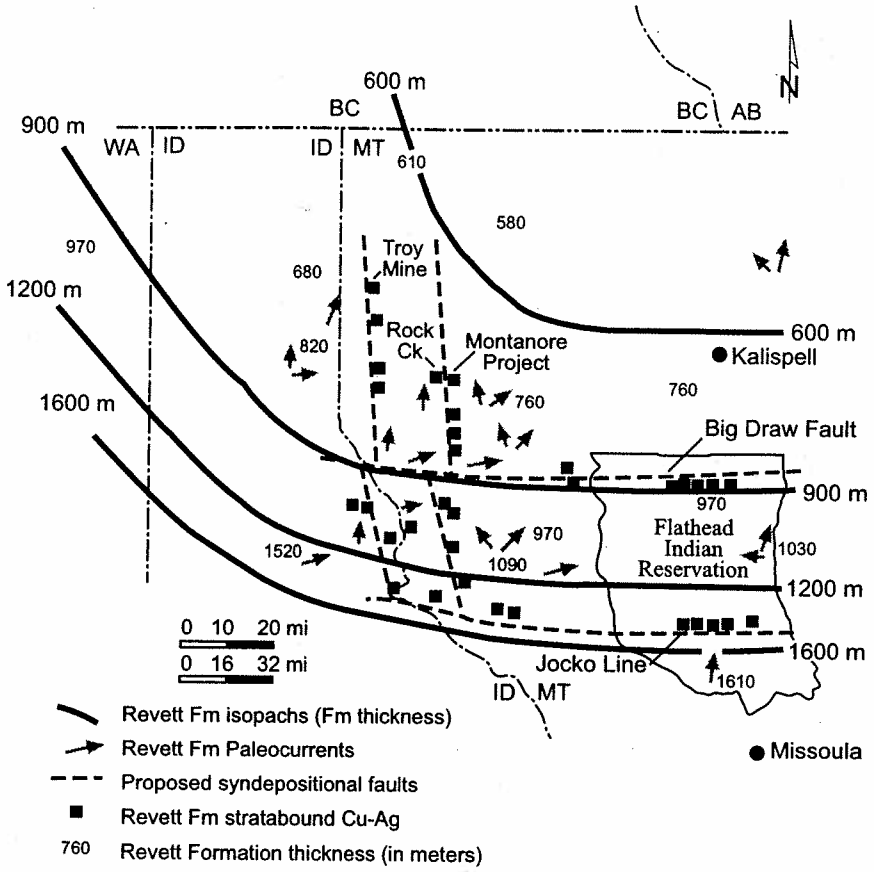

Figure 10. Revett Formation isopachs, paleocurrents, and the spatial association of stratabound Cu-Ag deposits in the western Montana copper belt (WMCB) and proposed syndepositional faults. Revett Formation thicknesses and paleocurrents are from Hrabar (1973), Thompson and Panteleyev (1976), Bowden (1977), Harrison et al. *(1979), Mauk (1983), Kuhn (1987), Cronin (1988), Young and Winston (1990), and this study. Faults are from Lange and Sherry (1983) and Winston (1986). Cu-Ag deposit localities are from Lange and Sherry (1983), Thorson (Written Communication 1994).*

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References

Alleman, D.G., 1983, Stratigraphy and sedimentation of the Precambrian Revett Formation, northwest Montana and northern Idaho [M.S. Thesis]: University of Montana, Missoula, 103 p.

Bouma, A.H., 1962, Sedimentology of some flysch deposits. Amsterdam: Elsevier Publishing Company, 168 p.

Bowden, T.D., 1977, Depositional processes and environments within the Revett Formation, Precambrian Belt Supergroup, northwestern Montana and northern Idaho [M.S. thesis]: University of California, Riverside, 161 p.

Buckley, S., and Ryan, P.C., 1991, Revised Revett Formation stratigraphy, Flathead Indian Reservation, Montana, and implications for exploration of Spar Lake-type stratabound Cu-Ag deposits: Northwest Mining Association, 97th Annual Meeting, Spokane, Washington, p. 15.

Cronin, C., 1988, Stratigraphy and sedimentology of the Ravalli Group (Middle Proterozoic Belt Supergroup) in the Mission, Swan and Flathead ranges, northwest Montana [M.S. thesis]: University of Montana, Missoula, 246 p.

Earhart, R.L., VanLoenen, R.E., and Whipple, J.W., 1980, Mineral and geothermal resources of the Flathead Indian Reservation: U.S. Geological Survey Administrative Report, 80 p.

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

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p.

Harrison, J.E., Lange, I.M., and Harrison, J.P., 1977, Stratabound copper occurrences in green beds of the Belt Supergroup, western Montana: Field Guide for Trip No. 3 Rocky Mountain Section, Geological Society of America, 12 p.

Harrison, J.E. and Reynolds, M.W., 1979, Preliminary geology of the Blacktail Mountain drilling site, Flathead County, Montana: U.S. Geological Survey Open-File Report 79-938, 36 p.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1986, Geologic and structure maps of the Wallace 1° x 2° quadrangle, Montana and Idaho: Montana Bureau of Mines and Geology Montana Atlas Series 4A. Scale 1:250,000.

Hayes, T.S. and Einaudi, M.T., 1986, Genesis of the Spar Lake stratabound copper-silver deposit, Montana: Part I. Controls inherited from sedimentation and pre-ore diagenesis: Economic Geology, v. 181, p. 1899–1931.

Hrabar, S.V., 1971, Stratigraphy and depositional environment of the St. Regis Formation of the Ravalli Group (Precambrian Belt Megagroup) northwestern Montana and Idaho [Ph.D. thesis]: University of Cincinnati, 188 p.

———, 1973, Deep-water sedimentation in the Ravalli Group (late Precambrian Belt Megagroup), northwest Montana, *in* Belt Symposium, D.T. Bishop and J.D. Powell (*eds.*): Idaho Bureau of Mines and Geology, v. 2, p. 67–81.

Jacobson, D., 1981, Rocks of the Ravalli Group mapped within the National Bison Range, Moise, Montana [Senior thesis]: University of Montana, Missoula, 9 p.

Kuhn, J.A., 1987, The stratigraphy and sedimentology of the Middle Proterozoic Grinnell Formation, Glacier National Park and the Whitefish Range, northwest Montana [M.S. thesis]: University of Montana, Missoula, 121 p.

Lange, I.M., 1975, Revett sulfide deposits and sandstone-type redbed copper deposits of the southwestern United States: Northwest Geology, v. 4, p. 59–76.

Lange, I.M., and Sherry, R.A., 1983, Genesis of the sandstone (Revett) type of copper-silver occurrences in the Belt Supergroup of northwestern Montana and northeastern Idaho: Geology, v. 11, p. 643–646.

Lange, I.M., Herberger, D., and Whipple, J.W., 1986, Stratabound Cu-Ag and Pb-Zn mineralization in the Spokane and Helena formations in the eastern part of the Belt basin, Montana: A common origin?: Geological Association of Canada, v. 11, 93 p.

Mauk, J., 1983, Stratigraphy and sedimentation of the Proterozoic Burke and Revett formations, Flathead Reservation, western Montana [M.S. thesis]: University of Montana, Missoula, 106 p.

Mikelsons, I. and Dunlavy, P., 1982, Stratigraphy and stratigraphic correlations of the Ravalli Group rocks, The National Bison Range, Moise, Montana [Senior thesis]: University of Montana, Missoula, 12 p.

Sears, J.W., 1988, Two major thrust slabs in the west-central Montana cordillera: Geological Society of America Memoir 171, p. 165–170. Thompson, R.I., and Pantaleyev, A., 1976, Stratabound mineral deposits of the Canadian Cordillera, *in* Handbook of Stratabound and Strataform Ore Deposits II. Regional Studies and Specific Deposits, K.H. Wolf (*ed.*): Elsevier, New York, p. 37–108.

Trammell, J.W., 1975, Stratabound copper mineralization in the Empire Formation and Ravalli Group, Belt Supergroup northwest Montana [Ph.D. thesis]: University of Washington, Seattle, 71 p.

Wells, J.D., 1974, Geologic map of the Alberton quadrangle, Missoula, Sanders, and Mineral counties, Montana: U.S. Geological Survey Quadrangle Map GQ-1157. Scale 1:62.000.

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

White, B.G., Winston, D., and Jacob, P.J., 1977, The Revett Formation near Kellogg, Idaho: Geological Society of America, Abstracts with Programs, v. 9, No. 6, p. 773.

Winston, D., 1986, Sedimentation and tectonics of the Middle Proterozoic Belt basin and their influence on Phanerozoic compression and extension in western Montana and northern Idaho, *in* Paleotectonics and sedimentation in the Rocky Mountain Region, United States, J.A. Peterson (*ed.*): American Association of Petroleum Geologists Memoir 41, p. 3–20.

Young, A.A., and Winston, D., 1990, Sheetflood deposition in the Revett Formation (Middle Proterozoic Belt Supergroup), northwestern Montana: Geological Society of America, Abstracts with Programs, v. 22, no. 6, p. 51.