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MIDWAY LATE CRETACEOUS AG-PB-ZN MANTO DEPOSIT, NORTHERN BRITISH COLUMBIA (104O/16)

Introduction

The Midway Ag-Pb-Zn deposit is located in map area 104O/16, 10 kilometres south of the B.C. - Yukon border and about 80 kilometres west-southwest of Watson Lake, Yukon Territory. The deposit is centred at latitude 59 55' north, longitude 130 20' west. Mineralization consists of irregular, pipe - like, open - space filling and replacement - type massive sulphide bodies in mid - Devonian McDame Group carbonates beneath a major unconformity. Reserves currently stand at 1.185 million tonnes grading 410 grams Ag, 9.6% Zn, and 7.0% Pb (Exploration in B.C., 1986). Regional mapping conducted during the 1986 field season showed that the deposit lies near the southern termination of a broad, north trending extensional fault system (Tootsee River fault zone)(Nelson and Bradford, 1987). This zone intersects a 5 kilometre long, northwesterly trending belt of hydrothermal alteration just south of the deposit. Intense sericitic alteration and quartz veining in Devono - Mississipian Earn Group sediments, and coincident gravity and magnetic anomalies strongly indicate that the buried intrusive body coring the Midway hydrothermal system underlies Brinco Hill, about 2 kilometres southeast of the Midway deposit. Deposit chemistry, sulphide mineralogy, isotopic signatures, and preliminary temperature data indicate that Midway is an epigenetic, manto -

type deposit; K-Ar dates and Pb isotope model ages support a Late Cretaceous age of mineralization. The following highlights some of the results of ongoing studies of the Midway deposit and environs by the senior author and others.

Deposit Geology

Stratigraphy

Strata exposed east of Silvertip Creek in the vicinity of Midway range from Devonian to Mississipian in age (Figure). Miogeoclinal carbonates of Lower to Middle Devonian age are unconformably overlain by Upper Devonian to Lower Mississipian (mid - Fammenian to mid - Tournasian: M. Orchard, personal communication, 1986) basinal shales and turbidite deposits of the Earn Group. The Earn Group is structurally overlain by oceanic sediments and volcanic and intrusive rocks of the Sylvester Allochthon.

McDame Group

McDame Group carbonates of Middle Devonian age (unit 2) para-conformably overlie Lower Devonian Tapioca sandstones (unit 1), and outcrop on Silvertip Hill west of Camp Creek Fault, on the south side of Silvertip Creek in the Midway portal area, and on the north end of Tour Peak, south of Silvertip Hill (Figure

). The base of the McDame grades down through a series of alternating light and dark grey, well laminated dolostones, into non - fetid dolostones and interbedded dolomitic quartz arenite of the upper Tapioca sandstone.

Total thickness of the McDame Group in the Midway area is about 350 metres. Dolomitic facies dominate in the lower third of the section, and consist of dark grey, fetid cryptalgal laminites and interbedded massive dolostone. The upper two - thirds of the section consists of fossiliferous, fetid rudstones, floatstones, wackestones, and packstones, with interbedded micritic limestones.Faunal assemblages of low diversity consist primarily of Stromatoporoids, with local concentrations of brachiopods, corals, crinoids, and bivalves (Mundy, 1984).

The upper McDame contact is a regional unconformity marked by topographic relief of over 100 metres. Erosional relief and widespread karsting as manifested in spar - healed breccias, vugs, and coarse spar - filled paleocaverns up to several metres across testify to uplift and subaerial exposure of parts of the carbonate platform prior to subsidence and deposition of Earn Group basinal shales. Detailed biostratigraphic correlations suggest that uplift may have been accompanied by local block faulting (Mundy, 1984). Following regional extension and submergence of the carbonate platform in middle Fammenian time, solution collapse within the karsted upper McDame accompanied deposition and diagenesis of the lower Earn. Mixed limestone and uncrenulated shale fragments in spar - healed and lime mud - filled cavities in the upper McDame are widespread. These breccias are commonly well compacted and contain abundant stylolites crosscutting and forming sutured clast boundaries as a result of later pressure solution during Earn diagenesis. Locally, well bedded mudstones and siltstones occur within compacted shale and limestone breccias in cavities 30 metres or more below the top of the McDame, indicating that some cavities were open to the ocean floor during deposition of the Earn.

Earn Group

Lowermost Earn Group sediments consist of carbonaceous, locally calcareous or siliceous, black shales (unit 3A, Figure) up to 40 metres thick. This euxinic basin facies contains a rich conodont faunule of mid-Fammenian age (M. Orchard,personal communication, 1986). Thickness is variable over short distances, while in places the unit is missing entirely, perhaps due to depositional control by McDame paleotopography. Graphitic slickensides are common, indicating that the unit served as a detachment surface between the McDame and overlying thick, coarse siliciclastic sediments. Some thickening and thinning, therefore, might be structural in nature.

The black shale unit is overlain by a thick (up to 250 metres) succession of coarse sandstone, mudstone, and pebble conglomerate characterized by ubiquitous normal and reverse graded bedding, load and flame structures, rip - ups, mud drapes, and sole marks (unit 3B). The sandstones are litharenites, consisting mainly of quartz, chert, and shale grains. According to Gordey et al. (1986), the development of this turbidite succession above the euxinic basin facies occurred as a result of local uplift and erosion of miogeoclinal blocks during early Mississipian extension.

A thick succession of argillite, slate, siltstone, calcarenite, and sandstone containing several exhalative horizons (unit 3C, Figure) overlies unit 3B coarse turbidites. Exhalite horizons exposed at surface consist of orange - weathering laminated silica, barite, pyrite, and locally, sphalerite. They rarely attain thicknesses of over 2 metres. Discontinuous exhalites are exposed along a strike length of almost 10 kilometres south from Midway. This probably represents a linear string of exhalative centres aligned along a basinal margin fault zone which also controlled later deposition of coarse turbidites.

A sequence of pebble to boulder conglomerate and lesser sandstone with a thickness of 150 to 200 metres (unit 3D) overlies exhalite - bearing fine clastics on Silvertip Mountain and Tour Peak. On Tour Peak, a section of well - rounded boulder conglomerate contains McDame limestone, Tapioca Sandstone quartzite and dolostone, possibly Lower Cambrian Boya

Formation quartzite, and black massive chert of undetermined origin.

The transition from fine clastics of unit 3C to conglomerates of unit 3D might represent a turbidite feeder channel prograding over its distal lower fan. The channel deposits are localized to the Silvertip Mountain - Tour Peak areas, with no thick conglomerate occurring to the south or west. Instead , thinner lensoid conglomerates are interbedded with and overlain by fine clastics in the Caribou Ridge area, south of Tour Peak, suggesting a lateral facies change.

A thick sequence of black argillite, limestone with black chert, and green thin - bedded chert and cherty phyllite, assigned to Division I of the Sylvester Allochthon (Nelson et al., 1988) abruptly overlies unit 3D. Conodonts from this section give a late Tournasian age, while unit 3C of Earn Group contains early to mid - Tournasian conodonts (M. Orchard, personal communication, 1986).

Structure

The main set of sulphide bodies at Midway which makes up the Silver Creek deposit is situated on the west limb of a shallowly southeasterly plunging open anticline (Figure). The east limb dips to the east at about 25 degrees, while the west limb is folded and cut by a strand of the Tootsee River fault zone. The anticlinal fold axis parallels southeasterly regional structural trends generated during Jurassic compression and emplacement of the Sylvester Allochthon. Locally, a later east - trending phase of folding deforms southeasterly trending structures. This phase is characterized by chevron and kink folds, that are often accompanied by en echelon quartz - filled extension gashes.

Thrust faulting can be inferred from diamond - drilling in the Silver Creek and Silvertip areas. In the southern part of the Silver Creek deposit (DDH MW 84, 86) a wedge of unit 3B is imbricated with unit 3C above the lowermost exhalite horizon. On Silvertip Hill (DDH MW 40) McDame limestone is imbricated with unit 3A, which has undergone possible structural thickening.

The Silvertip area is cut by several strands of the Tootsee River fault zone (TRFZ), a north - trending complex of anastomosing high angle faults extending from about 7 kilometres south of Midway to about 17 kilometres north of the British Columbia - Yukon Territory border (Lowey and Lowey, 1987). These include the Silvertip Creek, Camp Creek, and Brinco Creek faults (Figure).

The Silvertip Creek fault separates Silvertip Hill and Tricorn Mountain to the west. Rotation of large blocks juxtaposed a south dipping panel on Tricorn Mountain and east dipping strata on Silvertip Hill. Because of the discordant dips and convergence of several fault strands north of Midway, stratigraphic throw increases from 50 metres west of Silvertip Hill to over one kilometre (Rosella Formation against Sylvester) in a narrow zone in the Silvertip Creek valley, 3 kilometres to the north. Uplift on the west side of this zone, near the Silverknife showing, may be due in part to doming above a buried intrusion, as Kechika Group metasediments are strongly hornfelsed.

The Camp Creek fault juxtaposes McDame Group and Earn Group on Sivertip Hill, where it diverges into 2 main strands with offsets of about 50 metres, east side down. Between fault strands, strata are disrupted and locally overturned. Mineralization in the Silver Creek Deposit and the Silvertip showing is proximal to this fault zone, which may have served as a hydrothermal solution guide.

The Brinco Creek Fault offsets strata east of the Discovery Deposit, with a displacement of about 100 metres, east side down. Other faults with smaller offsets may occur west of the Brinco Creek Fault. The latter appears to die out to the southeast, as the base of the Sylvester Allochthon west of Brinco Hill is not offset.

Regionally, the TRFZ is proximal to both Late Cretaceous (Midway) and Eocene (Butler Mountain) intrusions as well as numerous Ag-Pb-Zn showings of the Rancheria district (Abbott, 1984). Overprinting of Early Mississipian exhalative and Cretaceous to Eocene intrusive related mineralization within the TRFZ suggests that it may represent a long lived, periodically remobilized zone of structural weakness and anomalous heat flow that was initiated in the Late Devonian during extension along the continental margin. Remobilization of old structures during Late Cretaceous to Eocene dextral wrench faulting may have contributed to localization of post Cassiar batholith intrusions. At the same time, anomalous heat flow might have induced crustal extension and thinning, and helped reactivate old extensional fault structures.

Alteration and Evidence for Intrusions

Intense sericitization of Earn Group and Sylvester sediments occurs in a northwesterly trending zone extending from Silvertip Hill southeast for about 5 kilometres to Gum Mountain. Strong alteration is also evident at deeper levels in diamond drill holes in the southeasterly part of the Midway drill grid (near DDH MW 16, 32, and 41), and south of Silvertip Mountain (near DDH B82-1). Its strongest expression is on the north side of Brinco Hill, which coincides with gravity and magnetic anomalies interpreted as consistent with a buried intrusion at depth (J. Hylands, personal communication, 1986). At Brinco Hill, Earn sandstones and conglomerates are altered to fine sericite, quartz, pyrite, rutile, and rare carbonate, with both matrix and non - silica clasts being completely replaced. The altered sediments are cut by numerous vuggy, locally comb - structured 1 - 10 centimetre thick quartz veins containing pyrite, chalcopyrite, and rare galena blebs. Isotopic analyses of alteration zone galena are pending, and may help support a genetic relationship between the alteration zone and carbonate hosted deposits at Midway.

Quartz - feldspar - biotite porphyry dykes are exposed at surface west of Gum Mountain, where they intrude intensely sericitized and pyritized Sylvester argillites and cherts. The dykes at surface are commonly altered to sericite, carbonate, quartz, and pyrite. Similar dykes were observed during the 1987 field season in the Blue Dome sheet (104P/12), where they occur as subparallel swarms associated with quartz veins in Sylvester basalts and argillites.

Alteration is associated with anomalous fluorine values. Grab samples indicate that QFP dykes near Gum Mountain contain up to 1200 ppm F, while sericitized conglomerates at Brinco Hill ran 790 ppm F. Microprobe analyses of sericites from surface and drill core show averaged values for several probe sites per sample ranging from 2900 to 21900 ppm F (W.D. Sinclair, written communication, 1986). Substitution of F for OH- groups in alteration zone micas probably reflects the contribution of magmatic volatiles to the hydrothermal system centered on Brinco

Hill.

Reclusive subvolcanic felsic intrusives, elevated fluorine in alteration minerals, and geological setting within an extensional fault system adjacent to an older, voluminous intrusion (Cassiar batholith), are all features typical of A - type (anorogenic) granites (W.D. Sinclair, personal communication, 1986; Collins et al., 1982). The presence of Sn mineralization (e.g. stannite and franckeite) at Midway is also consistent with this interpretation, although Sn is also associated with S - type granites. Intrusives coeval with the Midway system in the Cassiar Platform include the Troutline, Kuhn, and Windy stocks in the Cassiar area. Numerous Ag-Pb-Zn and W skarns and veins, F anomalies, fluorite veins, and Mo showings are associated with the young Cassiar granites (Panteleyev, 1980). Chemistry of this intrusive suite is more typical of S - type granites, or I - type granites strongly contaminated with upper crustal material (Cooke and Godwin 1984). In any case, strongly fractionated, volatile rich felsic intrusives, whether A or S - type, are apparently fundamental to generating hydrothermal systems associated with Ag-Pb-Zn±Sn mineralization. The presence of fluorine depresses the liquidus temperature, enabling prolonged fractionation of volatile rich phases, decreases melt viscosity, enabling magmatic ascent to subvolcanic levels, and facilitates formation of metal complexes in late - stage fluid - rich melts (e.g., Hannah and Stein, 1986).

K - Ar Dating

K - Ar dating of samples collected by JoAnne Nelson and coworkers during mapping of 1040/16 focussed on intrusives and alteration associated with Ag-Pb-Zn mineralization (Table). Two samples were dated from the alteration zone southeast of Midway (JN30-11 and JB23-2), one from a late intrusion less than 100 metres from surface exposures of sulfide bodies at the Amy property (JB26-12), and one from sericite envelopes around galena - rich quartz veins at the Lucky showing, hosted in the Cassiar batholith (KG28-7). The Midway samples include sericitized Earn Group sediments from Brinco Hill, and a sericitized quartz - feldspar porphyry dyke near Gum Mountain. These give a late Cretaceous age, interpreted as the age of alteration, and therefore appear to be coeval with emplacement of a hidden intrusive body at depth.

The intrusion sampled at the Amy property, a Ag-Pb-Zn replacement deposit in Cambro - Ordovician Kechika Group? marbles and calcsilicates, is a tourmaline bearing equigranular muscovite granite with coarse quartz - muscovite - tourmaline greisen zones. The date of 97.3 Ma (Table) suggests that this might represent a late - stage apophysis of the Cassiar batholith. The Amy deposit contains drill indicated reserves of 72,437 tonnes grading 367 grams/tonne Ag, 2.84% Pb, and 6.03% Zn.

Dating of the Lucky veins also suggests that these belong to a Cassiar batholith related mineralizing episode. This contradicts the suggestion of Abbott (1984), that galena - rich veins of the Midway - Rancheria district hosted in the Cassiar batholith are Tertiary in age.

Cretaceous - Tertiary mineralization in the Rancheria district occurred in three separate episodes. Mid - Cretaceous showings include Ag-Pb-Zn replacement deposits (Amy) and intrusive hosted veins (Lucky), and Mo-W showings at the margins of the Cassiar batholith (Nancy, Root) (Nelson and Bradford, 1987). Late Cretaceous intrusions are responsible for carbonate hosted Ag-Pb-Zn-Sn mineralization at Midway as well as proximal quartz veins (Brinco Hill, Tootsee Star). Eocene mineralization includes Ag $\pm$ Au-Pb-Zn showings (Butler Mountain) and Sn veins and greisens (Fiddler) (W.D. Sinclair, C.I. Godwin, unpublished data). The three intrusive and associated mineralizing episodes correspond to a similar set of intrusive ages in the Cassiar area (Panteleyev, 1985; Christopher et al., 1972).

Sulphide Paragenesis and Morphology

Sulphide bodies at Midway are characterized by a complex mineralogy, with at least 16 ore and gangue minerals identified

(Archambault, 1984). Microscopic and mesoscopic paragenetic relations indicate four main mineralizing episodes: (1) early silica - rich, (2) main - stage sulphide - silica, (3) late sulphide - sulphosalt, (4) late carbonate. In addition, post mineral supergene effects have caused some alteration of the sulphide - gangue assemblage. Mesoscopic textures suggest that conditions of sulphide deposition fluctuated cyclically, resulting, for example, in repeated layers of the sequence pyrite - galena - sphalerite. Thus within the overall compositional evolution of the hydrothermal system, variability of depositional conditions resulted in an inordinate variety of paragenetic relations. On the deposit scale, larger patterns of sulphide zonation probably reflect P - T - X gradients related to depth, proximity to the intrusive heat source, and shape of the fluid pathway.

Sulphide bodies are massive and irregular in form, with clean, sharp wallrock contacts which are locally bleached or silicified. Both sub - horizontal, pipe - like bodies and vertical, keel - shaped chimneys occur, but these do not have predictable compositional differences, as at some manto deposits (J. Hylands, 1986, personal communication; Lovering et al., 1978). Although wallrock contacts are sharp, one may see gradational transitions outward from massive sulphides, to sulphide - matrix breccias with angular "stoped" wallrock clasts, to carbonate - matrix mosaic and crackle breccias, to unbrecciated limestone. This suggests that sulphide deposition was partly controlled by pre - existing porosity as defined by carbonate - healed breccia haloes around premineralization open channels and vuggy breccias, now filled and partly replaced by sulphide.

In addition, stylolite - sutured mixed limestone - shale breccias with fine grained non - sparry carbonate matrix occur within and at the base of some sulphide bodies; these may be relict premineral solution collapse breccias in a lithified lime silt (calcarenite) karst - filling. Internally, massive sulphide bodies contain angular wallrock clasts from pebble to boulder size, occurring as single fragments, mosaics of clasts of diverse sizes, or jumbles of rotated clasts of mixed lithologies. Shale - clast breccia zones within massive sulphide bodies occur well below (> 100 metres) the Late Devonian unconformity. Mixing of shale and limestone clasts at such depths indicates that solution collapse of great vertical extent occurred within the McDame. In some cases shale fragments exhibit a strong crenulation lineation, showing that collapse occurred after Jurassic compressional deformation, probably during mineralization.

Massive sulphide bodies are most commonly found near the McDame - Earn contact, but also occur up to 100 metres below it. The relatively impermeable lowermost Earn black shales constituted an infiltration barrier to hydrothermal solutions and thus behaved as a fluid flow guide. The shales are commonly brecciated and veined above major sulphide bodies, with sulphides (especially pyrite) cutting shale along bedding and fracture planes. Concentration of sulphide bodies near the unconformity indicates that pre - existing carbonate porosity was probably greatest in the upper part of the McDame, producing favorable conditions for sulphide deposition along this horizon. Mixing of shale clasts into sulphide bodies adjacent to the unconformity is suggestive of syn - mineralization hydrothermal stoping along the contact.

A further set of breccias internal to massive sulphide bodies contain sulphide and quartz fragments from earlier phases of mineralization. Hydrothermal brecciation (possibly involving solution collapse of previously deposited sulphides) caused mixing of earlier sulphide fragments (most commonly pyrite, but in some cases including pyrrhotite, arsenopyrite, sphalerite, and galena) and shale clasts, sulphides and limestone clasts, or mixed sulphide - shale - limestone clasts in a later sulphide matrix. Mixed - clast breccias in carbonate matrix are also common; these post - date sulphide deposition and involve the latest phase of the hydrothermal system.

In summary, breccias at Midway are multi - episodic, and juxtapose diverse combinations of lithologies, sulphide, and gangue clasts. Pre-, syn-, and post - mineral brecciation episodes can be documented. Pre - mineral brecciation and clast mixing occurred during Earn diagenesis, and support a model by which early karsting of the upper McDame provided enhanced permeability for fluid flow and sulphide deposition.

Zoning

Skarn - manto systems often show a district scale compositional or mineralogical zonation, reflecting temperature and chemical gradients with respect to the intrusive heat ± volatile source, and pressure gradients with respect to surface (e.g. Darwin, California, Hall and MacKevett, 1962; Zimapan, Mexico, Simons and Mapes, 1956). Exploration at Midway has been sufficient to indicate analogous zoning patterns. Within the Silver Creek deposit, a north - south transect shows an apparent mineralogical shift which may be a function of distance from heat source and depth. In the northen part of the deposit, sulphide bodies have high Pb - Sb sulphosalt contents, commonly up to 15% and locally as high as 40%, while 300 metres to the south and at deeper levels mineralization contains relatively minor sulphosalts. In addition to indicating a possible zonation with respect to heat source and depth, such transitions may also be a function of pre - existing permeability, with high Pb/Zn and high Ag/Pb representing zones of high permeability (Birnie and Petersen, 1977).

The southern part of the Silver Creek deposit contains sulphide bodies with abundant pyrrhotite. Pyrrhotitic assemblages with chalcopyrite and negligible galena also predominate in sulphide intersections in the southern part of the Discovery deposit (MW 16, MW 26), and in B82-1, west of Brinco Hill. The change from galena - sulphosalt to pyrrhotite - chalcopyrite apparently defines a deposit - scale zonation pattern. Cordilleran Engineering, Assessment Report 11020, 1982 This provides evidence for relating the alteration zone centred on Brinco Hill to the sulphide pipes at Midway, since similar mineralogical transitions in better explored skarn - manto systems correlate with distance from intrusion, with Fe-Cu rich sulphides representing proximal mineralization, and Pb-As-Sb - rich zones representing distal mineralization. In addition, deep drill intersections closest to Brinco Hill (MW 26) contain calcsilicates (tremolite and epidote) intimately intermixed with pyrrhotite; skarn mineralogy has not been found elsewhere in the Midway system.

Tin mineralogy is also zoned. Tin is high (> 1000 ppm) in two areas, one in the northern part of the Silver Creek deposit, and another 300 metres to the south. The two areas differ in that Sn-Sb-Pb sulphosalts (franckeite) are the primary tin bearing minerals in the former case, whereas stannite is the only tin mineral in the latter, accompanying pyrrhotitic mineralization (Archambault, 1984).

In manto - skarn systems elsewhere, distal, shallower sulphosalt - rich zones are commonly silver - rich, while proximal, deeper, iron - rich sulphide zones are commonly gold - rich and silver - poor. In view of the limited exploration done in areas proximal to Brinco Hill (due to depth of cover rocks), Au mantos and veins in cover rocks may represent an interesting exploration possibility south of currently explored mineralization.

Summary

Studies of the Midway deposit and environs to date have suggested several exploration parametres and controls on mineralization. Regionally, localization of intrusive and associated hydrothermal systems along large - scale high - angle fault systems is important. The bulk of skarn - manto - vein systems in carbonates in the Cassiar Platform are associated with young felsic intrusives (post Cassiar batholith), which are commonly reclusive in outcrop, but generate large alteration haloes in non - carbonate cover rocks, and are associated with F, Sn, W, Mo, Pb, and Zn anomalies. Strongly fractionated late phases of older intrusions may also be mineralizers.

At the deposit scale, fault control of fluid pathways may be significant in areas with coeval or overlapping intrusion and faulting. At Midway, known sulphides are largely distributed between the Camp Creek and Brinco Creek faults, while no mineralization has been found west of the Silvertip Creek Fault. These faults converge north of Midway, and the convergent zone may have focussed fluid pathways. The coincidence of this fault convergence with an antiformal structure above which lies a shale cap of low permeabilty probably contributed to focussing of hydrothermal fluid migration in the vicinity of the Silver Creek deposit. The southeasterly plunge of this structure might have controlled upward and outward migration of fluids from the intrusive center to the trapping structure.

Stratigraphically, both a strongly brecciated, karsted carbonate sequence with enhanced permeability, and less permeable capping sequences are significant controls on sulphide deposition.

Deposit - scale mineral zoning may be useful in defining intrusive centres and their spatial relationship to ore bodies. At Midway, sporadic sulphides are found throughout the area bounded by the Camp Creek and Brinco Creek faults in veins in cover rocks, and in limestone where drilling has been undertaken. By comparison with skarn - manto systems elsewhere, major sulphide bodies are probably not limited to the relatively distal unskarned environment of the Silver Creek deposit, and mineralization of different tenor may be expected closer to the intrusive core of the system.

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