SEDIMENTARY EXHALATIVE (SEDEX) Zn-Pb-Ag E14

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Refer to preface for general references and formatting significance.
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IDENTIFICATION

SYNONYMS: Shale-hosted Zn-Pb-Ag; sediment-hosted massive sulphide Zn-Pb-Ag; SEDEX Zn-Pb.

COMMODITIES (*BYPRODUCTS*): Zn, Pb, Ag (*minor Cu, barite*).

EXAMPLES: **(Yukon): Grum, Dy, Swim, Faro, Vangorda (Anvil District), XY, Anniv (Howard's Pass), Tom, Jason (Macmillan Pass), Clear Lake (Tintina Trench), Mel, Matt Berry (southeast Yukon);**
(British Columbia - *Canada/International*): Cirque, Sullivan, Driftpile; *Red Dog (Alaska, USA), McArthur River and Mt. Isa (Australia); Megen and Rammelsberg (Germany).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Beds and laminations of sphalerite, galena, pyrite, pyrrhotite and rare chalcopyrite, with or without barite, in euxinic clastic marine sedimentary strata. Deposits are typically tabular to lensoidal in shape and range from centimetres to tens of metres thick. Multiple horizons may occur over stratigraphic intervals of 1000 m or more.

TECTONIC SETTING: Intracratonic or continental margin environments in fault-controlled basins and troughs. Troughs are typically half grabens developed by extension along continental margins or within back-arc basins. **The Yukon deposits are located along the margins of Selwyn Basin near the transition to Cassiar Platform to the southwest (Anvil District, Clear Lake and Matt Berry), and to Mackenzie Platform to the northeast (Macmillan Pass, Howard's Pass, Mel).**

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Restricted second and third order basins within linear, fault-controlled marine, epicratonic troughs and basins. There is commonly evidence of penecontemporaneous movement on faults bounding sites of sulphide deposition. The depositional environment varies from deep, starved marine to ?shallow-water restricted shelf.

AGE OF MINERALIZATION: The major metallogenic events are Middle Proterozoic, Early Cambrian, Early Silurian and Middle to Late Devonian to Mississippian. The Middle Proterozoic and Devonian-Mississippian events are recognized worldwide. In the Canadian Cordillera, minor metallogenic events occur in the Middle Ordovician and Early Devonian. **In Yukon, major metallogenic events are Cambro-Ordovician (Faro District), Early Silurian (Howard's Pass), and Devonian-Mississippian (Macmillan Pass, Clear Lake). Minor**

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metallogenic events are Early Cambrian (Mel deposit; Miller and Wright, 1983) and Ordovician (Matt Berry, J. Mortensen, pers. comm., 2000).

HOST/ASSOCIATED ROCK TYPES: The most common host rocks are those found in euxinic, starved basin environments, namely, carbonaceous black shale, siltstone, cherty argillite and chert. Thin interbeds of turbiditic sandstone, granule to pebble conglomerate, pelagic limestone and dolostone, although volumetrically minor, are common. Evaporites, calcareous siltstone and mudstone are common in shelf settings. Small volumes of volcanic rocks, typically tuff and submarine mafic flows, may be present within the host succession. Slump breccia, fan conglomerates and similar deposits occur near synsedimentary growth faults. Rapid facies and thickness changes are found near the margins of second and third order basins. In some basins high-level mafic sills with minor dikes are important. **In Yukon, the most prospective host rocks are: Cambrian and Ordovician Vangorda and Menzie Creek Formations (Anvil District), which are age-correlative to the regional Upper Cambrian and Ordovician Rabbitkettle Formation; Ordovician to Silurian Road River Group (Howard's Pass); and Devonian and Mississippian Earn Group (Macmillan Pass).**

DEPOSIT FORM: These deposits are stratabound, tabular to lens shaped and are typically comprised of many beds of laminae of sulphide minerals and/or barite. Frequently the lenses are stacked and more than one horizon is economic. Ore lenses and mineralized beds commonly are part of a sedimentary succession up to hundreds of metres thick. Horizontal extent is usually much greater than vertical extent. Individual laminae or beds may persist over tens of kilometres within the depositional basin.

TEXTURE/STRUCTURE: Sulphide and barite laminae are commonly very finely crystalline where deformation is minor. In intensely folded deposits, coarser grained, recrystallized zones are common. Sulphide laminae are typically monomineralic.

ORE MINERALOGY [Principal and *subordinate*]: The principal sulphide minerals are pyrite, pyrrhotite, sphalerite and galena. Some deposits contain significant amounts of *chalcopyrite*, but most do not. Barite may or may not be a major component of the ore zone. Trace amounts of *marcasite, arsenopyrite, bismuthinite, molybdenite, enargite, millerite, freibergite, cobaltite, cassiterite, valleriite and melnikovite* have been reported from these deposits. These minerals are commonly present in very minor amounts.

ALTERATION MINERALOGY: Alteration varies from well developed to nonexistent. In some deposits a stockwork and disseminated feeder zone lies beneath, or adjacent to, the stratiform mineralization. Alteration minerals, if present, include silica, tourmaline, carbonate, albite, chlorite and dolomite. They formed in a relatively low temperature environment. Celsian, Ba-muscovite and ammonium clay minerals have also been reported but are probably not common.

ORE CONTROLS: Favourable sedimentary sequences, major structural breaks, basins.

GENETIC MODEL: The deposits accumulate in restricted second and third order basins or half grabens bounded by synsedimentary growth faults. Exhalative centres occur along these faults and the exhaled brines accumulate in adjacent seafloor depressions. Biogenic reduction of seawater sulphate within an anoxic brine pool is believed to control sulphide precipitation.

ASSOCIATED DEPOSIT TYPES: Associated deposit types include carbonate-hosted sedimentary exhalative, such as the Kootenay Arc and Irish deposits (E13), bedded barite (E17) and iron formation (F10).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: The deposits are typically zoned with Pb found closest to the vent grading outward and upward into more Zn-rich facies. Cu is commonly found either within the feeder zone or close to the exhalative vent. Barite, exhalative chert and hematite-chert iron formation, if present, are usually found as a distal facies. Sediments such as pelagic limestone interbedded with the ore zone may be enriched in Mn. NH_3 anomalies have been documented at some deposits, as have Zn, Pb and Mn haloes. The host stratigraphic succession may also be enriched in Ba on a basin-wide scale.

GEOPHYSICAL SIGNATURE: Airborne and ground geophysical surveys, such as electromagnetics or magnetics should detect deposits that have massive sulphide zones, especially if these are steeply dipping. However, the presence of graphite-rich zones in the host sediments can complicate the interpretation of EM conductors. Also, if the deposits are flat lying and comprise fine laminae distributed over a significant stratigraphic interval, the geophysical response is commonly too weak to be definitive. Induced polarization can detect flat-lying deposits, especially if disseminated feeder zones are present.

OTHER EXPLORATION GUIDES: The principal exploration guidelines are appropriate sedimentary environment and stratigraphic age. Restricted marine sedimentary sequences deposited in an epicratonic extensional tectonic setting during the Middle Proterozoic, Early Cambrian, Early Silurian or Devono-Mississippian ages are the most favourable.

ECONOMIC FACTORS

GRADE AND TONNAGE: The median tonnage for this type of deposit worldwide is 15 Mt, with 10 % of deposits in excess of 130 Mt (Briskey, 1986). The median grades worldwide are Zn - 5.6%, Pb -2.8% and Ag - 30 g/t. The Sullivan deposit, one of the largest deposits of this type ever discovered, has a total size of more than 155 Mt grading 5.7% Zn, 6.6% Pb and 7 g/t Ag. Reserves at the Cirque are 32.2 Mt grading 7.9% Zn, 2.1% Pb and 48 g/t Ag. **The median size for Selwyn Basin and Kechika Trough deposits (the southerly extension of Selwyn Basin into British Columbia) is 14.5 million tonnes. The giant Howard's Pass deposits have geological resources estimated in excess of 550 million tonnes, and inferred reserves in excess of 362 million tonnes (Deklerk, 2003). Silver grade is low in comparison to other SEDEX deposits worldwide. At Clear Lake, over 75% of the outlined sulphide reserves consist of barren pyrite.**

ECONOMIC LIMITATIONS: The large, near-surface deposits are amenable to high volume, open pit mining operations. Underground mining is used for some deposits. **Remoteness and lack of infrastructure are the principal reasons for the limited exploration in the Macmillan Pass and Howard's Pass areas. For example, the Howard's Pass deposits are more than 80 km from the nearest road. The Anvil District is covered by glacial overburden, which has rendered conventional geochemical exploration methods inefficient.**

IMPORTANCE: Sedimentary exhalative deposits currently produce a significant proportion of the world's Zn and Pb. Their large tonnage potential and associated Ag values make them an attractive exploration target. **During mine operations, the Anvil District was an important source of wealth and employment, and was a driving force behind major infrastructure initiatives. Large tonnages and the clustered character of SEDEX deposits make the Howard's Pass and Macmillan Pass areas attractive for mineral exploration.**

SELECTED BIBLIOGRAPHY

Abbott, J.G., Gordey, S.P. and Tempelman-Kluit, D.J., 1987. Setting of sediment-hosted stratiform lead-zinc deposits in Yukon and northeastern British Columbia. ***In:***

Morin, J.A., (ed.), Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 1-18.

Abbott, J.G. and Turner, R.J.W., 1990. Character and paleotectonic setting of Devonian stratiform sediment-hosted Zn, Pb, Ba deposits, Macmillan Fold Belt, Yukon. *In:* Abbott, J.G. and Turner, R.J.W., eds., Mineral Deposits of the Northern Canadian Cordillera, International Association on the Genesis of Ore Deposits, 8th Symposium, Ottawa, Field Trip 14 Guidebook, p. 99-492.

Ansdell, K.M., Nesbitt, B.E. and Longstaffe, J., 1989. A fluid inclusion and stable isotope study of the Tom Ba-Pb-Zn deposit, Yukon Territory, Canada. Economic Geology, v. 84, p. 841-856.

Bailes, R.J., Smee, B.W., Blackadar, D.W. and Gardner, H.D., 1987. Geology of the Jason lead-zinc-silver deposits, Macmillan Pass, eastern Yukon. *In:* Morin, J.A., ed., Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 87-99.

Briskey, J.A., 1986. Descriptive Model of Sedimentary Exhalative Zn-Pb. *In:* Mineral Deposit Models, Cox, D.P. and Singer, D.A. (eds.), *U.S. Geological Survey*, Bulletin 1693, 379 p.

Carne, R.C., 1979. Geological setting of stratiform lead-zinc-barite mineralization, Tom claims, Macmillan Pass, Yukon Territory. Indian and Northern Affairs Canada, Ottawa, Report 1979-4, 30 p.

Carne, R.C. and Cathro, R.J., 1982. Sedimentary-exhalative (Sedex) Zn-Pb-Ag Deposits, Northern Canadian Cordillera; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 75, pages 66-78.

Cecile, M.P., 1982. The Lower Paleozoic Misty Creek Embayment, Selwyn Basin, Yukon and Northwest Territories, Geological Survey of Canada, Bulletin 335, 78 p.

Gardner, H.D. and Hutcheon, I., 1985. Geochemistry, mineralogy and geology of the Jason Pb-Zn deposits, Macmillan Pass, Yukon, Canada. Economic Geology, v. 80, p. 1257-1276.

Godwin, C.I., Sinclair, A.J., and Ryan, B.D., 1982. Lead isotope model for the genesis of carbonate-hosted Zn-Pb, shale-hosted Ba-Zn-Pb, and silver-rich deposits in the northern Canadian Cordillera. Economic Geology, v. 77, p. 82-94.

Goodfellow, W.D., 1984. Geochemistry of rocks hosting the Howard's Pass (XY) strata-bound Zn-Pb deposit, Selwyn Basin, Yukon Territory, Canada. *In:* Janelidze, T.V., and Tvalchrelidze, A.G., eds., Sixth Quadrennial IAGOD Symposium, Proceedings: E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart, Germany, p. 91-112.

Goodfellow, W.D., 1987. Anoxic stratified oceans as a source of sulphur in sediment-hosted stratiform Zn-Pb deposits, Selwyn Basin, Yukon, Canada. Chemical Geology, v. 65, p. 359-382.

Goodfellow, W.D. and Jonasson, I.R., 1984. Ocean stagnation and ventilation defined by $\delta^{34}S$ secular trends for pyrite and barite, Selwyn Basin, Yukon, Geology, v. 12, p. 583-586.

Goodfellow, W.D. and Jonasson, I.R., 1987. Environment of formation of the Howard's Pass (XY) Zn-Pb deposit, Selwyn Basin, Yukon. *In:* Morin, J.A., ed., Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 19-50.

Goodfellow, W.D., and Rhodes, D., 1990. Geological setting, geochemistry and origin of the Tom stratiform Zn-Pb-Ag-barite deposits. *In:* Abbott, J.G., and Turner, R.J.W., eds., Mineral Deposits of the Northern Canadian Cordillera: International Association on the Genesis of Ore Deposits, 8th Symposium, Ottawa, Field Trip 14 Guidebook, p. 177-244.

Gordey, S.P., Abbott, J.G. and Orchard, M.J., 1982. Devono-Mississippian Earn Group and younger strata in east-central Yukon. Geological Survey of Canada, Paper 82-1B, p. 93-100.

Gustafson, L.B. and Williams, N. 1981. Sediment-hosted Stratiform Deposits of Copper, Lead and Zinc; *in* Economic Geology Seventy-fifth Anniversary Volume, 1905-1980, Skinner, B.J., Editor, *Economic Geology Publishing Co*., pages 139-178.

Jennings, D.S. and Jilson, G.A., 1987. Geology and sulphide deposits of the Anvil Range, Yukon. *In:* Morin, J.A., ed., Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 339-361.

Jonasson, I.R. and Goodfellow, W.D., 1987. Sedimentary and diagenetic textures, and deformation structures within sulphide zones of Howards Pass (XY) Zn-Pb deposit, Yukon and Northwest Territories. *In:* Morin, J.A., ed., Mineral Deposits of Northern Cordillera: Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 51-70.

Large, D.E., 1981. Sediment-hosted Submarine Exhalative Sulphide Deposits - a Review of their Geological Characteristics and Genesis; *in* Handbook of Stratabound and Stratiform Ore Deposits, Wolfe, K.E., Editor, *Geological Association of Canada*, Volume 9, pages 459-507.

Large, D.E., 1983. Sediment-hosted Massive Sulphide Lead-Zinc Deposits; *in* Short Course in Sedimentary Stratiform Lead-Zinc Deposits, Sangster, D.F., Editor, *Mineralogical Association of Canada*, pages 1-29.

Lydon, J.W., Goodfellow, W.D. and Jonasson, I.R., 1985. A general genetic model for stratiform baritic deposits of the Selwyn Basin, Yukon Territory and district of Mackenzie. Geological Survey of Canada, Paper 85-1A, p. 651-660.

MacIntyre, D.G. 1991. Sedex - Sedimentary-exhalative Deposits. *In:* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, McMillan, W.J., Coordinator, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 25-69.

McClay, K.R. and Bidwell, G.E., 1987. Geology of the Tom Deposit, Macmillan Pass, Yukon. *In:* Morin, J.A. , (ed.), Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 100-114.

Miller, D. and Wright, J., 1987. Mel barite-zinc-lead deposit, Yukon – An exploration case history. *In :* Morin, J.A., ed., Mineral Deposits of Northern Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 129-141.

Norford, B.S. and Orchard, M.J., 1985. Early Silurian age of rocks hosting lead-zinc mineralization at Howards Pass, Yukon Territory and district of Mackenzie; Local biostratigraphy of the Road River Formation and Earn Group. Geological Survey of Canada, Paper 83-18, 35 p.

Pigage, L.C., 1990. Anvil Pb-Zn-Ag District, Yukon Territory, Canada. *In:* Abbott, J.G., and Turner, R.J.W., eds., Mineral Deposits of the Northern Canadian Cordillera: International Association on the Genesis of Ore Deposits, 8th Symposium, Ottawa, Field Trip 14 Guidebook, p. 283-308.

Sangster, D.F., 1986. Classifications, Distribution and Grade-Tonnage Summaries of Canadian Lead-Zinc Deposits; *Geological Survey of Canada*, Economic Geology Report 37, 68 pages.

Shanks, W.C., III, Woodruff, L.G., Jilson, G.A., Jennings, D.S., Modene, J.S. and Ryan, B.D., 1987. Sulfur and lead isotope studies of stratiform Zn-Pb-Ag deposits, Anvil Range, Yukon: Basinal brine exhalation and anoxic bottom-water mixing. Economic Geology, v. 82, p. 600-634.

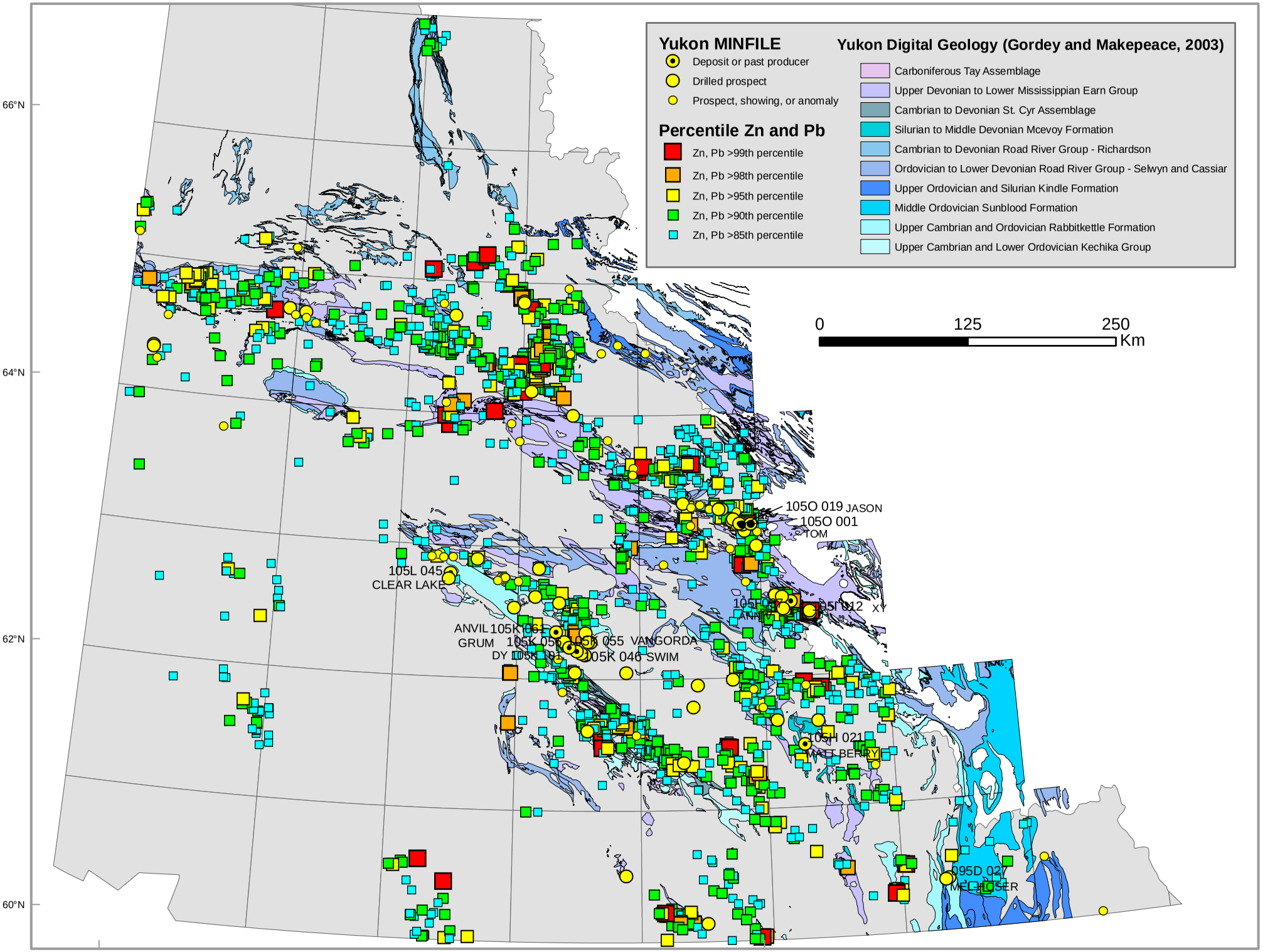
Turner, R.J.W., 1990. Jason stratiform Zn-Pb barite deposit, Selwyn Basin, Canada (NTS 105O/1): Geological setting, hydrothermal facies and genesis. *In:* Abbott, J.G. and Turner, R.J.W., eds., Mineral Deposits of the Northern Canadian Cordillera, International Association on the Genesis of Ore Deposits, 8th Symposium, Ottawa, Field Trip 14 Guidebook, p. 137-175.

E14 - Sedimentary exhalative Zn-Pb-Ag - BC and Yukon Deposits

Deposit	Country	Tonnes	Ag (g/t)	Pb (%)	Zn (%)
MATT BERRY	CNYK	533 434	102.9	6.10	4.80
OGO (SWIM)	CNYK	4 300 000	42.0	3.80	4.70
BEND CANYON	CNBC	5 000 000	7.0	0.60	2.30
CLEAR LAKE	CNYK	6 100 000	40.8	2.15	11.34
MEL	CNYK	6 800 000	0.0	2.00	7.10
VANGORDA	CNYK	71 000 000	48.0	3.40	4.30
JASON	CNYK	14 100 000	79.9	7.09	6.57
TOM	CNYK	14 528 247	42.3	40.60	7.48
DRIFTPILE	CNBC	18 000 000	0.0	0.00	2.38
BOB (DY)	CNYK	20 300 000	82.0	5.70	7.00
CHAMP (GRUM)	CNYK	30 800 000	49.0	3.10	4.90
CIRQUE	CNBC	32 200 000	48.0	2.20	7.90
FARO	CNYK	57 600 000	0.0	3.40	4.70
SULLIVAN	CNBC	151 000 000	63.3	5.82	5.54
HOWARD'S PASS (XY + ANNIV)	CNYK	550 000 000	9.0	2.00	5.00

Yukon MINFILE

MINFILE	NAMES	STATUS
105K 055	VANGORDA	OPEN PIT PAST PRODUCER
105K 056	GRUM	OPEN PIT PAST PRODUCER
105K 061	FARO	OPEN PIT PAST PRODUCER
095D 005	MEL, JEAN	DEPOSIT
105H 021	MATT BERRY	DEPOSIT
105I 012	HOWARDS PASS, SUMMIT LAKE, XY	DEPOSIT
105I 037	ANNIV	DEPOSIT
105K 046	SWIM	DEPOSIT
105K 101	DY, GRIZZLY	DEPOSIT
105L 045	CLEAR LAKE	DEPOSIT
105O 001	TOM	DEPOSIT
105O 019	JASON	DEPOSIT
095D 032	JERI	DRILLED PROSPECT
105B 054	OULETTE, OMO	DRILLED PROSPECT
105F 091	ANGIE	DRILLED PROSPECT
105G 056	PAY	DRILLED PROSPECT
105G 093	NEBOCAT, CYR, TAR, ANO, HOOLE	DRILLED PROSPECT
105G 094	DWONK	DRILLED PROSPECT
105H 047	FIN	DRILLED PROSPECT
105H 075	MAXI	DRILLED PROSPECT
105I 032	SHIELD	DRILLED PROSPECT
105I 038	ABBEY	DRILLED PROSPECT
105I 053	BRODELL, OP	DRILLED PROSPECT
105I 058	RITZ	DRILLED PROSPECT
105J 012	ROG	DRILLED PROSPECT
105K 010	FARGO, SUNSET, AL, KIRK, RIM	DRILLED PROSPECT
105K 034	ADAMSON, ACE	DRILLED PROSPECT
105K 036	BETA	DRILLED PROSPECT
105K 042	SEA	DRILLED PROSPECT
105K 043	SB	DRILLED PROSPECT
105K 049	ST. LUCIE	DRILLED PROSPECT
105K 054	SHRIMP	DRILLED PROSPECT
105K 057	KULAN, FIRTH	DRILLED PROSPECT
105K 067	LORNA	DRILLED PROSPECT
105K 074	COLT, BLUE, TWO	DRILLED PROSPECT
105K 104	DEV	DRILLED PROSPECT
105K 105	SIR JOHN A., MONI, TELE	DRILLED PROSPECT
105L 017	LOBO	DRILLED PROSPECT
105L 030	HACHEY	DRILLED PROSPECT
105L 039	ALPHABET	DRILLED PROSPECT
105L 041	KELLY	DRILLED PROSPECT
105L 056	TUM	DRILLED PROSPECT
105N 015	KIDD	DRILLED PROSPECT
105O 006	SCOT	DRILLED PROSPECT
105O 024	NIDD	DRILLED PROSPECT
105O 025	BREMNER	DRILLED PROSPECT
116A 024	SANGUINETTI	DRILLED PROSPECT
116B 170	TAIGA	DRILLED PROSPECT
116C 116	MICKEY, BRILL	DRILLED PROSPECT
095C 068	BEAV	PROSPECT
105F 106	HOWRU	PROSPECT
105F 115	MT. ROSS	PROSPECT
105G 070	RENO, ELECTRIC MINE	PROSPECT
105J 011	IVOR, BEETHOVEN	PROSPECT
105J 013	CLYDE, ITSI	PROSPECT
105K 103	TENAS	PROSPECT
105L 037	CAVE, MCARTHUR	PROSPECT
116A 013	RIMROCK	PROSPECT
116C 115	CLIP	PROSPECT
095C 037	BEAVERCROW	SHOWING
105F 064	ASKIN	SHOWING
105F 116	HOLLAND	SHOWING
105G 096	WAD, SAS	SHOWING
105H 095	COME	SHOWING
105I 043	DIANNE	SHOWING
105J 025	ST GODARD	SHOWING
105O 011	BEN	SHOWING
105O 036	FAN	SHOWING
116B 142	GRAPS	SHOWING
116F 007	BURGOYNE	SHOWING
095C 024	TROPICAL, SWAN, PYRO	ANOMALY
105G 042	MCEVOY	ANOMALY
105I 029	SUMMIT	ANOMALY
105I 034	BLACK GIANT	ANOMALY
105J 034	DYAK	ANOMALY
105K 012	CASCA, LYN, RIDGE	ANOMALY
105L 032	HORSFALL	ANOMALY
105N 023	KEG	ANOMALY
105O 029	GOW, TH	ANOMALY
106C 072	LINDBERG	ANOMALY
106C 091	TELL	ANOMALY
116A 023	SKETCH	ANOMALY
095C 066	MARS, DEEK	UNKNOWN
105O 026	DICKIE	UNKNOWN
116A 022	SHINE	UNKNOWN



Map of Yukon showing Selwyn Basin rocks that host SEDEX mineralization, SEDEX type mineral occurrences and combined Pb- Zn geochemistry