# EARTH 471
# Mineral Deposits

## Hydrothermal Ore deposits (II)
## SEDEX and MVT

**REMINDER**: **Commodity report is due on Friday February 9th at 5:00pm**

In the course outline:
"The mark on the report will go down 10% for each 24 hours (or portion thereof) following the due date"

**Turnitin** will be used to screen reports.

# SEDEX
sedimentary exhalative deposits

## 13.9 Sediment-Hosted Zinc–Lead Mineralization: Processes and Perspectives

JJ Wilkinson, Imperial College London, London, UK; University of Tasmania, Hobart, Tasmania, Australia





**Glossary**

**Aquiclude** An impermeable sedimentary layer that acts as a barrier to fluid flow.

**Anoxia** The condition of extreme oxygen depletion.

**Bacteriogenic** Produced by the action of bacteria, normally used in reference to the bacterial production of $H_2S$ from seawater sulfate.

**Basement** The region beneath an unconformity at the bottom of a sedimentary basin, typically composed of igneous or metamorphic rocks.

**Bittern** The residual brine produced by the evaporation of seawater past the point at which halite precipitates.

**Connate** Pertaining to pore waters trapped within sediment during deposition and subsequently buried. May be expelled later due to compaction or other processes.

**Convective flow** Flow of fluid driven by buoyancy forces, typically due to temperature-controlled density variations.

**Diachronous** An equivalent process occurring at different locations and times. Normally used in reference to sedimentation, such as during marine transgression or regression, when the same sedimentary facies is deposited in different places at different times.

**Epigenetic** Occurring after lithification of the host rocks, normally used in reference to mineralization. In rocks that

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## Sedimentary Exhalative (SEDEX) Deposits

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**Abstract**

There are 132 SEDEX (including Irish and BHT subtypes) deposits worldwide with known grade and tonnage, and of these, 50 have geological resources equal to or greater than 20 Mt. In Canada, there are 35 deposits, seven with measured geological resources of more than 20 Mt, including the Sullivan deposit with 162 Mt. Twelve Canadian deposits are past producers, the largest of which is the Sullivan deposit, which produced 149 Mt of 5.33 percent Zn and 5.64 percent Pb.

The morphology of SEDEX deposits is highly variable and includes mounds, lenses, and tabular or sheet-like bodies. Their internal architecture is controlled by the proximity of seafloor sulphides to fluid discharge vents. Vent-proximal deposits typically formed from buoyant hydrothermal fluids, whereas vent-distal deposits formed from fluids that are denser than seawater and pooled in bathymetric depressions that may be remote from seafloor vents.

Most SEDEX deposits are hosted by organic-rich sedimentary rocks that were deposited in basins during periods in the Earth's history when the oceans were stratified with a lower anoxic and $H_2S$-rich water column. In the Paleozoic Selwyn Basin, for example, there is a close temporal relationship between upward-increasing $\delta^{34}S$ secular trends in sedimentary pyrite, anoxic laminated carbonaceous shales and cherts, and three major SEDEX forming events in the Late Cambrian, Early Silurian, and Late Devonian.

The typical basinal architecture of most SEDEX deposits is a continental rift basin with at least 2 to 5 km of syn-rift, coarse-grained, permeable clastics and related volcanic rocks and/or volcaniclastics overlain by post-rift relatively impermeable basinal shales or carbonates. Hydrothermal discharge to the seafloor was commonly focused at the intersection of extensional and transform faults. There is close temporal and, in many cases, spatial association of SEDEX deposits with basaltic volcanic rocks, dykes, and sills. The low rigidity, permeability, and thermal conductivity of host sediments served to focus and prolong hydrothermal discharge at a restricted number of vent sites, thereby generating deposits that are an order of magnitude larger on average than VMS deposits.

SEDEX deposits most likely formed from oxidized and therefore $H_2S$-poor fluids generated in geopressured hydrothermal reservoirs within syn-rift clastic (and evaporitic) sediments sealed by fine-grained marine sediments. The large variability in the temperature, salinity, metal content, and redox conditions of SEDEX fluids was controlled by a number of parameters including the local thermal regime, the redox state of the reservoir sediments, and the presence or absence of evaporates. Because most of the fluids that formed SEDEX deposits were probably depleted in reduced S, an essential requirement for this deposit type is a sufficient supply of reduced S at the site of deposition. In the case of well-bedded deposits that formed at the seafloor, the most likely S source is bacteriogenic $H_2S$ generated in an ambient anoxic water column.

**Résumé**

À l'échelle du monde, il existe 132 gîtes SEDEX, y compris les gîtes irlandais et de type Broken Hill avec teneurs et tonnages connus, et 50 d'entre eux renferment des ressources géologiques supérieures à 20 millions de tonnes. Le Canada possède 35 gîtes de ressources géologiques mesurées, dont sept renferment plus de 20 millions de tonnes, y compris le gisement de Sullivan avec 162 millions de tonnes. Douze gisements canadiens sont des producteurs passés et, le plus important d'entre eux, le gisement Sullivan, a produit 149 millions de tonnes avec 5,33 % de Zn et 5,64 % de Pb. D'une grande diversité, la géomorphologie des gîtes SEDEX comprend buttes, lentilles et corps tabulaires ou feuilletés.

La structure interne de ces gîtes est régie par la proximité des sulfures du plancher océanique par rapport aux évents relâchant des fluides. En général, les gîtes à proximité des évents se forment par l'intensité des fluides hydrothermaux; en revanche, ceux formés à distance des évents sont formés par des fluides plus denses que l'eau de mer et se concentrent dans les dépressions du plancher océanique qui peuvent être à l'écart des évents.

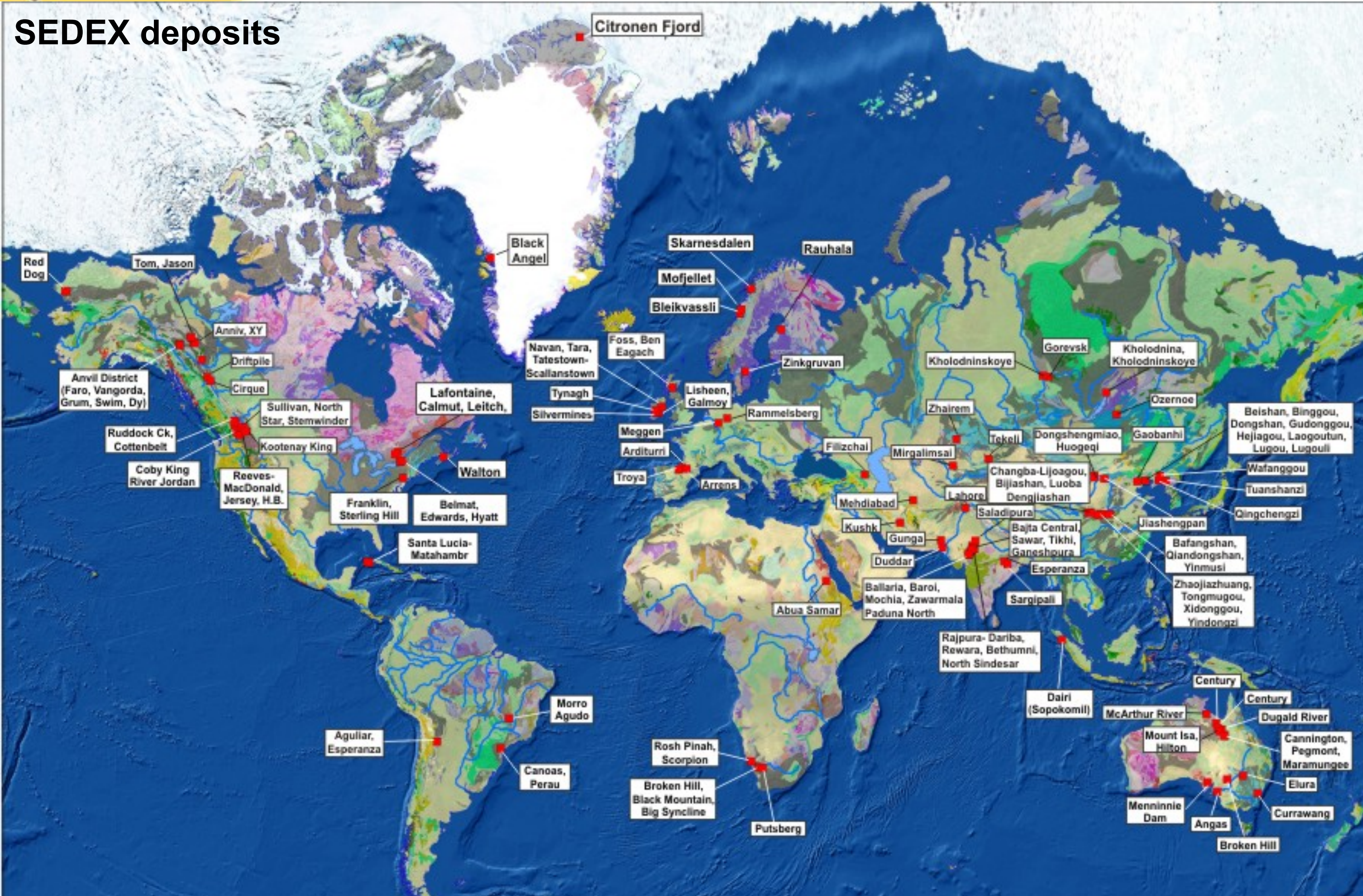
La plupart des gîtes SEDEX sont encaissés dans des sédiments carbonés déposés durant une période de l'histoire de la Terre au cours de laquelle les océans furent stratifiés avec une colonne d'eau anoxique plus basse et riche en $H_2S$. Dans le bassin de Selwyn du Paléozoïque, notamment, une relation étroite existe entre les tendances séculaires d'augmentation à la hausse de $\delta^{34}S$ dans la pyrite sédimentaire, les shales et les cherts laminés anoxiques et trois événements d'importance dans la formation des gîtes SEDEX au cours du Cambrien supérieur, du Silurien inférieur et du Dévonien supérieur.

La structure type des bassins de la plupart des gîtes SEDEX se caractérise par un bassin d'effondrement continental avec au moins 2 à 5 km de dépôts clastiques, volcaniques ou volcano-détritiques à gros grain, contemporains au rift, recouverts de shales ou de carbonates de bassins imperméables, lesquels sont postérieurs au rift. Les jaillissements hydrothermaux sur le plancher marin se produisaient habituellement à l'intersection des failles d'extension et de transformation. Il existe une association temporelle étroite et, en maints cas, spatiale des gîtes SEDEX avec les roches volcaniques basaltiques, les dykes et les filons-couches. La faible rigidité, la perméabilité et la conductivité thermale des sédiments hôtes ont servi à concentrer et à prolonger le jaillissement thermal dans un nombre restreint de sites d'évents, ce qui a créé des gîtes plus importants que les gîtes de sulfures massifs volcanogènes.

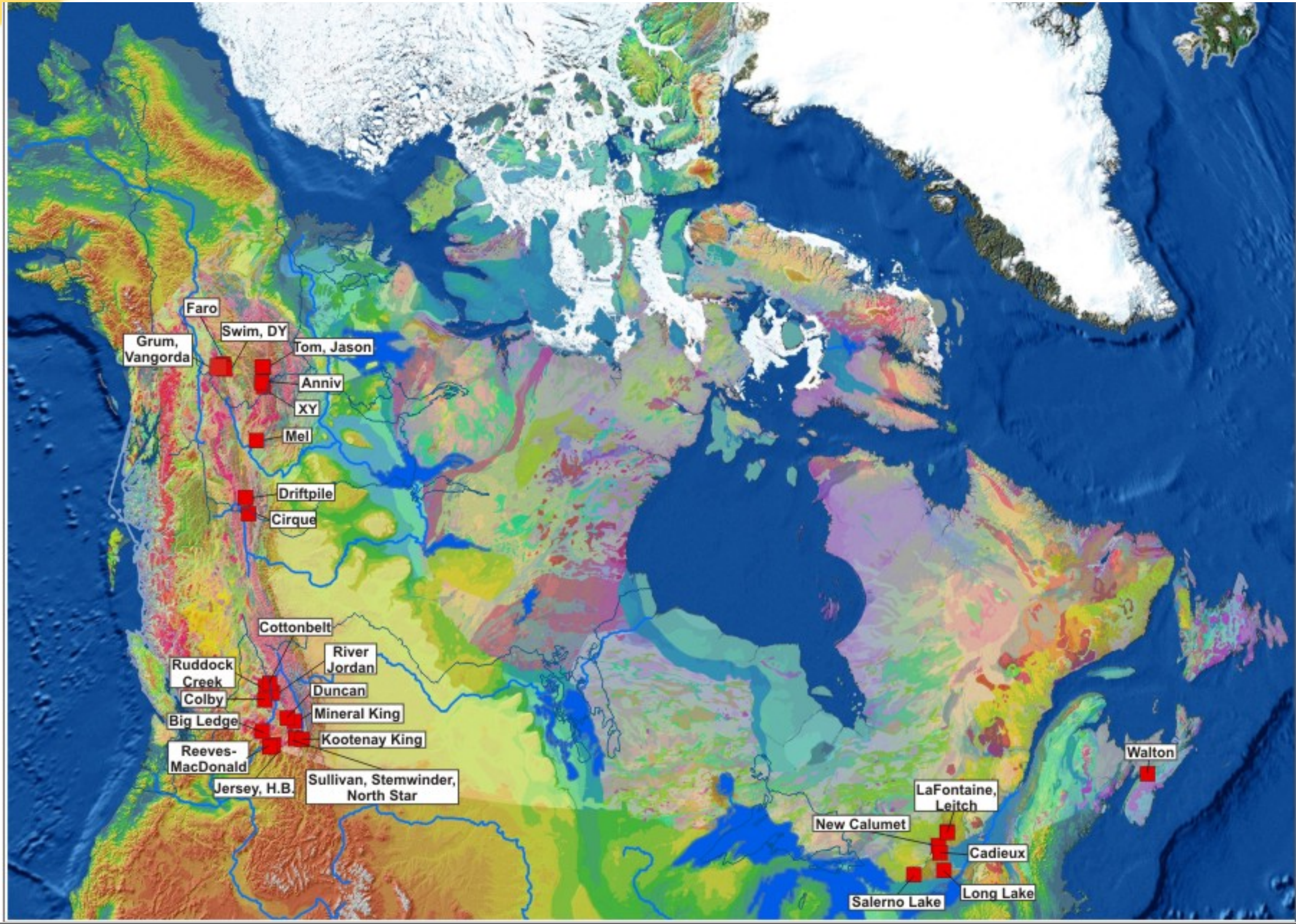
Selon toute probabilité, les gîtes SEDEX ont été formés de fluides oxydés, donc pauvres en $H_2S$ produits par des réservoirs hydrothermaux géopressurés dans les sédiments clastiques (et évaporitiques), contemporains au rift, enveloppés

Goodfellow, W.D., and Lydon, J.W., 2007, Sedimentary exhalative (SEDEX) deposits, *in* Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 163-183.

# SEDEX deposits




Goodfellow, W. D., Lydon, J. W. , SEDIMENTARY EXHALATIVE (SEDEX) DEPOSITS, in Goodfellow, W.D., ed., Mineral Deposits of Canada

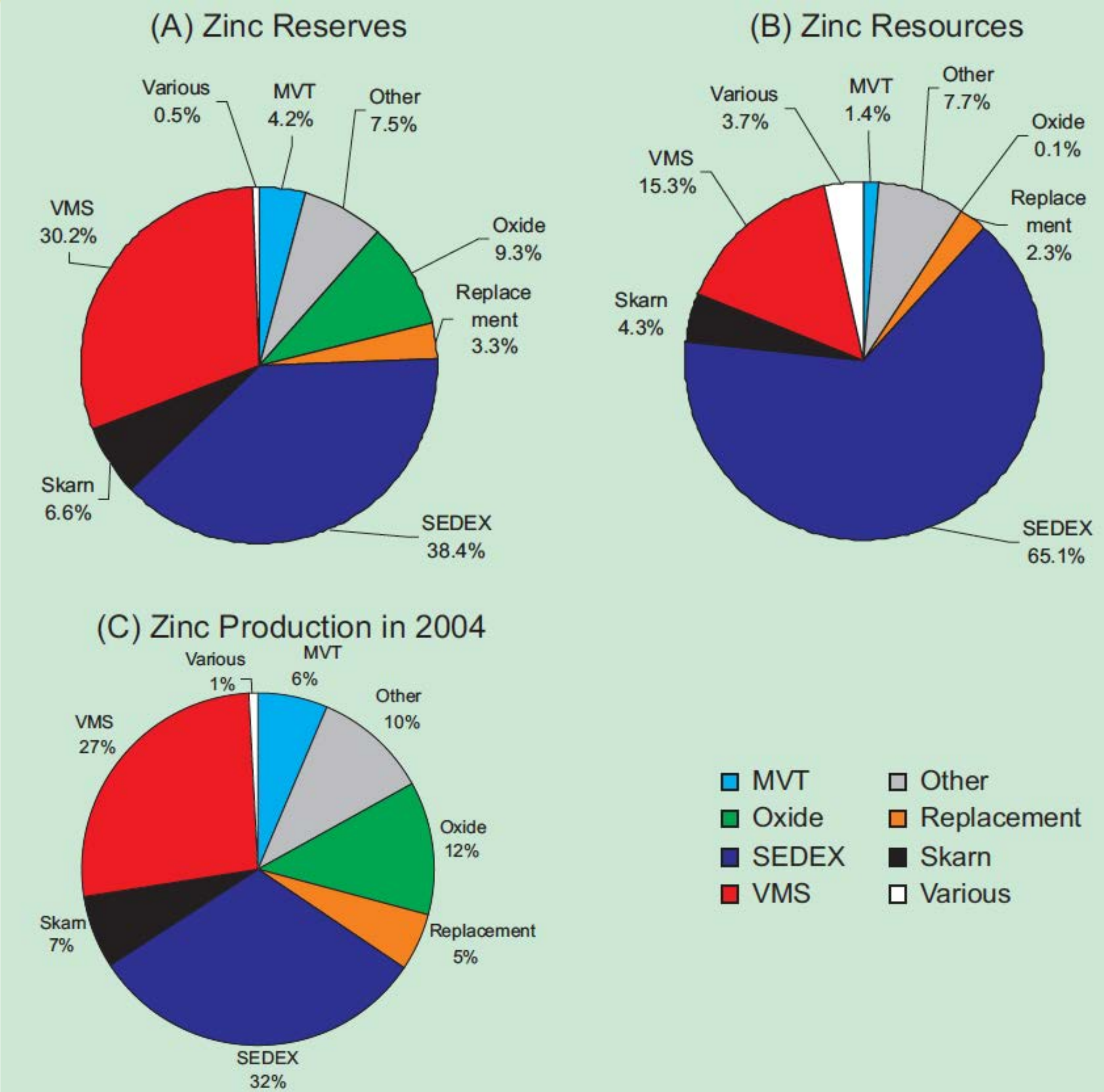

Faro
Swim, DY
Grum, Vangorda
Tom, Jason
Anniv
XY
Mel
Driftpile
Cirque
Cottonbelt
River Jordan
Ruddock Creek
Duncan
Colby
Mineral King
Big Ledge
Kootenay King
Reeves-MacDonald
Jersey, H.B.
Sullivan, Stemwinder, North Star
Walton
LaFontaine, Leitch
New Calumet
Cadieux
Long Lake
Salerno Lake

# SEDEX

Important resource of Zn and Pb

~38% of worlds Zn reserves

~65% of world's Zn resources



# SEDEX

**Biggest**

- Broken Hill (Australia; Paleoproterozoic)
- HYC (McArthur River, Australia, Paleoproterozoic)

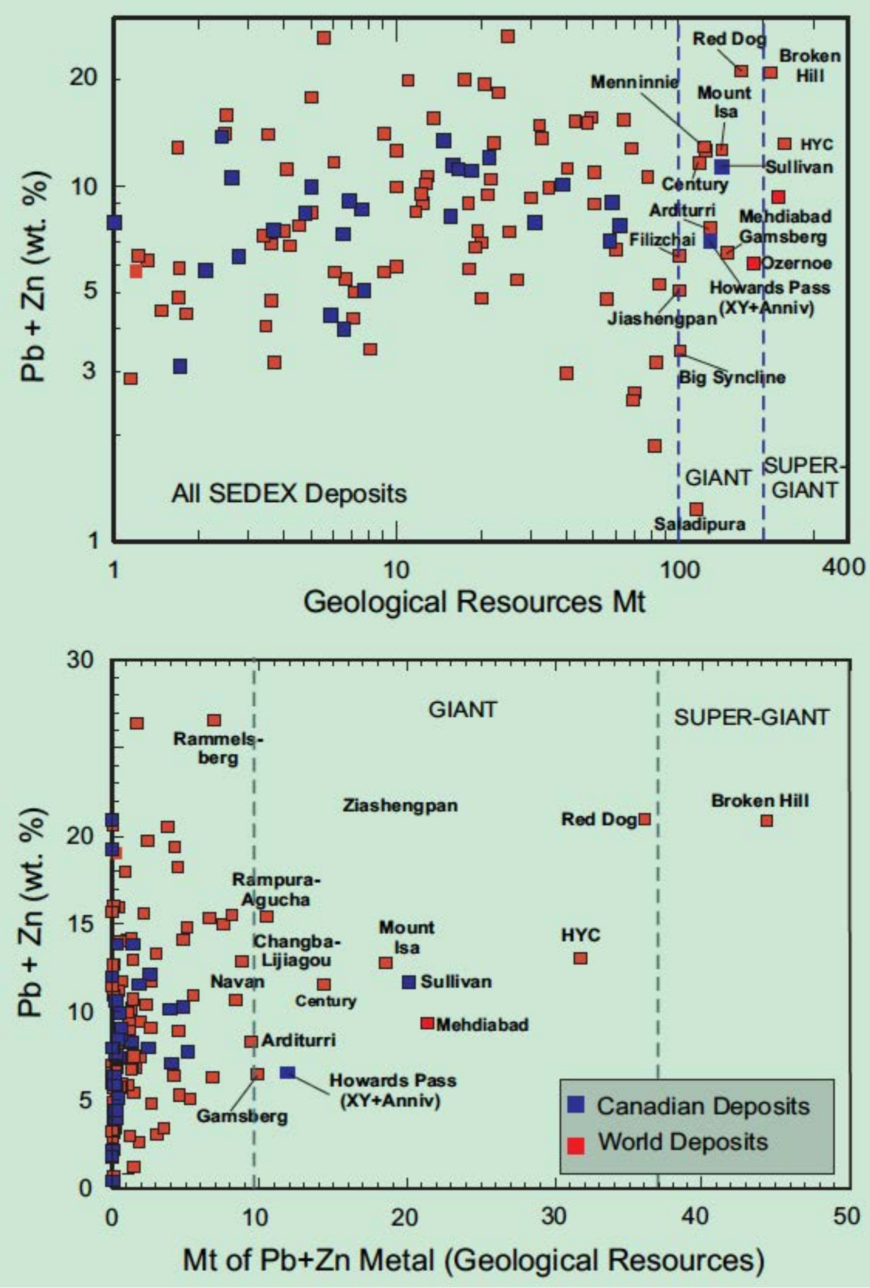
**Note that HYC is classified as super giant (ore Mt) or giant (metal Mt)

**Canadian (2 unambiguous giants):**

Most Canadian SEDEX districts are in southern British Columbia (Belt–Purcell and Selwyn Basins):

Sullivan: produced 149Mt of 5.33% Zn and 5.64% Pb (Mesoproterozoic)

Howards Pass: ☹ Not currently economic (Silurian)



# SEDEX – tectonic settings

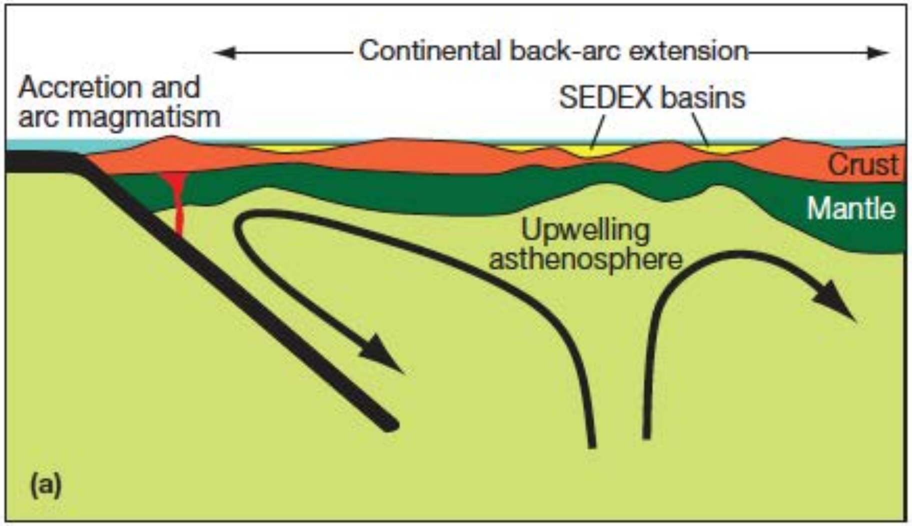
Two main settings:

1) Intercontinental or failed rifts (Australian Paleoproterozic SEDEX)
2) Atlantic-type continental margins (B.C. Paleozoic SEDEX)

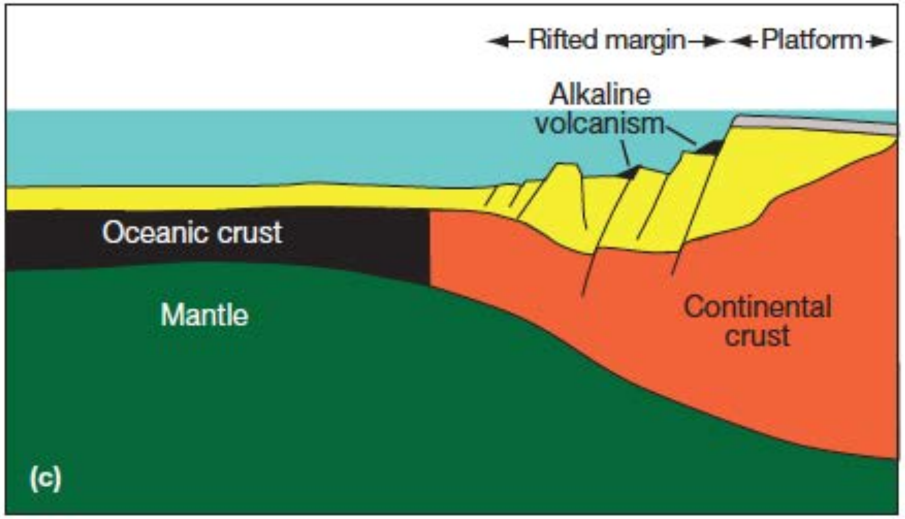
Form in long-lived sedimentary basins (contain many small sub-basins bounded by synsedimentary normal faults)

Most SEDEX deposits coincide with periods in Earth's history where the ocean floor was anoxic and $H_2S$ rich

## Intracontinental or failed rift




## Rifted passive margin



# SEDEX subtypes – 1
**(International system)**

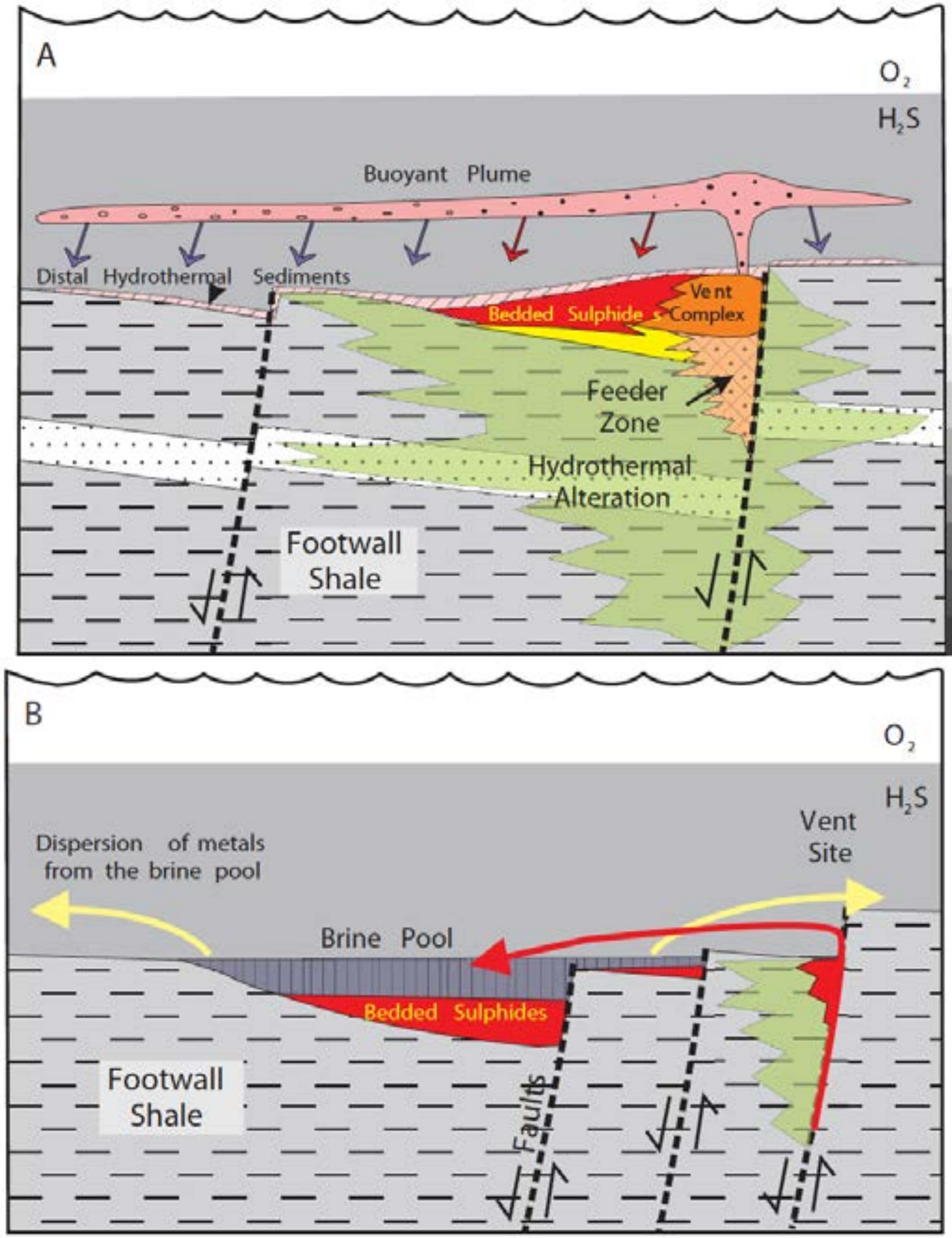
**Broken Hill type**
- Part of a continuum with VMS deposits (but much larger)
- Formed at the sea floor
- Bimodal felsic–mafic volcanic/intrusive and clastic sedimentary host rocks
- Mineralization driven by venting hydrothermal fluids into seawater

**Irish type**
- Part of a continuum with MVT deposits
- Formed below (but near) the sea floor
- Hosted mainly by carbonate rocks
- Carbonate platforms highly soluble in mildly acidic ore fluids; ore minerals deposited in open spaces (voids, breccia)
- Mineralization due mainly to migration of basinal metalliferous fluids

# SEDEX subtypes – 2
## (Canadian system)

**Vent-proximal deposits**
- Close to the vent
- Similar to VMS
- Sulfide minerals precipitated from buoyant plume or into permeable sediments
- Large alteration zones

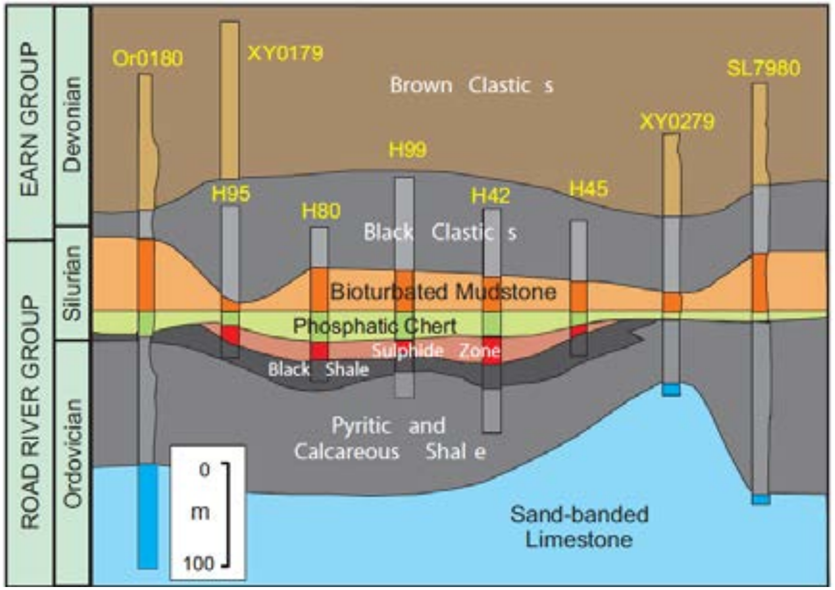
**Vent-distal deposits**
- Bedded sulfides found away from vent (little alteration)
- Mineralization in second- or third-order normal-fault bound basins
- Sulfides precipitated from a brine (salty) pool denser than the overlying water



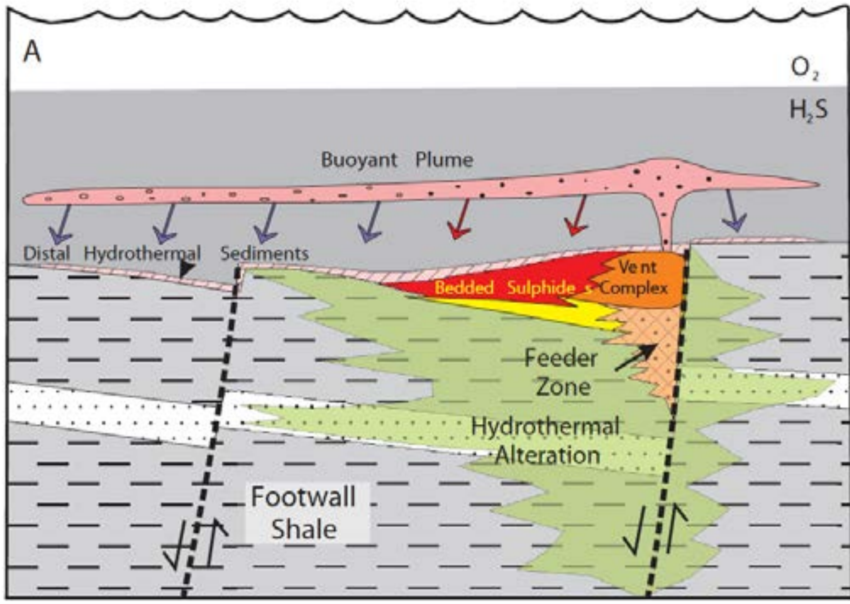
# SEDEX geology

- Originally thought to be only from precipitation of laminated sulfides onto the sea floor (but now includes sub seafloor replacement)
- Syngenetic
- Stratiform or stratabound (sheets or lenses)
- Mineralization hosted in shales and siltstones (± carbonates)
- Reduced marine basins
- Can be 100s–1000s metres long and 10 m thick

Howards Pass, BC

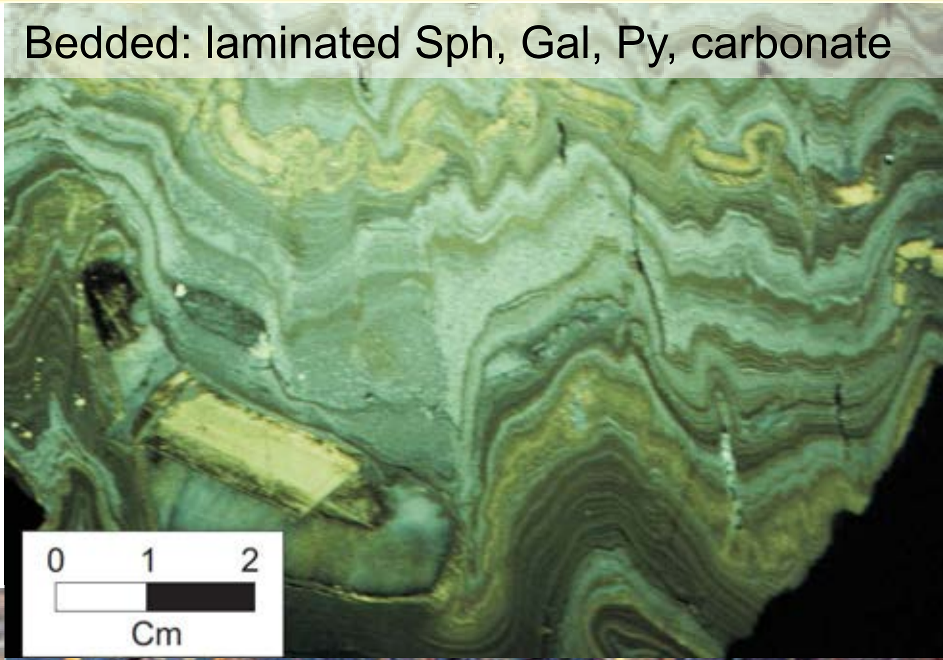


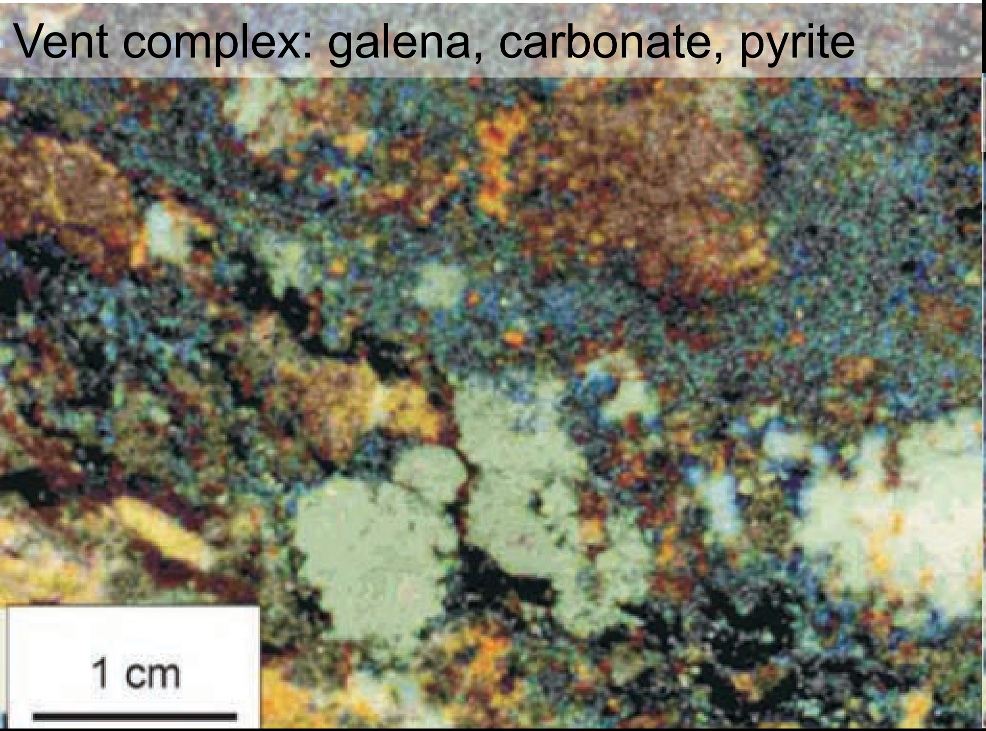

Simplified model of vent-proximal deposit

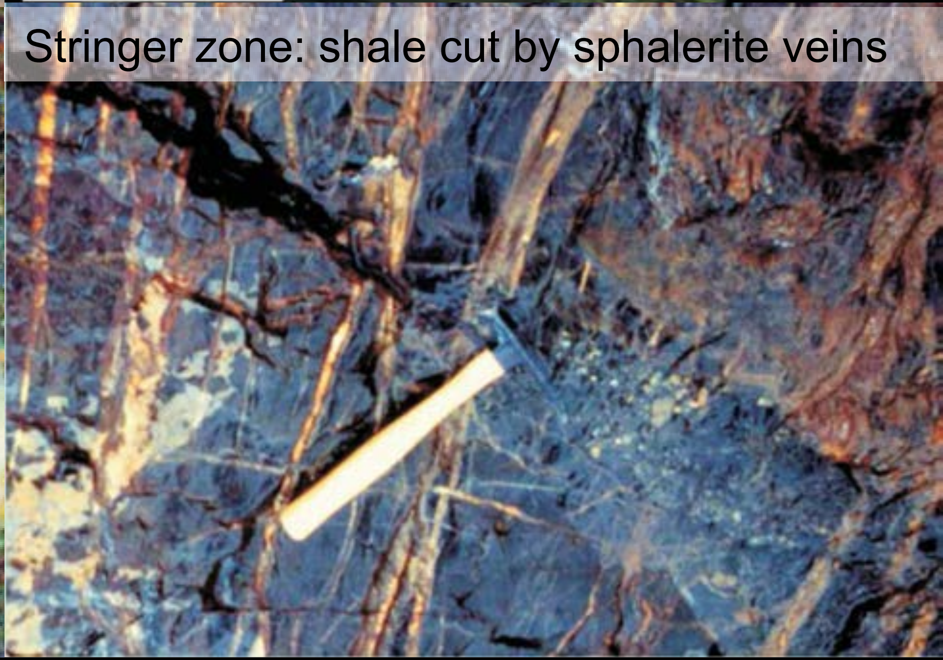


# SEDEX ore minerals

- Pyrite with sphalerite and galena (± chalcopyrite, barite, chert)
- Sulfide ores are massive, bedded (mm to cm scale layering), or stringer



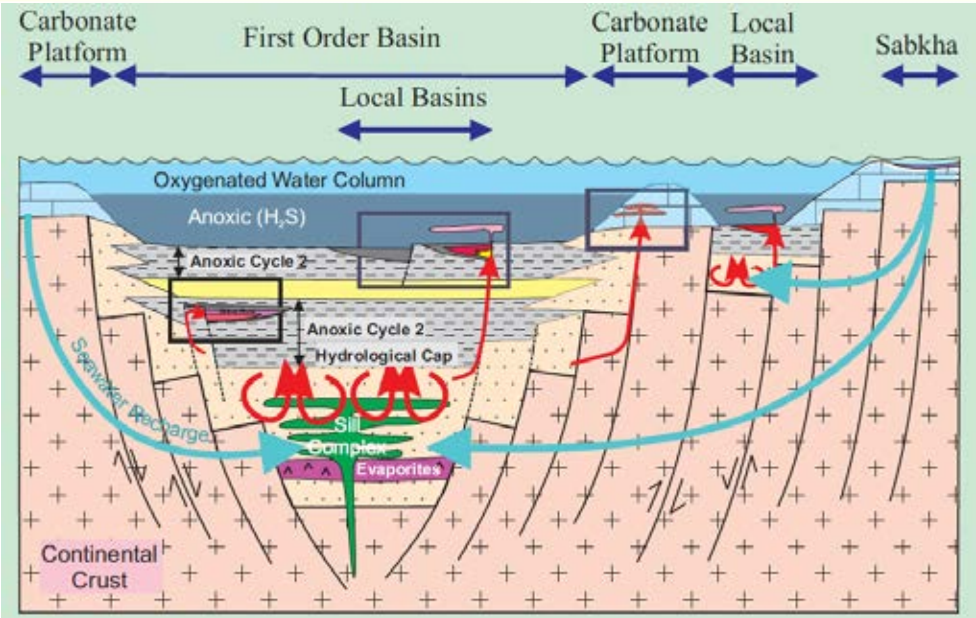
# SEDEX genetic model

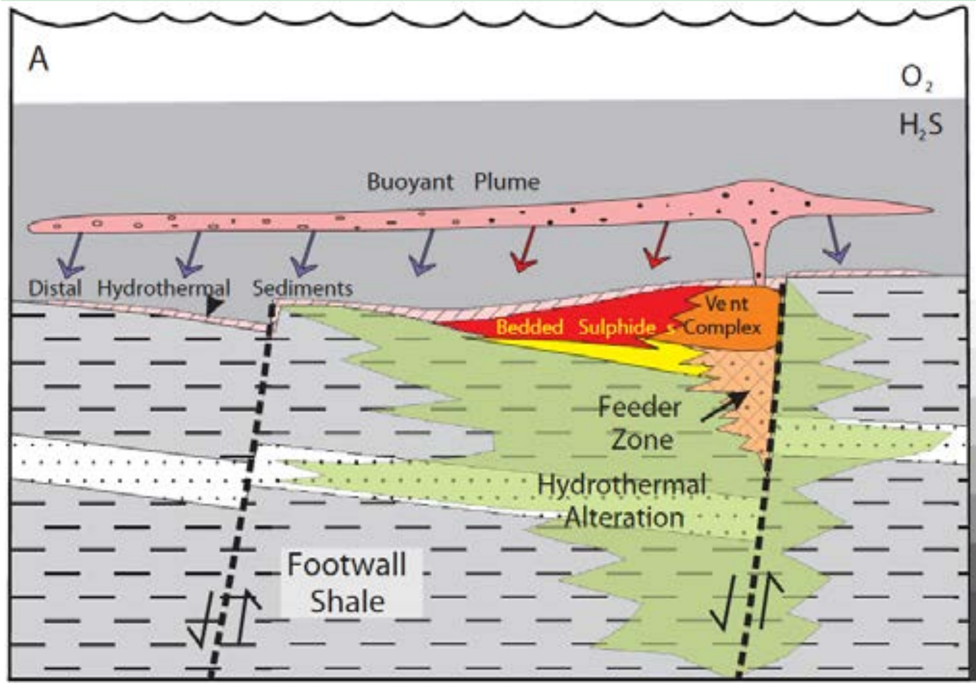
1) In long-lived sedimentary basins sediment accumulation leads to over-pressured basinal fluids

2) Oxidized ($H_2S$ poor, $Cl^-$ rich) basin fluids are driven by hydrothermal circulation (200–300°C) and leach Zn and Pb from host rocks (as chloride complexes)

3) Some tectonic event re-activates old normal faults

4) Faults act as transport conduits and fluids move upwards…



# SEDEX genetic model

5) Fluids exhaled into seawater or interact with reduced shales near the seawater–sediment interface

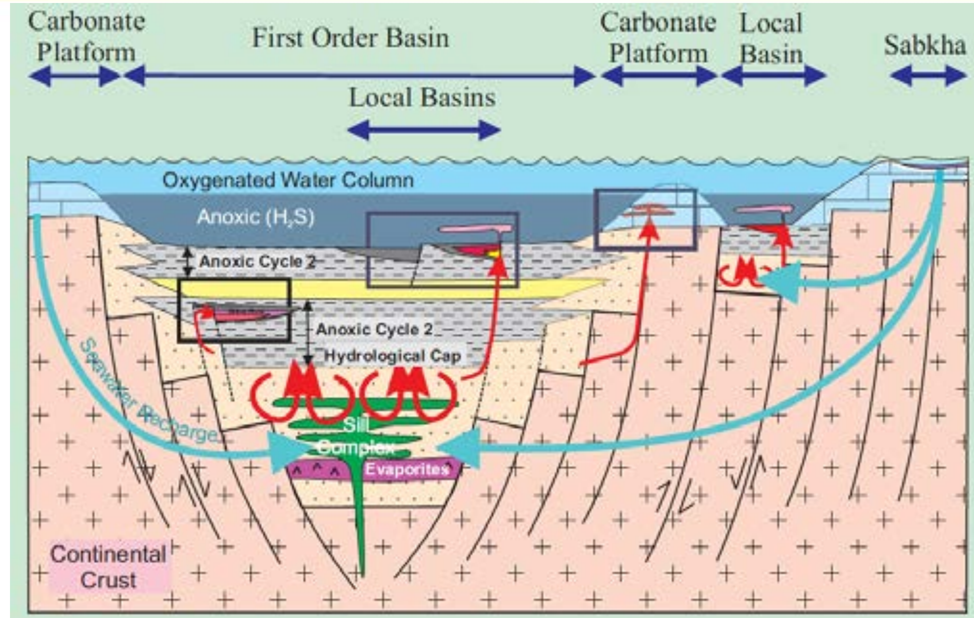
6) Fluids react with $H_2S$*:

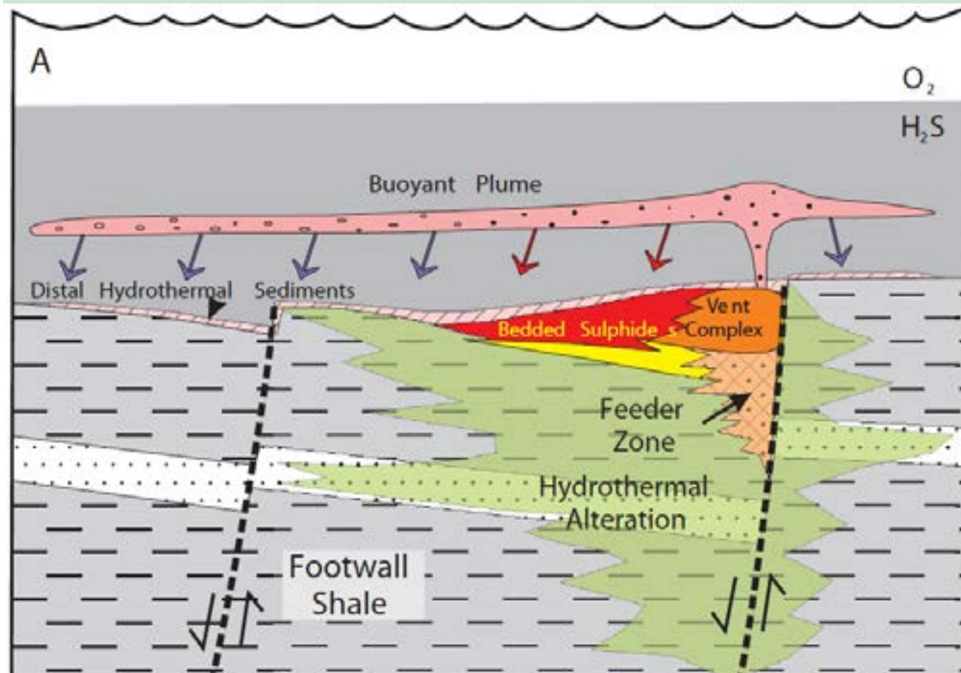
**Zn**$Cl_{2\,(aq)}$ + $H_2S_{(aq)}$ -> **Zn**$S_{(s)}$ + 2 $H^+$ + 2 $Cl^-$

*Source of S is thought to be biogenic $H_2S$, which is typically enriched in <u>anoxic</u> water columns

7) Sulfides either precipitate onto seafloor (bedded/laminated) or into permeable reduced sediments (replacement/stringer)

8) Circulation continues: seawater is transported down into the basin, heats up, leaches Zn–Pb, ascends…etc.



# Zoning in the Tom Deposit (Yukon)

## **Vent-proximal subtype**

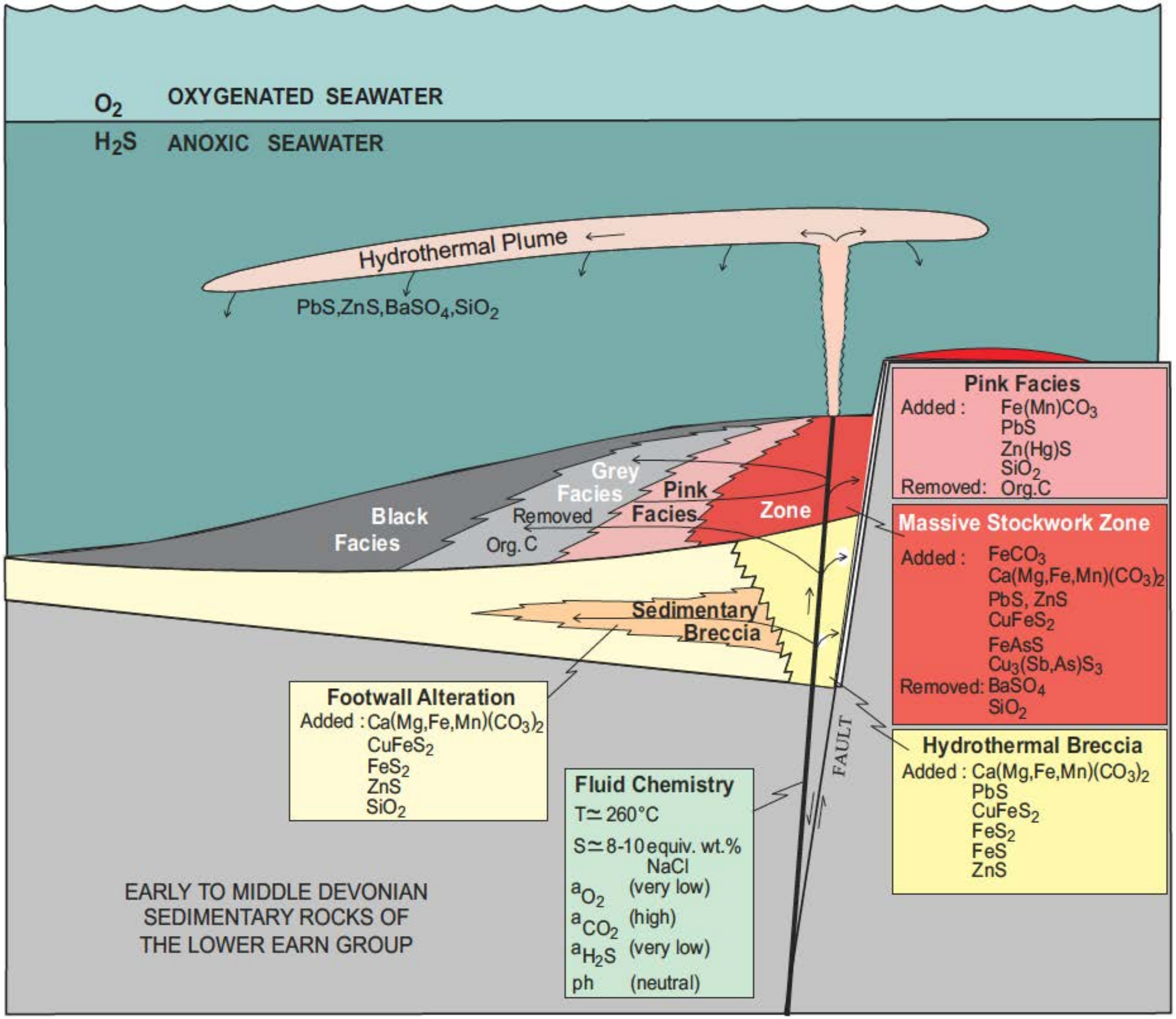
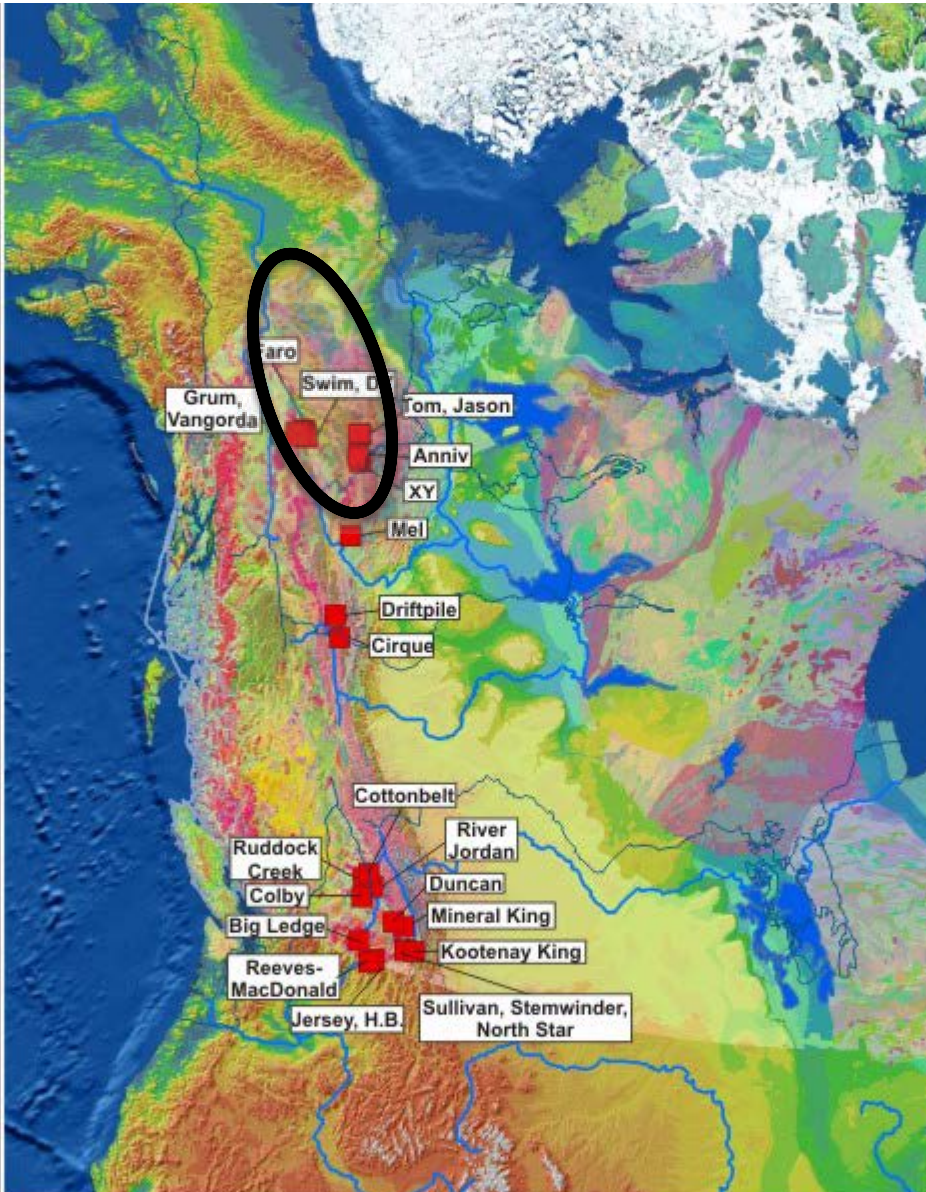
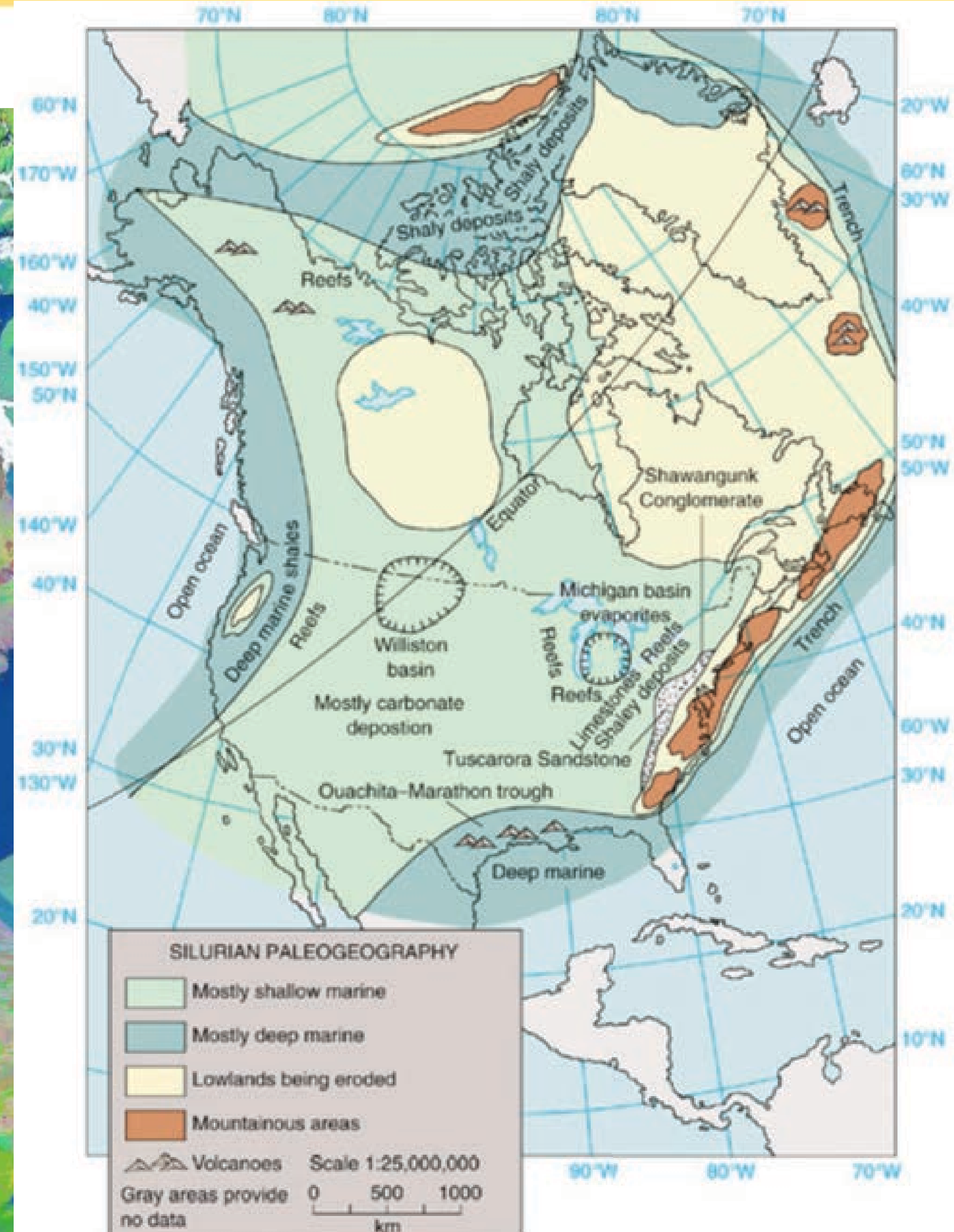



FIGURE 18. Genetic model for the Tom deposit, MacMillan Pass, Yukon (from Goodfellow and Rhodes, 1990).

# Selwyn Basin (Silurian–Devonian)

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# Selwyn Basin

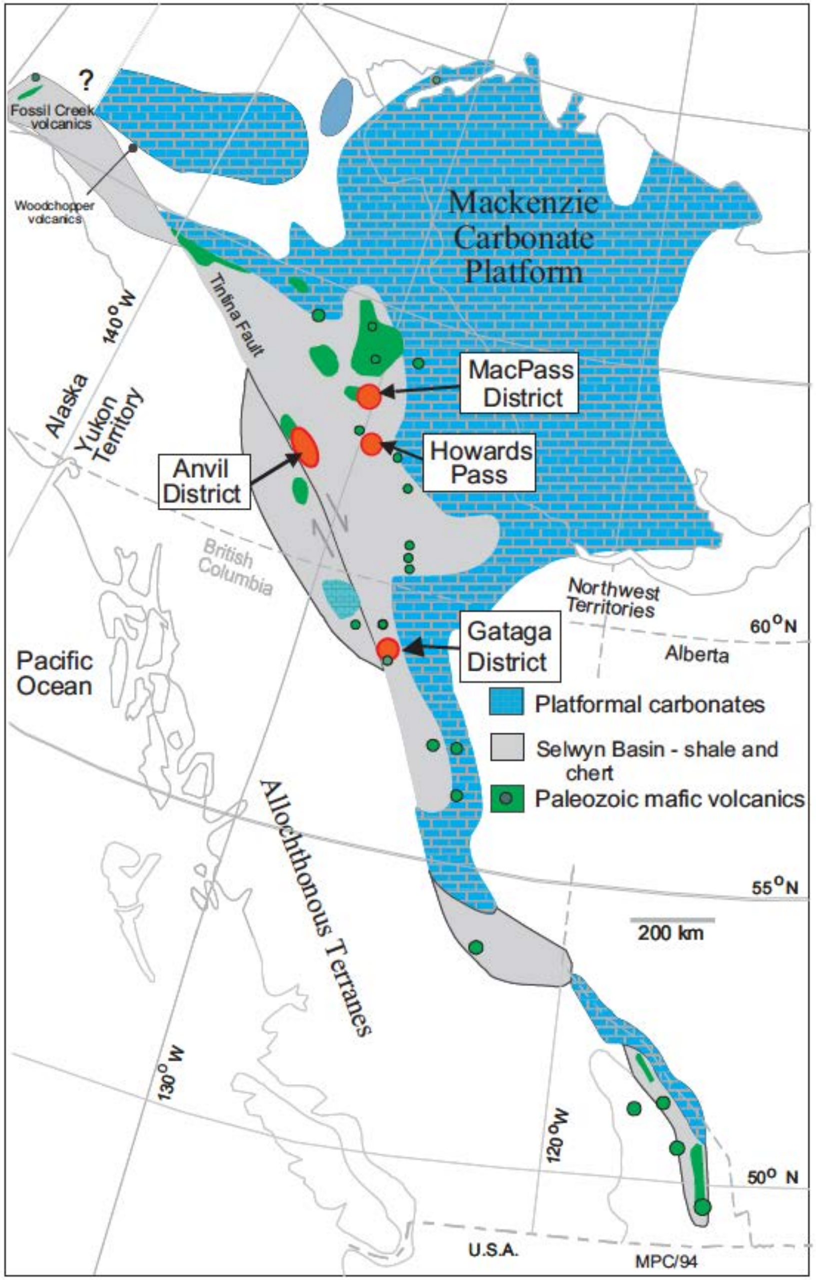
Large lenticular sedimentary basin that occupied western margin of North America in the Paleozoic

Extends for 1000s of km from Alaska, Yukon, NWT and into BC

One of the most productive for Zn–Pb–Ag SEDEX and barite deposits in the world

Twelve major SEDEX deposits, largest is the **giant** Howards Pass deposit (115 Mt @ 5.4% Zn and 2.1% Pb)

First deposit (Tom) discovered in 1951; red-stained creek draining mineralization



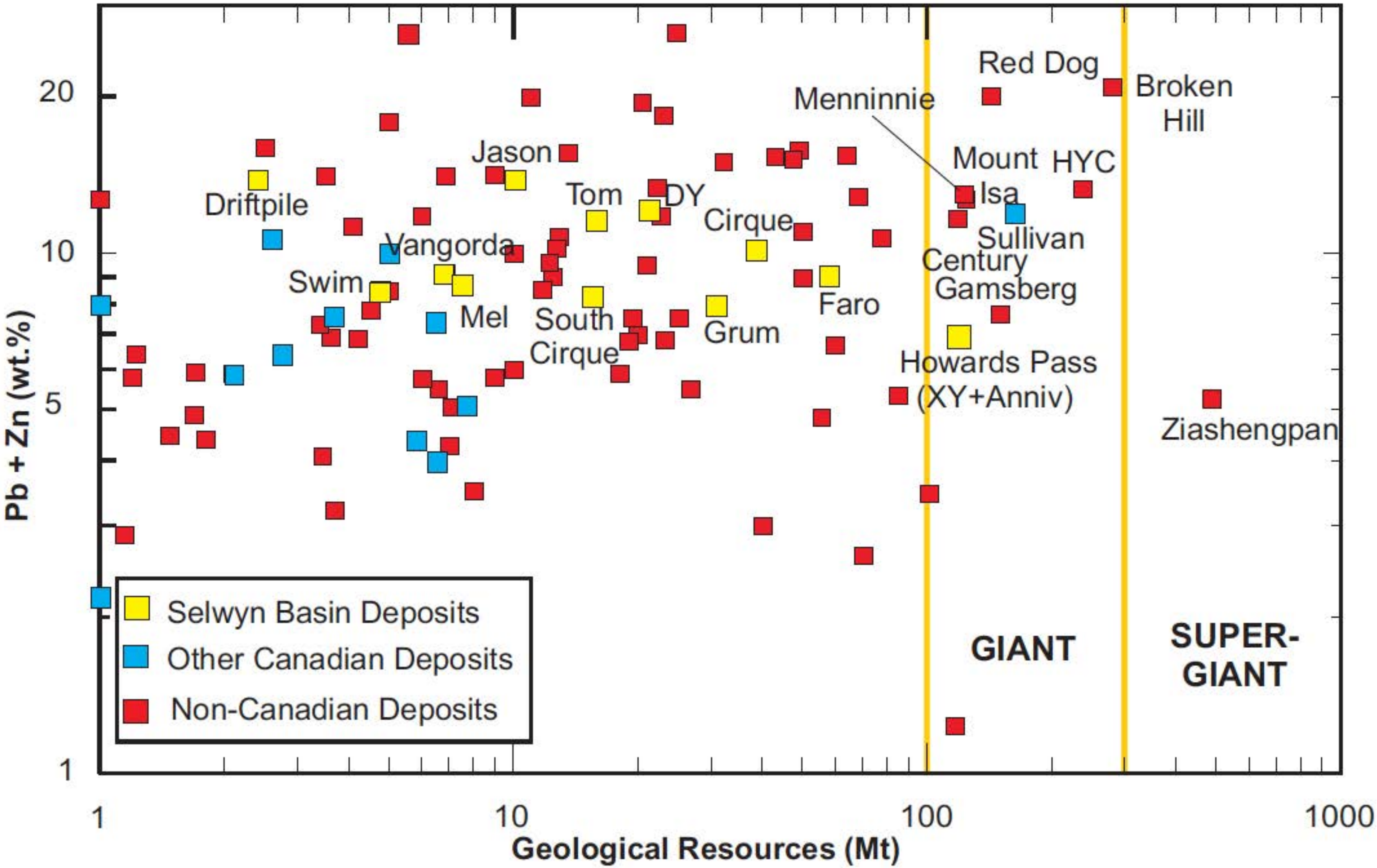



FIGURE 8. Grade (Pb+Zn wt.%) versus geological resources (million tonnes) for global, Canadian, and Selwyn Basin sedimentary exhalative deposits.

# Geology of the Selwyn Basin

Synrift Proterozoic–Cambrian clastic sedimentary rocks

Postrift Cambro–Ordovician deep-water carbonates

Overlain by basinal facies ***chert and black shale*** (Dev.–Miss.)

Bounded by carbonate platforms to E and N (these can host MVT deposits)

**Paleozoic mafic volcanism**

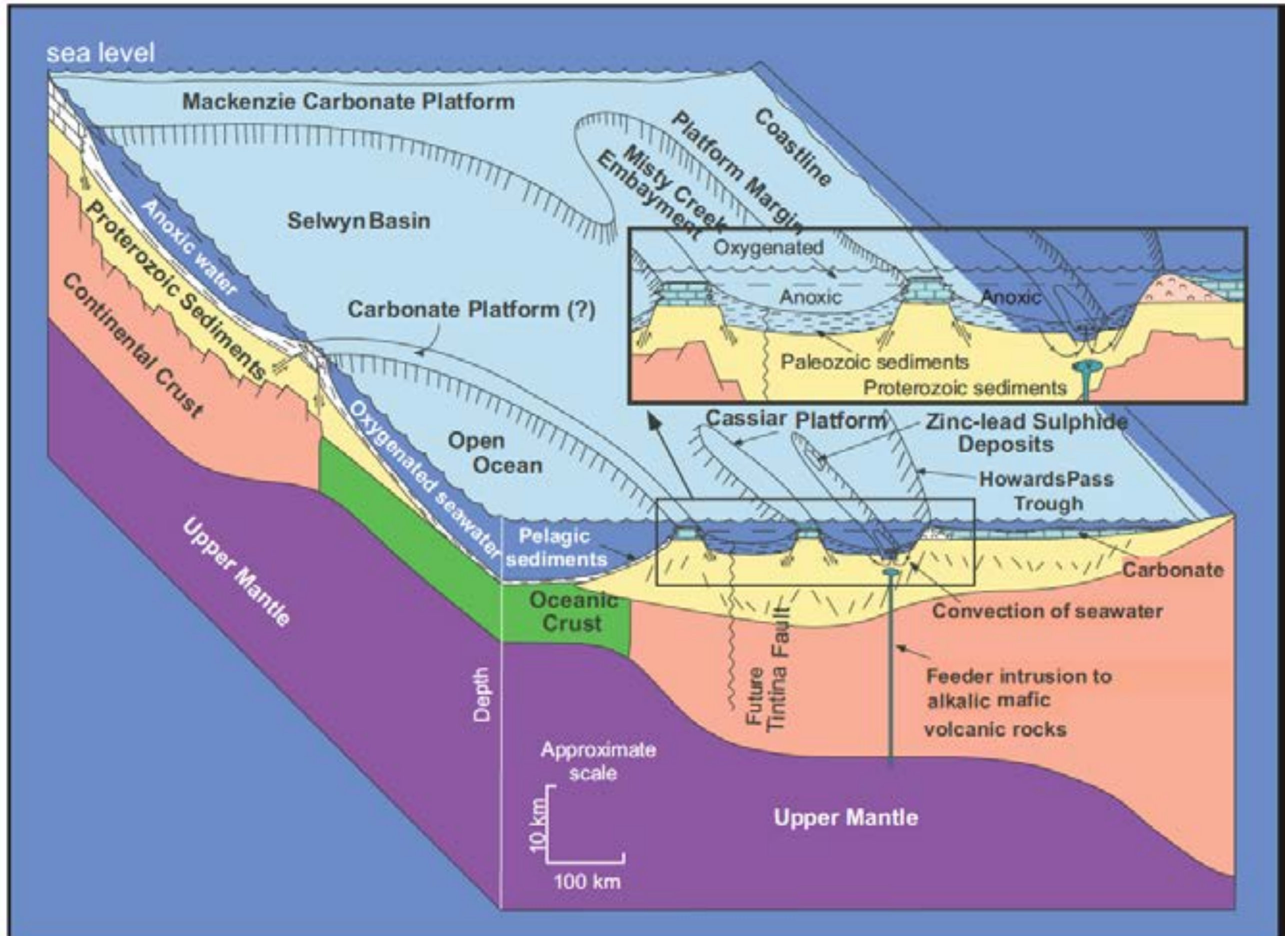
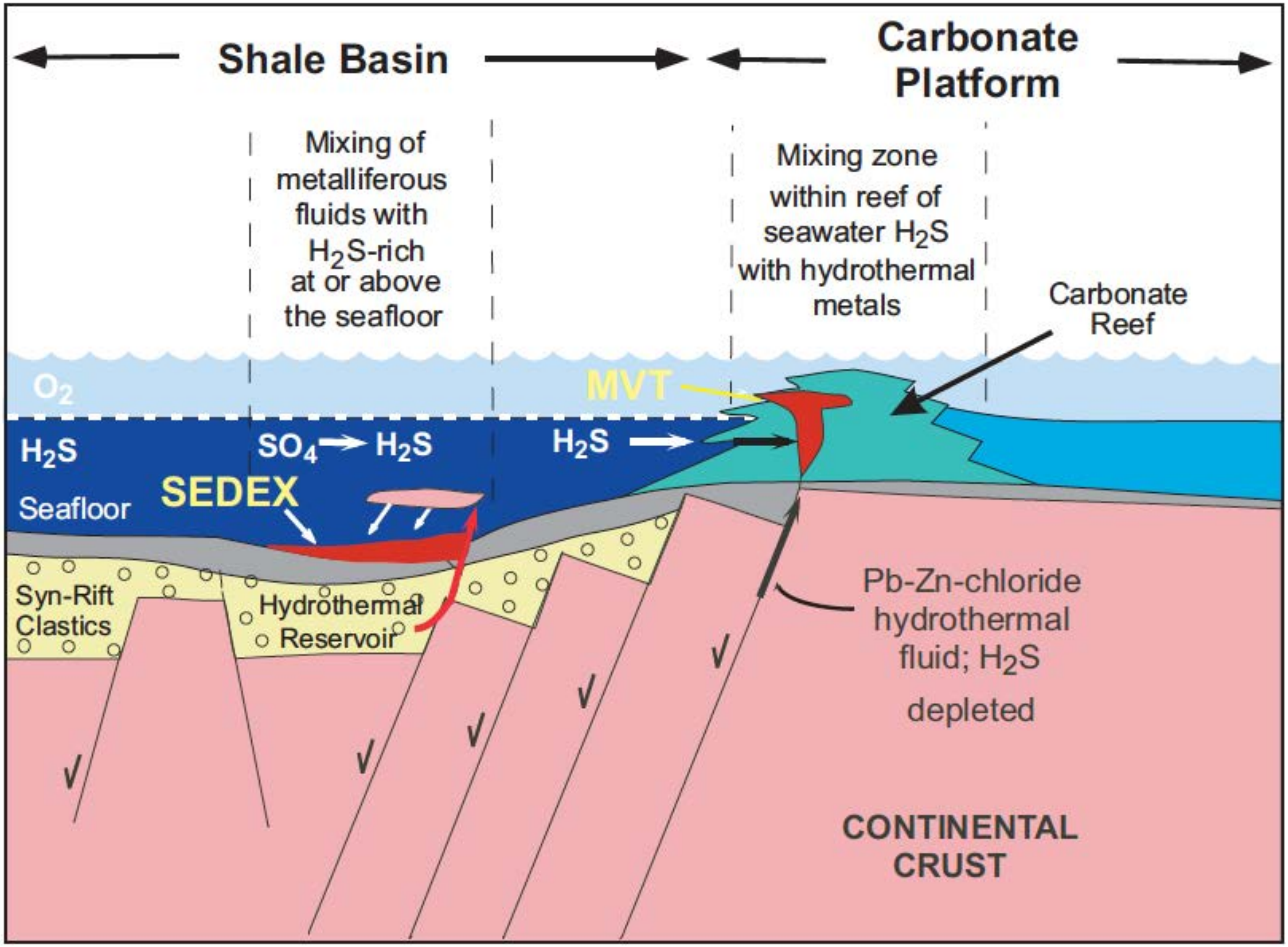



FIGURE 3. Block diagram of the rifted Paleozoic continental margin of northwestern Canada showing the stratigraphic and facies relationships between syn-rift clastic and postrift or sag basinal and platformal sequences, magmatism, hydrothermal activity, and ambient anoxic seawater conditions (Goodfellow et al., 1993).

# SEDEX deposited under anoxic conditions



# Howards Pass – vent distal

Contains XY, Anniv and OP deposits (called the 'zinc corridor')

Mineralization hosted in Ord–Sil black highly carbonaceous shales and chert

Mineralized zones are are thicker in the centre – suggests local basin control

Hydrothermal fluids initially acted as buoyant plumes then migrated as 'bottom-hugging' brines

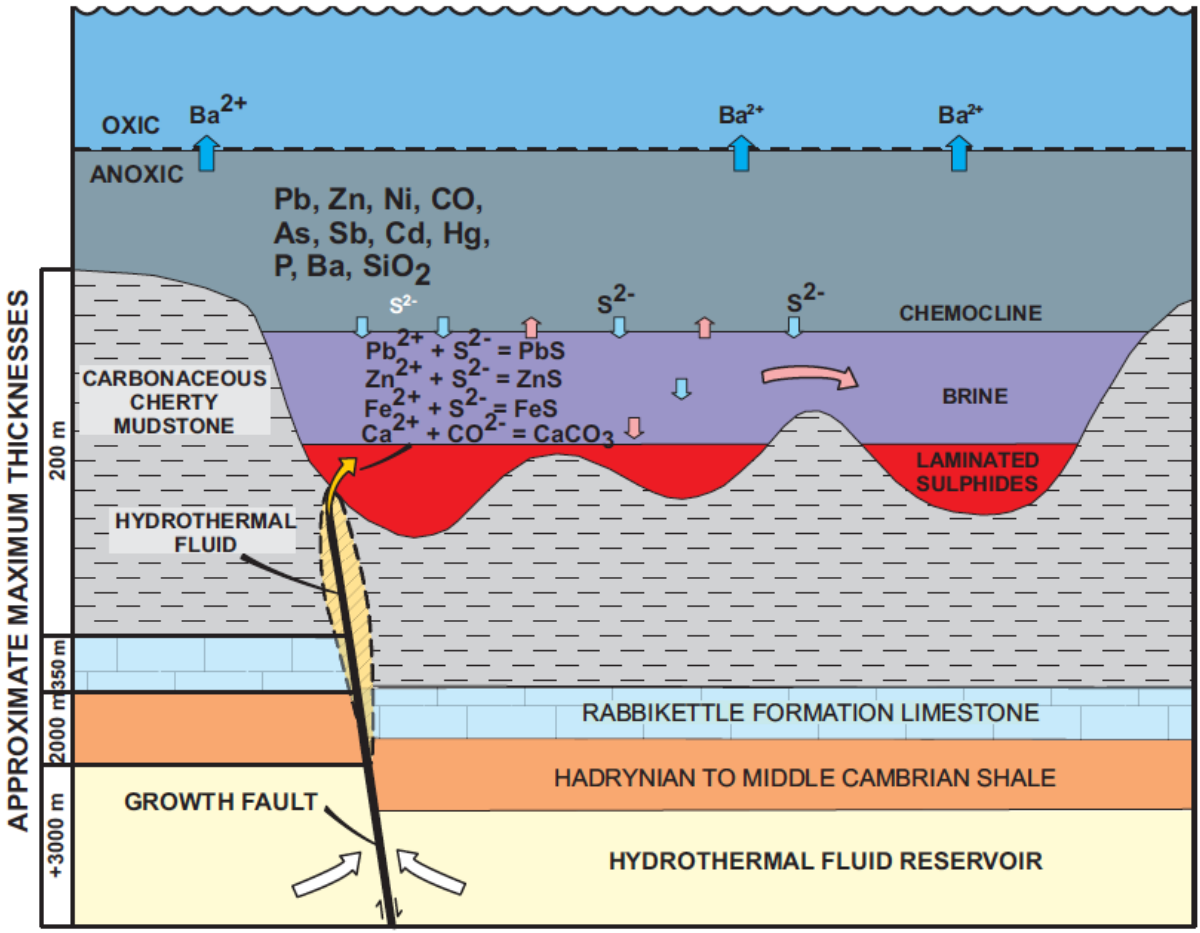
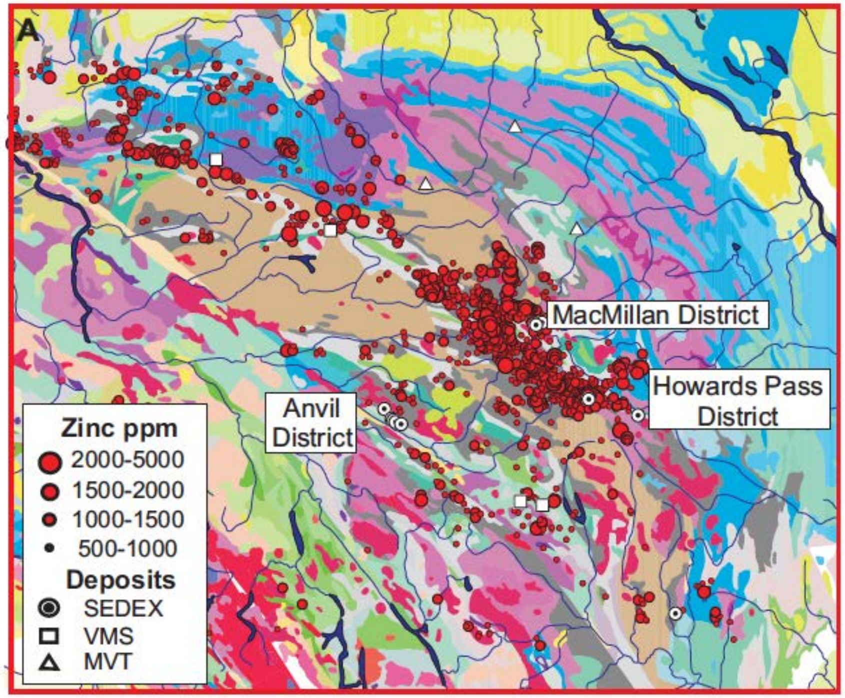



FIGURE 19. Genetic model for the Howards Pass (XY) deposit, MacMillan Pass, Yukon (from Goodfellow, 2004).

# Exploration techniques

Concentration of Zn in stream water samples




Green Zn-rich moss overlies mineralization at Howards Pass (XY)

# SEDEX Summary

- Syngenetic (sometimes epigenetic)
- Stratiform or stratabound
- Accumulation of base metal sulfides that formed at or near the sea floor by settling of buoyant plume or brines
- Mineralization is 'laminated', 'massive' or 'stringer'
- Require anoxic and reducing conditions for formation

Fluid: seawater ($Cl^-$ ligands)
Source: underlying sedimentary rocks
Transport: hydrothermal fluids driven by convective circulation
Trap: chemical and thermal interaction of oxidized metal-rich fluids with anoxic seawater or reducing sediments

# MVT
## Mississippi Valley Type

## 13.9 Sediment-Hosted Zinc–Lead Mineralization: Processes and Perspectives

JJ Wilkinson, Imperial College London, London, UK; University of Tasmania, Hobart, Tasmania, Australia





**Glossary**

**Aquiclude** An impermeable sedimentary layer that acts as a barrier to fluid flow.

**Anoxia** The condition of extreme oxygen depletion.

**Bacteriogenic** Produced by the action of bacteria, normally used in reference to the bacterial production of $H_2S$ from seawater sulfate.

**Basement** The region beneath an unconformity at the bottom of a sedimentary basin, typically composed of igneous or metamorphic rocks.

**Bittern** The residual brine produced by the evaporation of seawater past the point at which halite precipitates.

**Connate** Pertaining to pore waters trapped within sediment during deposition and subsequently buried. May be expelled later due to compaction or other processes.

**Convective flow** Flow of fluid driven by buoyancy forces, typically due to temperature-controlled density variations.

**Diachronous** An equivalent process occurring at different locations and times. Normally used in reference to sedimentation, such as during marine transgression or regression, when the same sedimentary facies is deposited in different places at different times.

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## Mississippi Valley-Type Lead-Zinc Deposits

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**Abstract**

Mississippi Valley-type (MVT) deposits are epigenetic, stratabound, carbonate-hosted sulphide bodies composed predominantly of sphalerite, galena, iron oxides (pyrite, marcasite), and carbonates (calcite, dolomite). MVT deposits are important Zn and Pb reserves and resources in the world. Silver, barite, gypsum, and fluorite may also be economically recovered from these deposits. Major world MVT deposits are found in Canada (Pine Point, Polaris, Nanisivik, Gays River, and Daniel's Harbour), mid-United States districts (Upper Mississippi Valley, Missouri, Tri-State, and Tennessee), Australia (Lennard Shelf and Coxco), and Europe (Silesia, Alpine, Reocin and Cévennes).

The mineralization occurs as open-space fillings of breccias and fractures, and/or as replacement of the host dolostone. Less commonly, sulphide and gangue minerals occupy primary carbonate porosity.

Most MVT deposits are found in carbonate platforms adjacent to cratonic sedimentary basins; they occur in limestone less frequently. They are also restricted to rocks younger than two billion years and formed during short time intervals, primarily within the Phanerozoic. MVT mineral districts are the product of regional- or subcontinental-scale fluid migration. Deposits are formed by the migration of warm saline aqueous solutions, similar to oilfield brines, through aquifers within platform-carbonate sequences toward the basin periphery. One of the most popular models relates ore-fluid migration to compressive tectonic regimes associated with continental accretion. This model is not universally applicable, however, as some of the MVT deposits most likely formed under an extensional tectonic regime.

**Résumé**

Les gisements du type Mississippi Valley consistent en des corps sulfurés stratoïdes épigénétiques encaissés dans des carbonates et se composent principalement de sphalérite, de galène, d'oxydes de fer (pyrite et marcassite) et de carbonates (calcite et dolomite). Ils constituent d'importantes réserves et ressources mondiales de Zn et Pb, et il est parfois possible d'extraire de manière rentable de l'argent, de la baryte, du gypse et de la fluorine de ces gisements. Les plus importants gisements de ce genre reposent au Canada (Pine Point, Polaris, Nanisivik, Gays River et Daniel's Harbour), dans les districts du milieu des É.-U. (Upper Mississippi Valley, Missouri, Tri-State, et Tennessee), en Australie (plate-forme de Lennard et Coxco) et en Europe (Silésie, Alpes, Reocin, et Cévennes).

Les minéralisations se présentent comme des remplissages dans des brèches et des fractures ou comme un remplacement de la dolomie encaissante. Moins fréquemment, les minéraux sulfurés et de gangue occupent les pores primaires des carbonates.

La plupart des gisements du type Mississippi Valley reposent dans des plates-formes carbonatées contiguës à des bassins sédimentaires cratoniques, mais parfois, ils sont logés dans du calcaire. Par ailleurs, ils sont encaissés dans des roches de moins de 2 Ga qui se sont formées rapidement, principalement pendant le Phanérozoïque. Les districts minéraux du type Mississippi Valley résultent d'une migration de fluides régionale ou sous continentale. Les gisements sont issus de solutions aqueuses salines chaudes qui sont similaires à des saumures de champ de pétrole qui ont circulé par des aquifères, dans des séquences de roches carbonatées néritiques, jusqu'aux environs d'un bassin. L'un des modèles les plus populaires établit un lien entre la migration du minerai et les régimes tectoniques compressifs rattachés à une accrétion continentale. Ce modèle n'est pas toujours applicable, car certains gisements du type Mississippi Valley se sont fort probablement formés dans un régime tectonique de distension.

**Definition**

Mississippi Valley-type (MVT) deposits are epigenetic, stratabound, carbonate-hosted bodies composed predominantly of sphalerite, galena, iron sulphides, and carbonates. The deposits account for approximately 27 percent of the world's current lead and zinc resources[1] (Tikkanen, 1986). They are so-named because several classic MVT deposits are located in carbonate rocks within the drainage basin of the Mississippi River in the central United States (US). Important Canadian deposits include Pine Point, Polaris, Nanisivik, Daniel's Harbour, Gays River, Monarch-Kicking Horse, and Robb Lake.

The deposits occur mainly in dolostone as open-space fillings, collapse breccias, and/or as replacement of the carbonate host rock. Less commonly, sulphide and gangue minerals occupy primary carbonate porosity. The deposits are epigenetic, having been emplaced after lithification of the host rocks.

MVT deposits originate from saline basinal metalliferous fluids at temperatures in the range of 75 to 200°C (Leach and Sangster, 1993). They are located in carbonate platform settings, typically in relatively undeformed orogenic foreland rocks, commonly in foreland thrust belts, and rarely in rift zones (Leach and Sangster, 1993).

Individual deposits are generally less than 2 million tonnes, are zinc-dominant, and possess grades that rarely exceed 10% (Pb+Zn). The deposits do, however, characteristically occur in clusters, referred to as "districts". A metallogenic district is defined as a continuous area that contains the expressions of the geological environment and tectonic events that controlled the formation of MVT deposits. For example, the Cornwallis district in Nunavut hosts one deposit[2], the Polaris mine, and approximately 80 showings[3] (Dewing et al., 2007). Another example is the Pine Point district in the Northwest Territories, which hosts the Pine Point

Paradis, S., Hannigan, P., and Dewing, K., 2007, Mississippi Valley-type lead-zinc deposits, *in* Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 185-203.

# MVT deposits worldwide

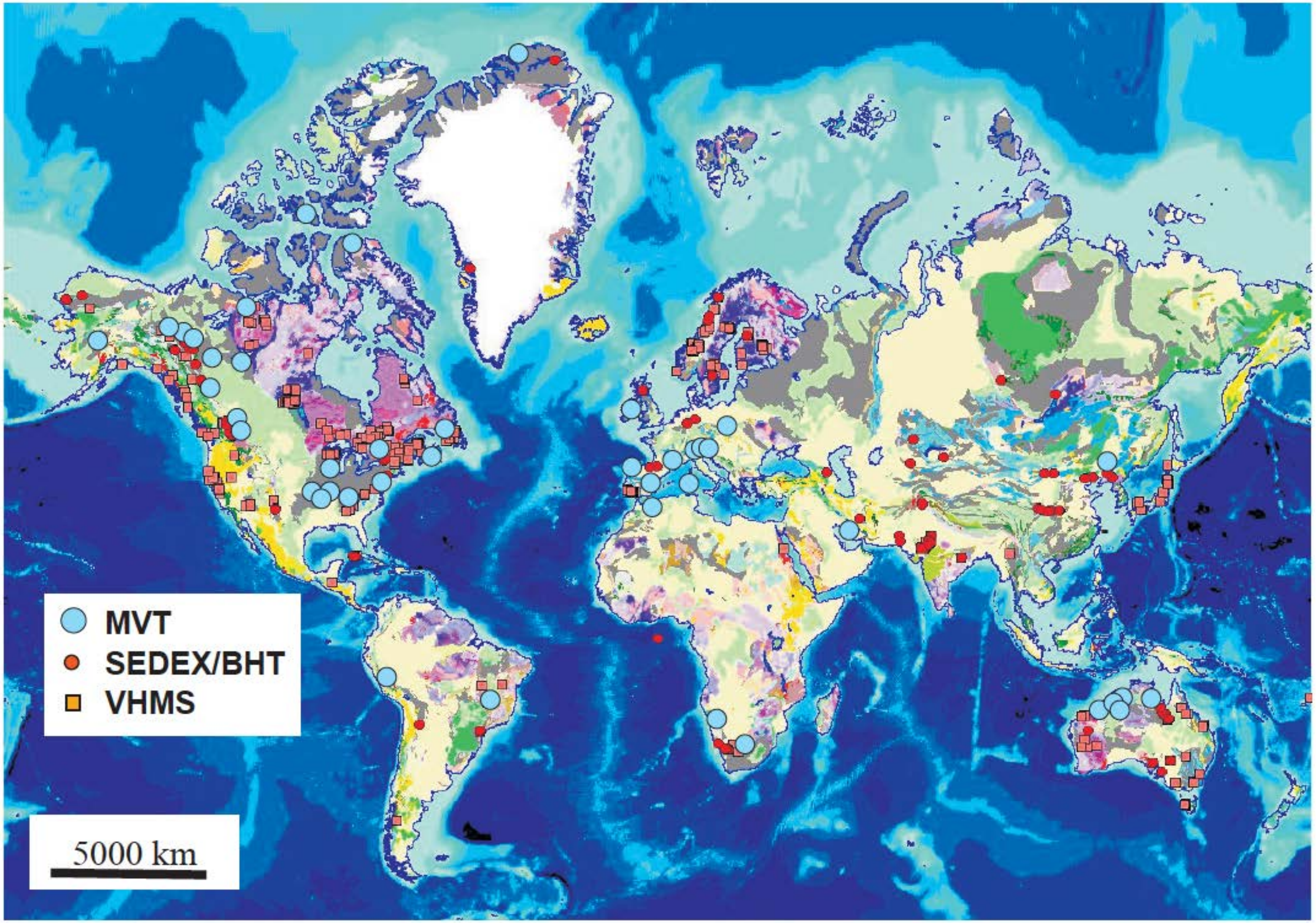



FIGURE 1. Distribution of Mississippi Valley-type deposits and districts worldwide. BHT = Broken Hill-type, MVT = Mississippi Valley-type, SEDEX = sedimentary exhalative, and VHMS = volcanic-hosted massive sulphides.

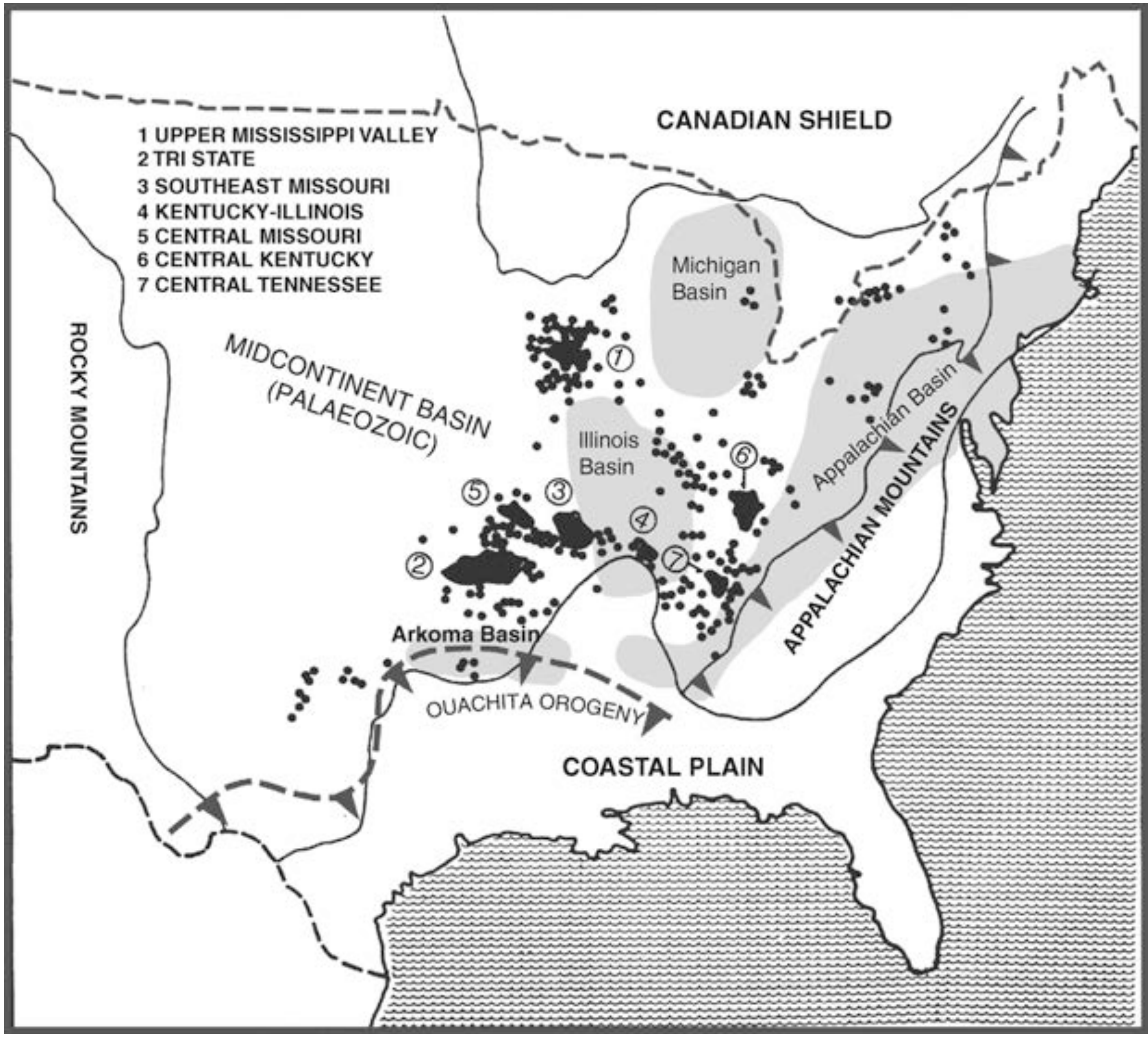
# MVT type locality

Midcontinental Basin of Paleozoic age (Mississippi valley)

Gray areas are depocentres (hydrocarbons found here)

MVT deposits found on ridges or over basement highs

Appalachian orogen



# MVT deposits in Canada

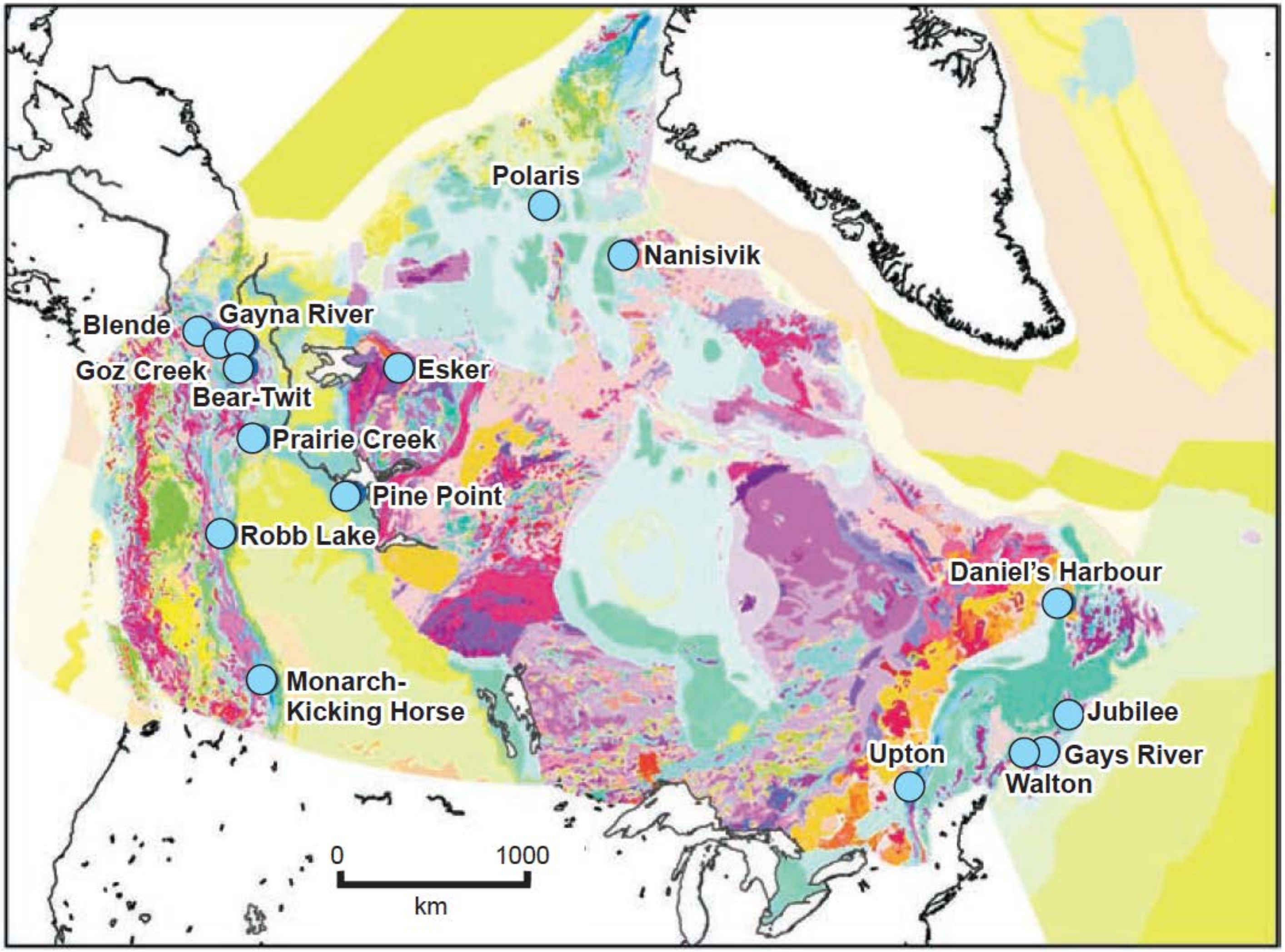
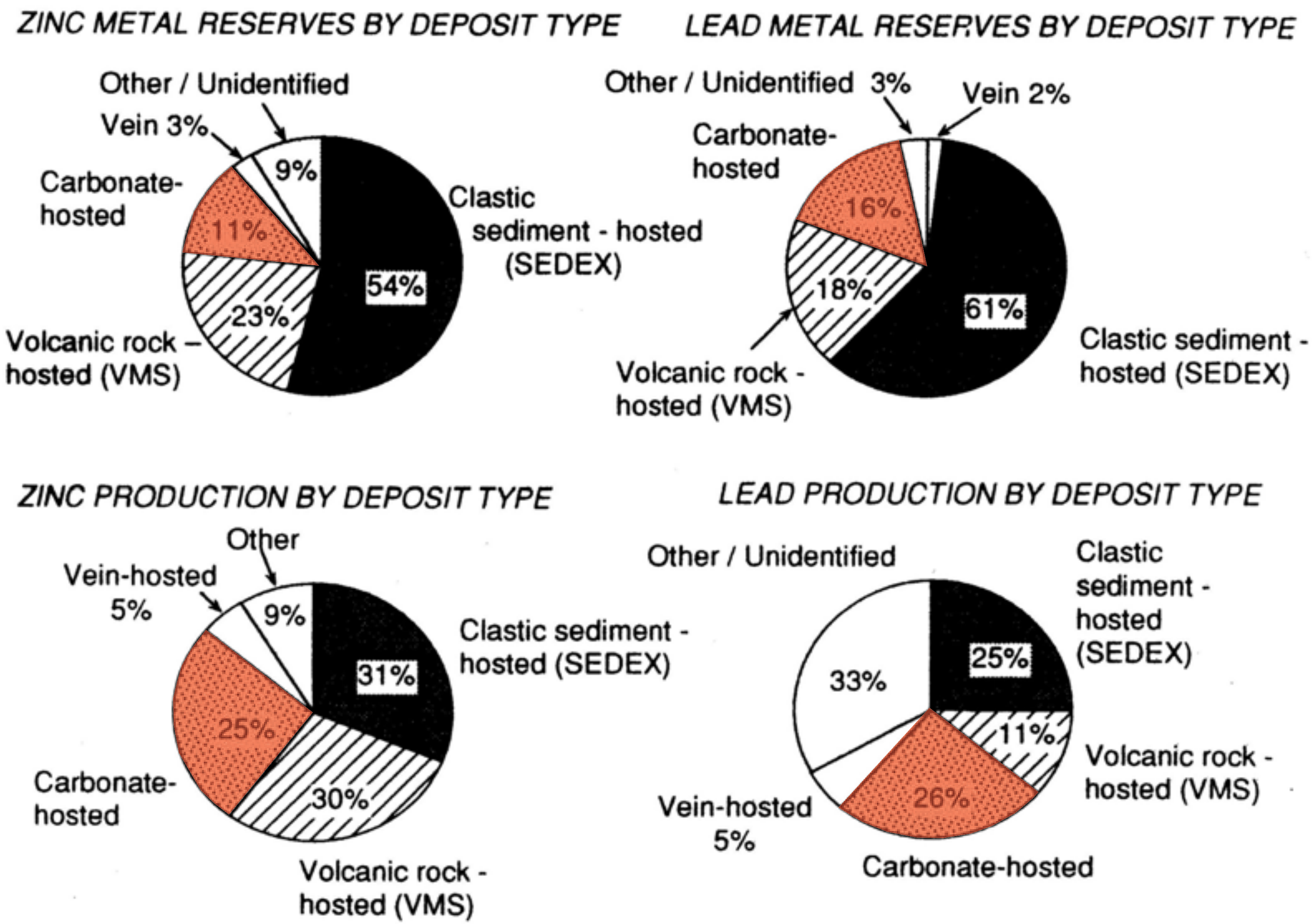



FIGURE 2. Distribution of Mississippi Valley-type deposits plotted on a simplified geological map of Canada (Map D1860A). Major attributes of these deposits are listed in Appendix 1.

# MVT ore grades and such…



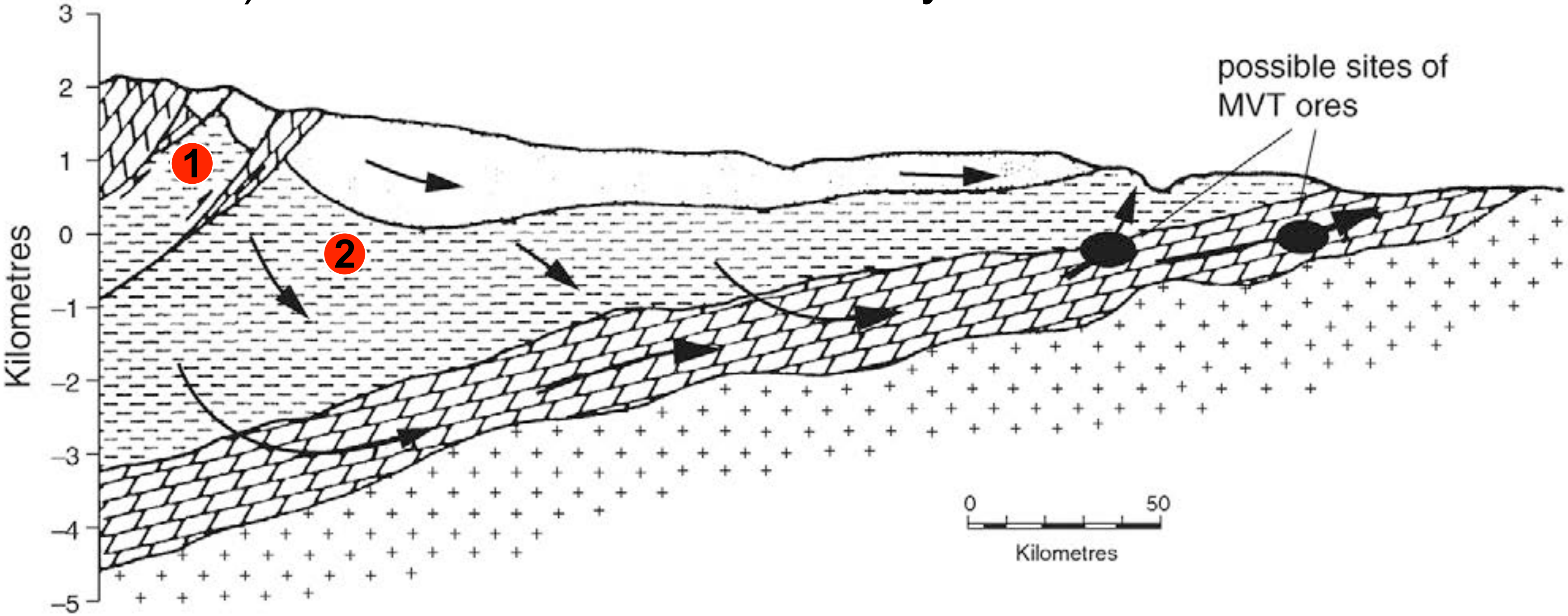
# MVT fun facts

- Epigenetic
- Ore minerals: sphalerite and galena (Zn and Pb)
- Associated with carbonate rocks
- Grades range from a few to ~10 wt% each of Zn and Pb
- Nearly all occur in Phanerozoic sedimentary basins

# MVT – genetic model

1) Orogenesis (mountain building) thickens the crust and creates lateral gradients in pressure

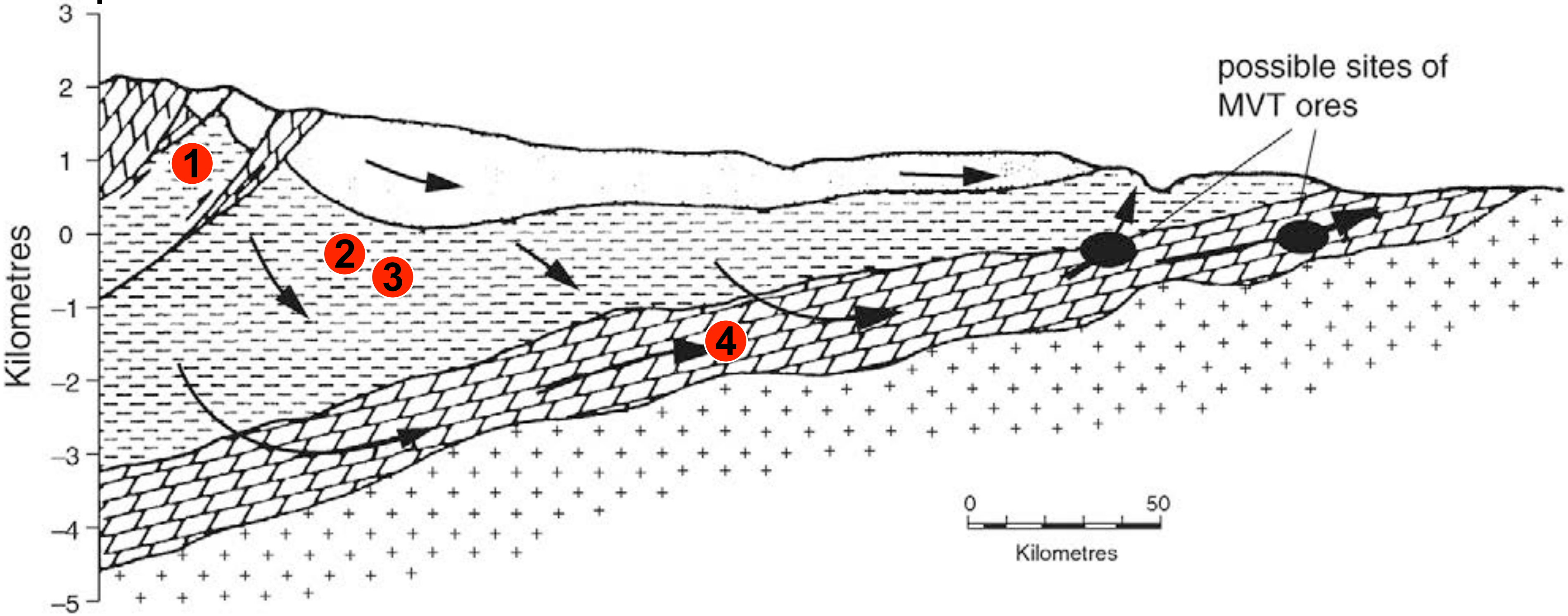
2) Connate fluids are heated to higher temperatures (150–200°C) in the thickened sedimentary basins



# MVT – genetic model

3) Connate fluids are rich in $Cl^-$ (former sea water) and leach metals from clays and organic matter

4) Fluids migrate up dip along structures or through permeable rocks towards the surface



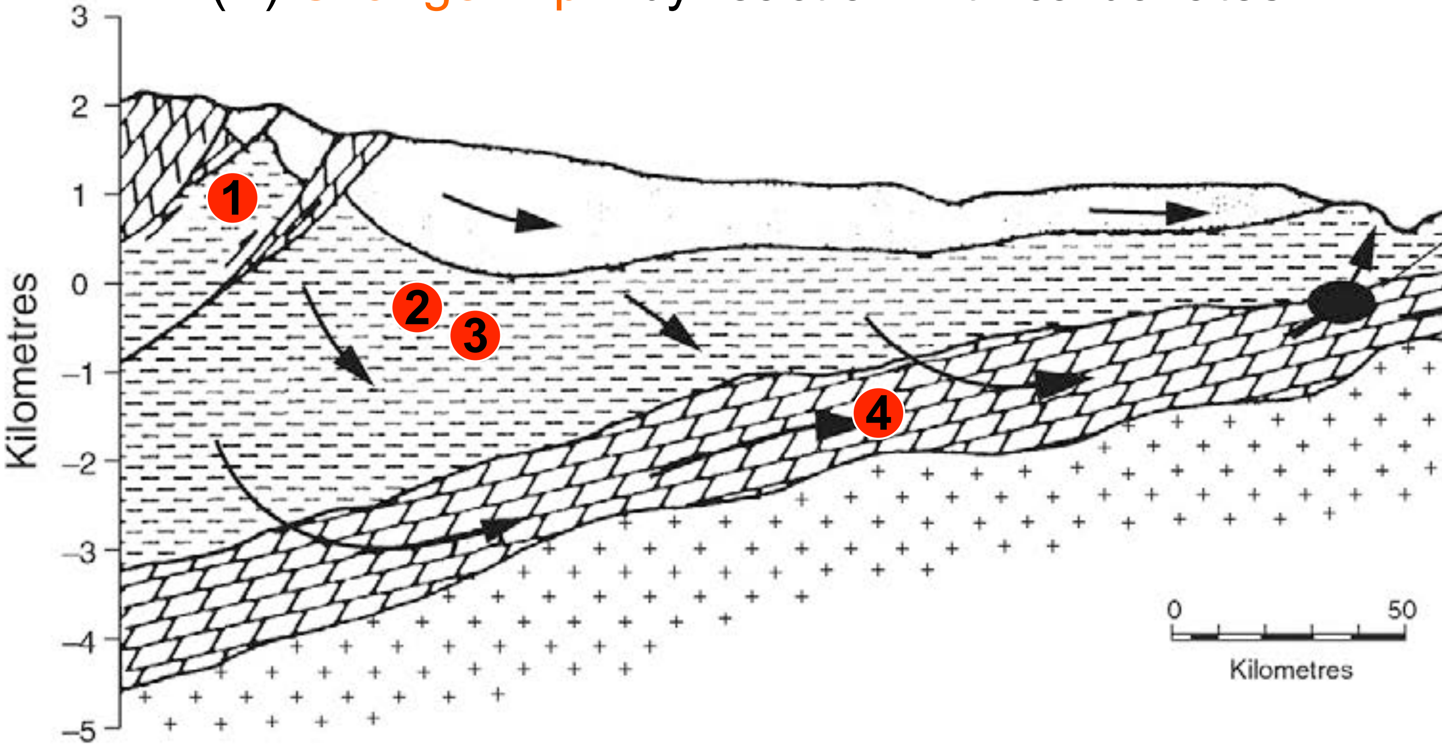
$MeCl_{2(aq)} + H_2S_{(aq)} \rightarrow MeS_{(s)} + 2\,H^+ + 2\,Cl^-$

# MVT – genetic model

$CaCO_3 + 2H^+ \leftrightarrow Ca^{2+} + H_2CO_3$

5) Hydrothermal fluid encounters a local trap (reef, karst, facies change, etc…); metal sulfide precipitation:

- (i) Mixing of metal-rich brines with fluids containing hydrogen sulfide
- (ii) Sulfate reduction ($SO_4^{2-} \rightarrow H_2S$) due to interaction with organic matter
- (iii) Change in pH by reaction with carbonates




# Canadian MVT deposits

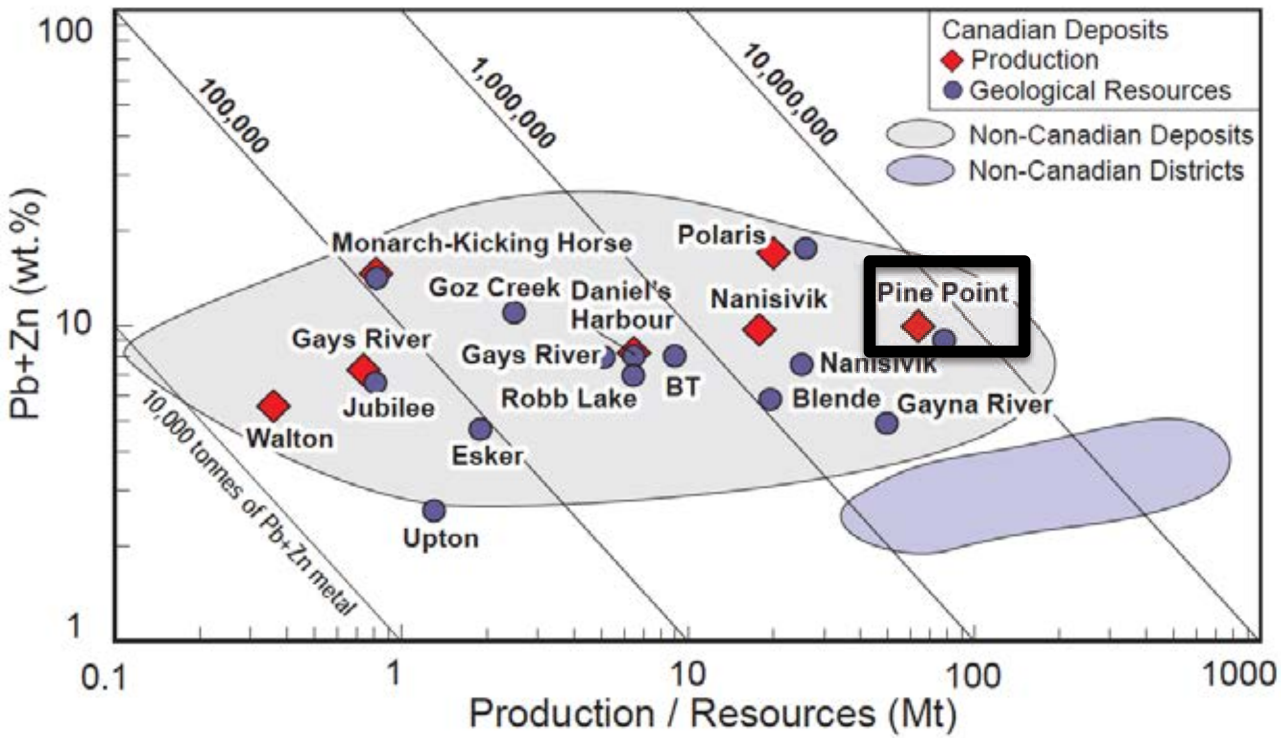


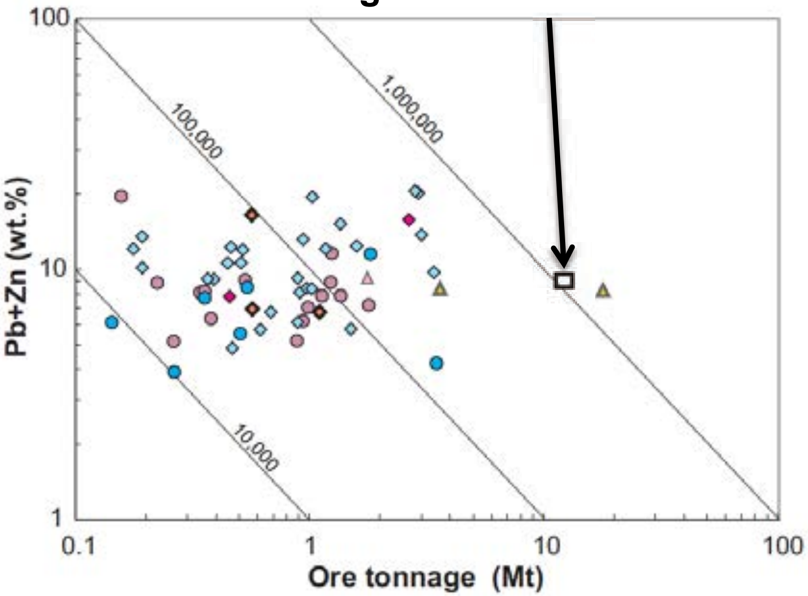

**FIGURE 3.** Grade-tonnage for Canadian Mississippi Valley-type deposits with geological and production resources. Diagonal lines represent total

# Pine Point, NWT

- One of Canada's most important Pb and Zn districts
- 1929: Exploration started
- 1947: Staked by Cominco
- 1948–1963: Extensive exploration – 8.8 Mt of ore: 2.6% Pb and 5.9% Zn
- 1964–1988: produced 26% of Pb and 17% of Zn in Canada

- Resource: 9% Pb, 6% Zn
- 1987: $500 million in ore; 50% of NWT production
- 700 employees during production
- Reclamation – no more Pine Point


Remaining resource at Pine Point



# Pine Point – Geology

- Precambrian basement
- Overlain by passive margin sequence (W. Canada Sedimentary Basin)
- Platformal carbonate sequence
- Mid-Devonian tectonic adjustments (large scale open folds) with NE-trending hinge lines
- Carbonates in the fold hinges reached the surface and were **karstified**…

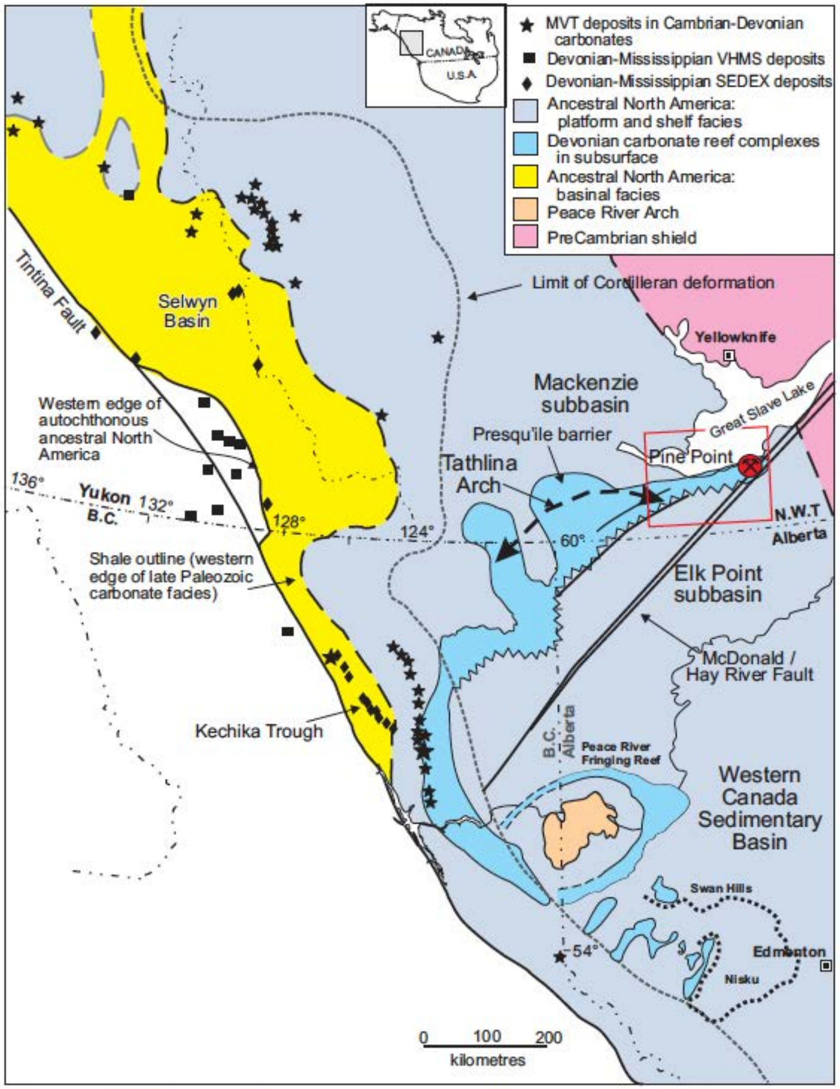
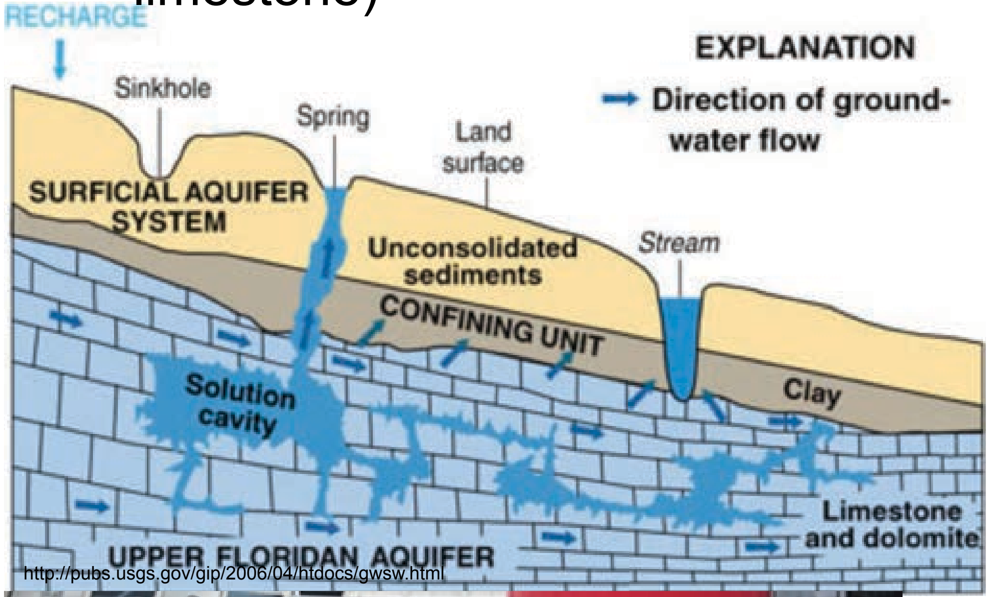


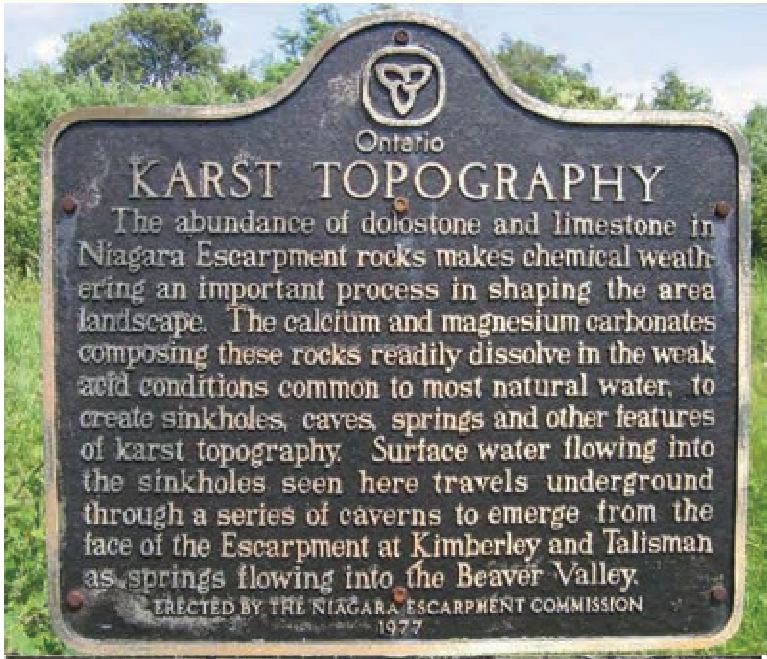

Figure 1. Devonian-Mississippian tectonic framework of the western Canadian continental margin, and location of the Pine Point mineral deposit on the eastern flank of the Western Canada Sedimentary Basin (adapted from Nelson et al., 2002). The Devonian Presqu'ile barrier complex separating two depositional subbasins is shown. The Mackenzie subbasin north of the barrier exhibits normal marine sedimentation and the Elk Point sub-

**Karst:** landform produced through the dissolution of soluble rocks (mostly limestone)




http://pubs.usgs.gov/gip/2006/04/htdocs/gwsw.html

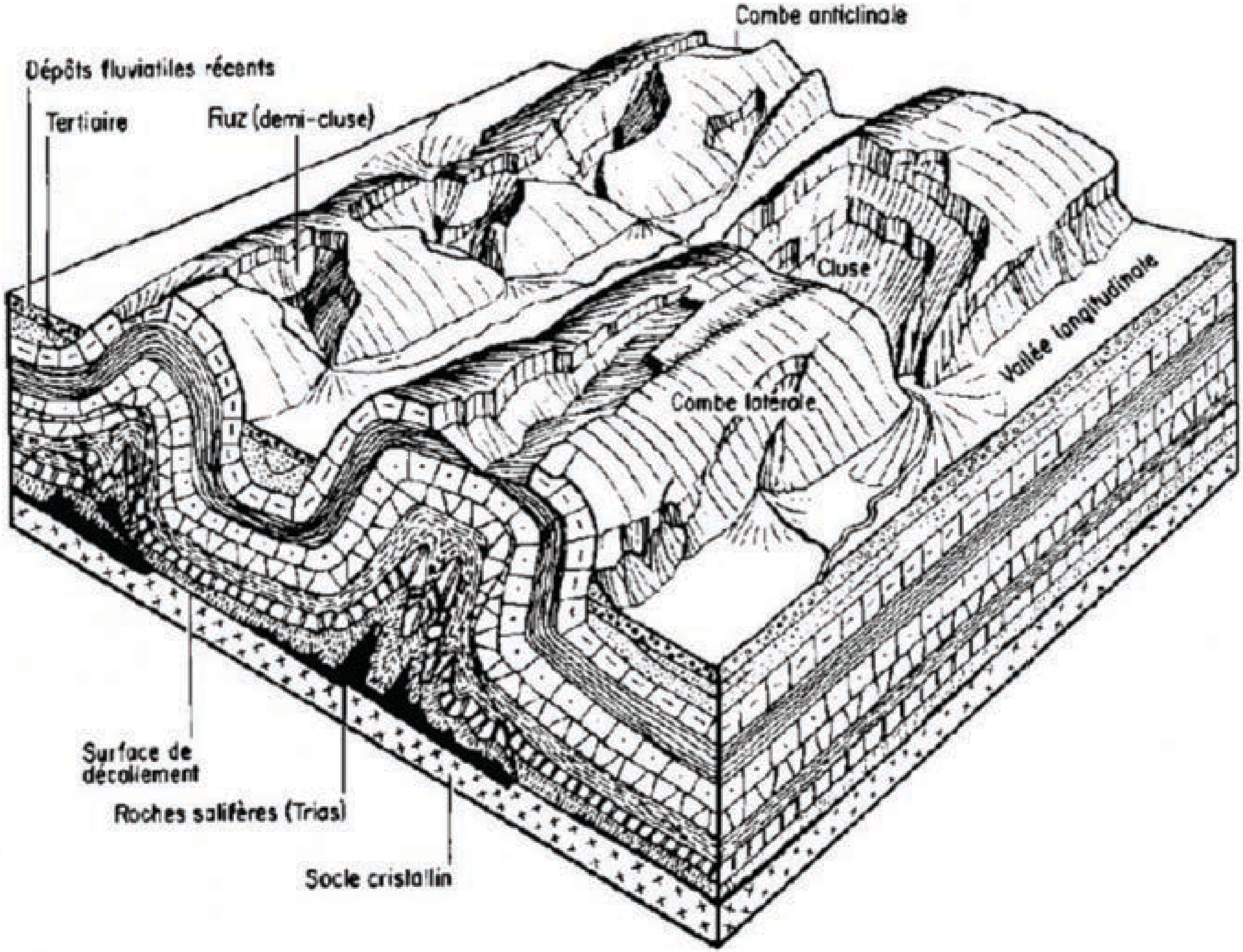
National Corvette Museum/Associated Press




http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/GRS005/karst-map.pdf

Figure 3. Sinkholes that formed during past paleodrainage conditions within mini-cuesta-forming limestones of lower Bobcaygeon and upper Gull River formations, Tyendinaga, southeastern Ontario.

**Fold hinges are weak –** easy targets for karstification (open space!)




http://www.architecturalpapers.ch/images/articles/115_7_w1000h600.jpg

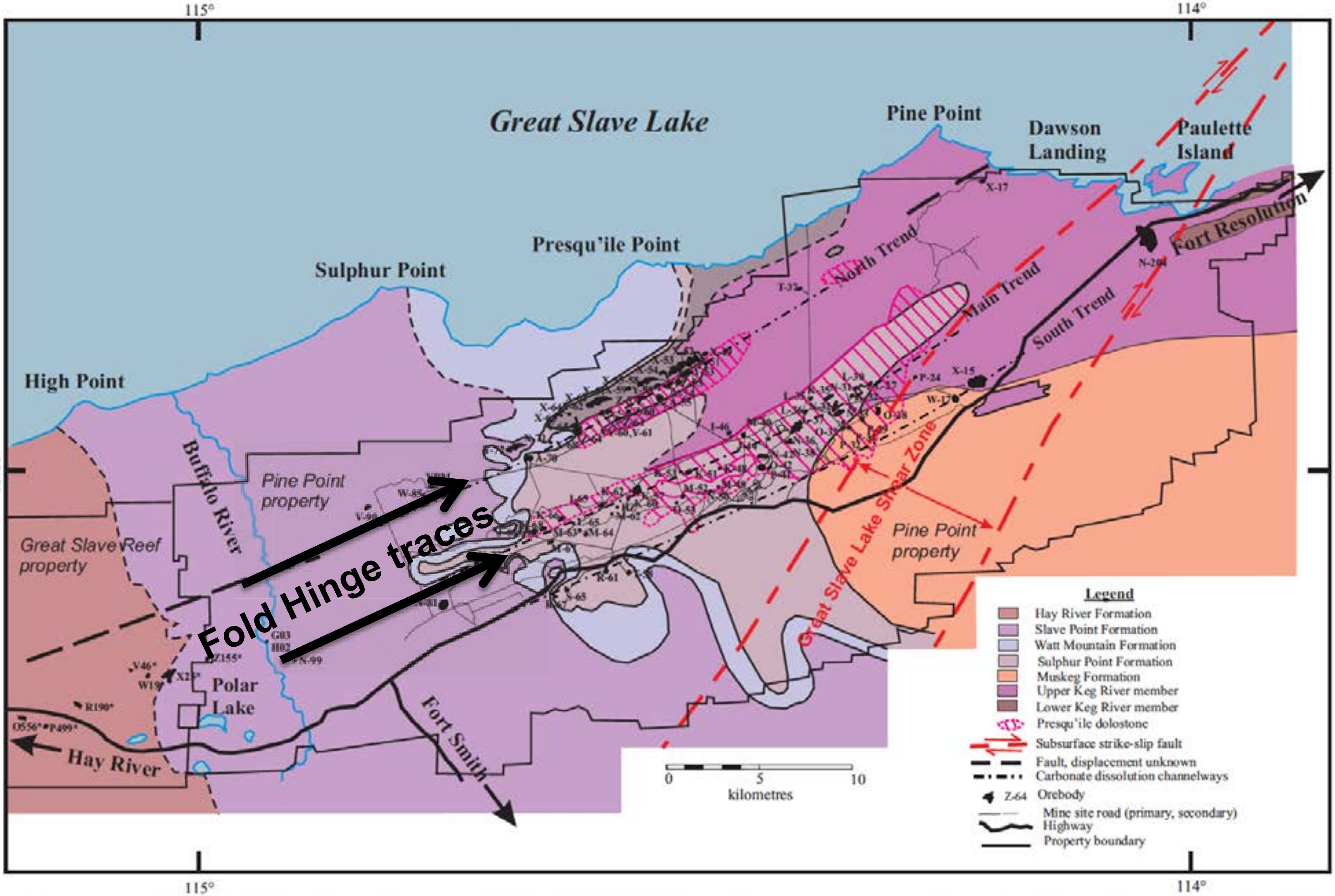
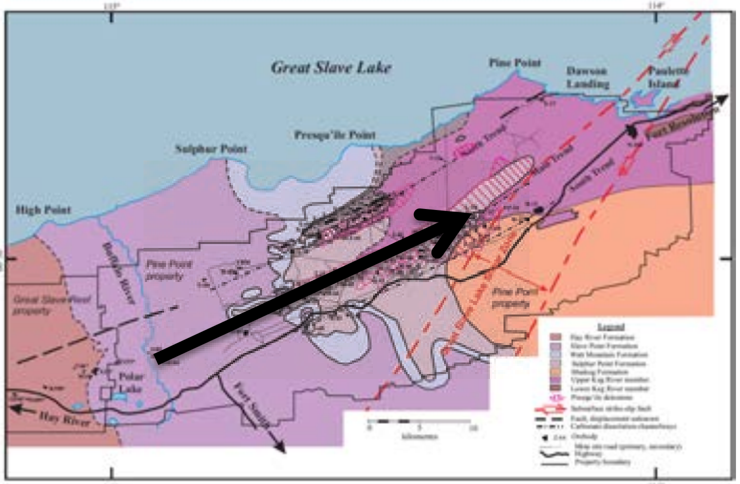



FIGURE 2. General geology of the Pine Point mining camp with orebody locations in the Pine Point and Great Slave Reef properties (starred orebodies in Great Slave Reef property) (adapted from Rhodes et al., 1984). Major mineralized trends (i.e. North, Main, and South trends) on carbonate dissolution channelways are shown.

# Pine Point




View eastward of mined-out karst trend at Pine Point.

# Pine Point, NWT – Ore bodies

- Most hosted in Sulphur Point Formation (limestone and dolostone)
- Distributed along zones of weakness (fold hinge lines)
- Ore deposited in paleokarst networks
- ~100 main ore bodies
- Open-cavity filling and local replacement
- Sphalerite and galena are the main ore minerals

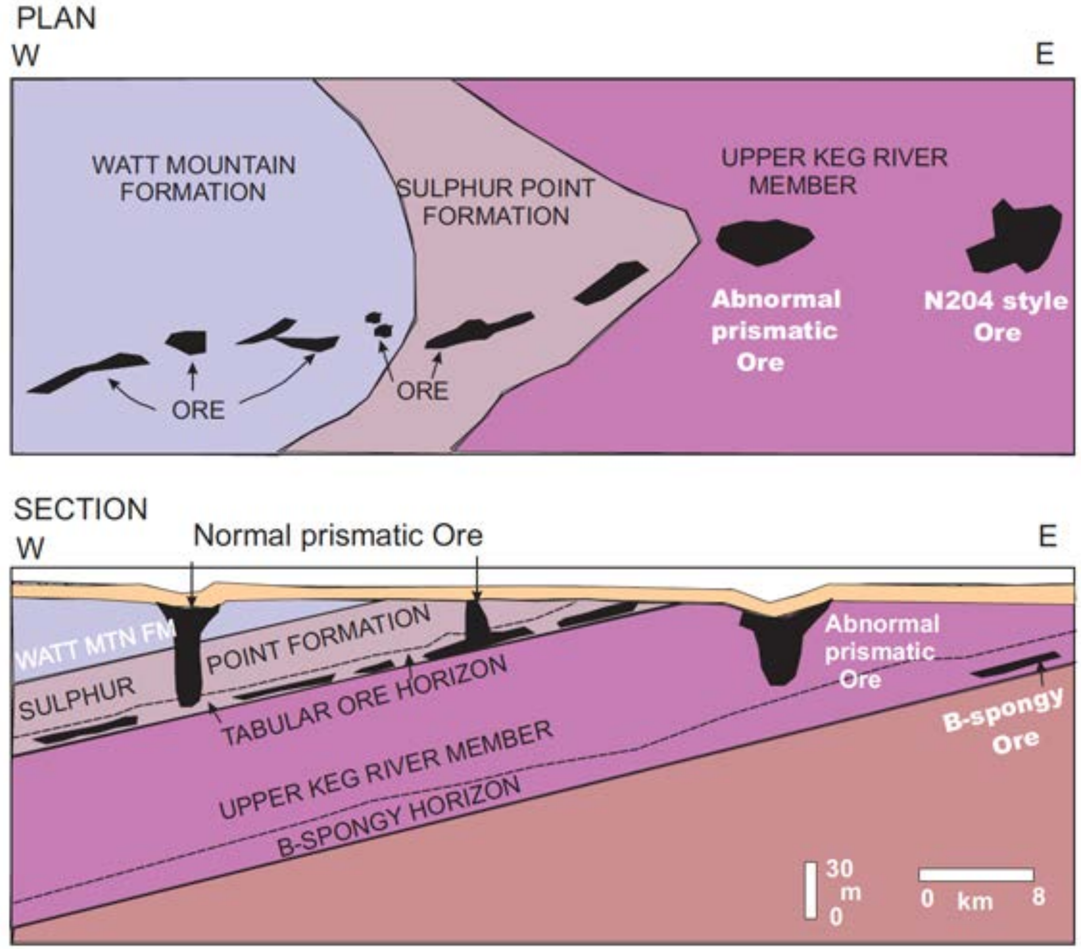
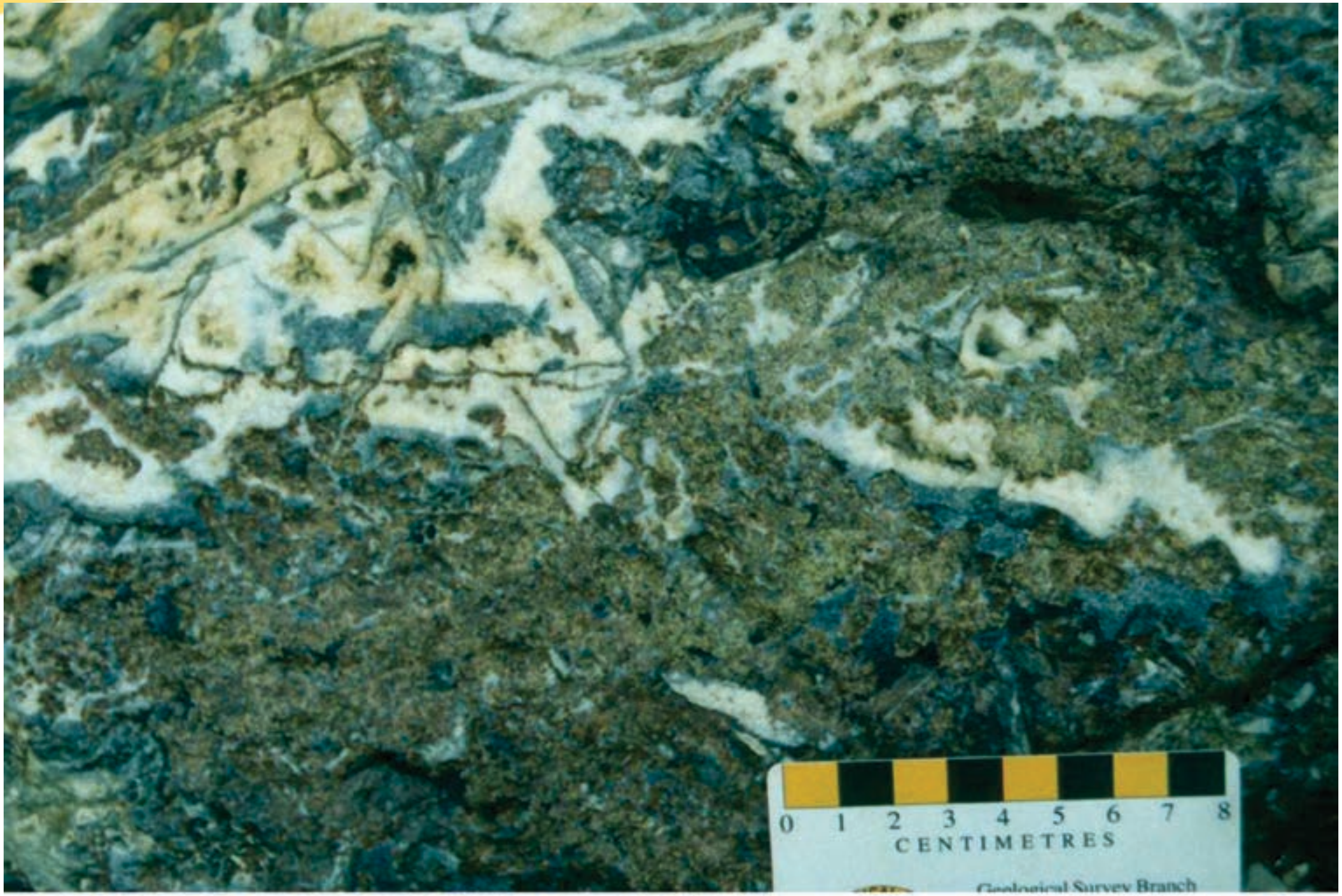


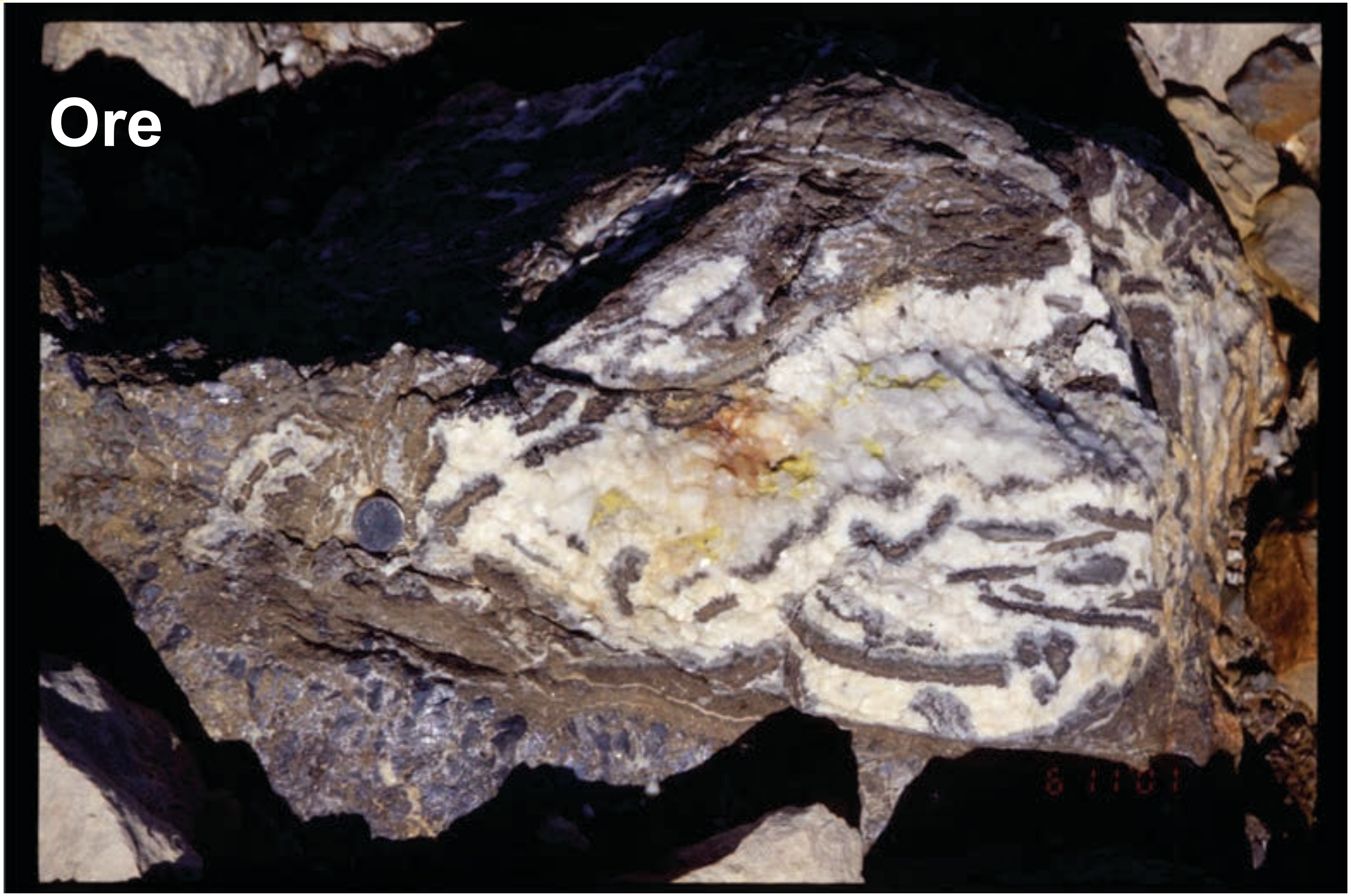

FIGURE 8. Schematic plan and vertical section of orebody types and their relation to the regional stratigraphy (adapted from Rhodes et al., 1984).

# Dissolution creates space!

**(From Hannigan, 2007)** Dolomite boulder from rubble pile at Pine Point mine-site. Very porous partly-cemented rubble packbreccia layer underlain by laminated dolostone strata. Abundant rock dissolution in the stratabound packbreccia horizon produced breccia-moldic cavities subsequently cemented by white sparry or saddle dolomite. The breccia layer, a horizon of enhanced porosity and permeability, may form tabular karst structures that commonly host tabular sulphide concentrations at Pine Point. The laminated dolostone probably exhibits original fabric due to dissolution and cementation of selected laminae. Photo taken by D. W. Morrow.




**From Hannigan (2007); Fig. 14:** Aggregates of massive sphalerite crystals and white sparry dolomite filling small fractures in brecciated carbonate strata at Pine Point (courtesy of S. Paradis).




**From Hanningan (2007); Fig. 13:** Ore from the Pine Point mine. Collapse breccia containing open-space filling white sparry dolomite surrounding broken angular fragments of dolomitic internal sediment impregnated by fine-grained dark brown sphalerite. Late white and coarse calcite with associated native sulphur fill the core of the former cavity. Fine-grained dark brown sphalerite replaces laminated sandy interval on floor (?) of cavity. The internal sediment layer is underlain by coarse-crystalline matrix dolomite containing abundant fine- to coarse-crystalline galena.

# Pine Point – paragenetic sequence

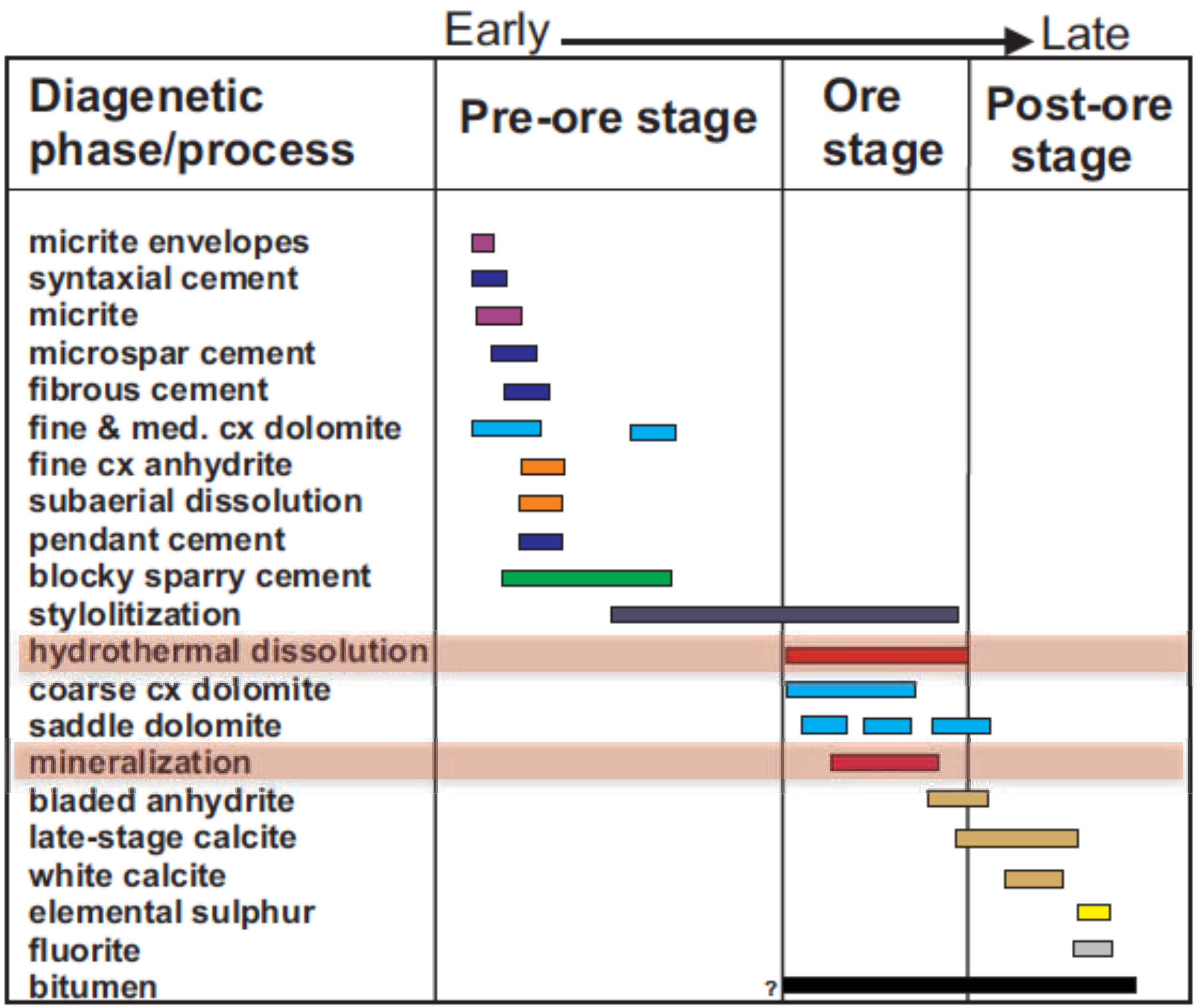



FIGURE 11. Paragenetic sequence at Pine Point. Pre-ore, ore, and post-ore stage diagenetic phases and processes are depicted. Adapted from Krebs and Macqueen (1984) and Qing (1991). (cx = crystalline)

# Pine Point – Genetic model

1. Karstification
2. Basin-derived fluids (or brines) acquire heat, metals, ligands during migration
3. Fluid flow driven by topography
4. Metals precipitate by mixing of acidic hydrothermal fluids with meteoric water (e.g. increase pH)

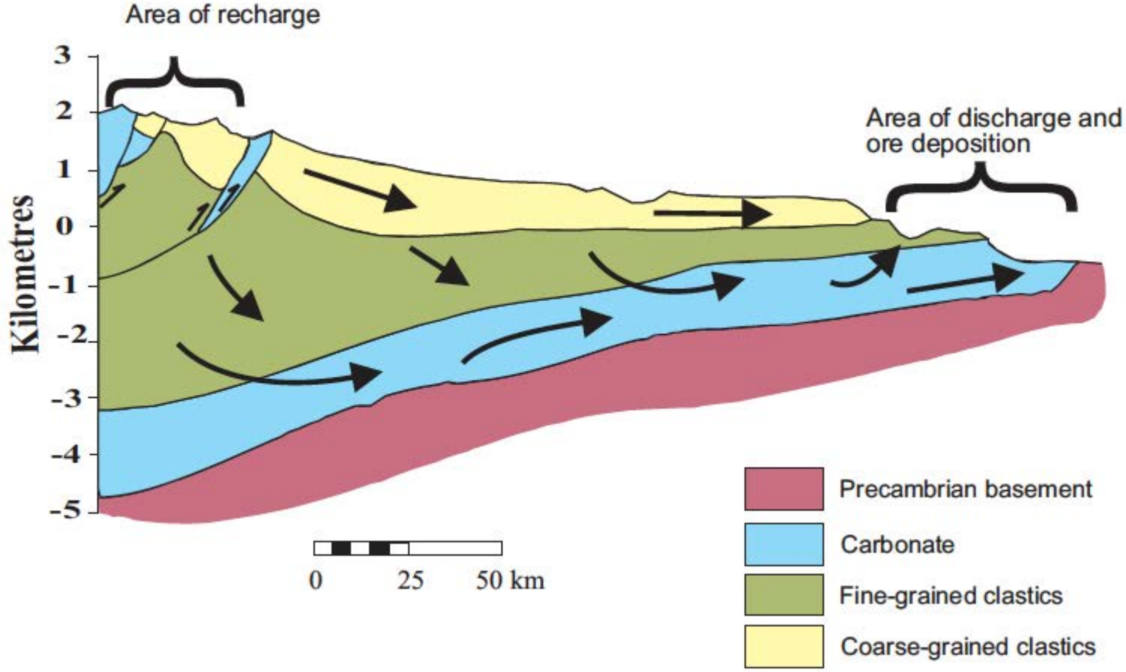


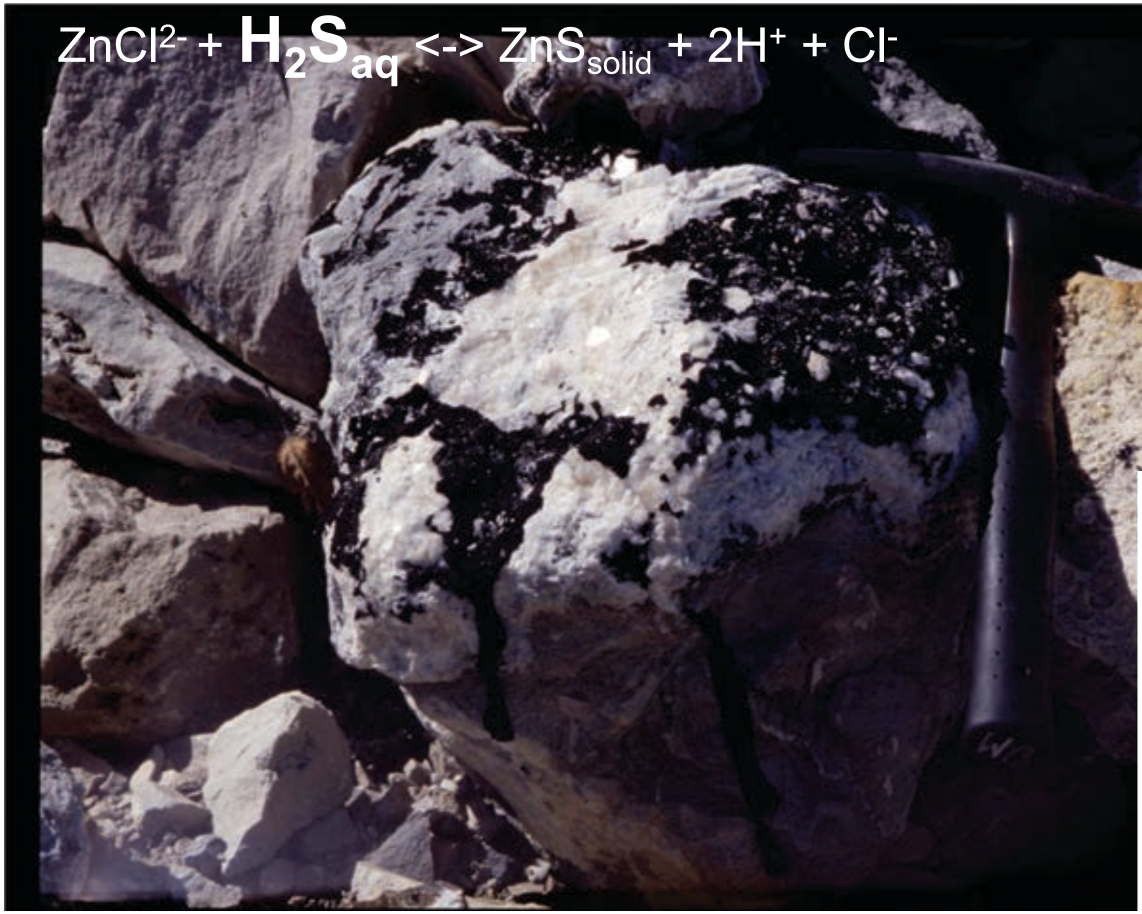

FIGURE 12. Topographically induced fluid-flow by Garven and Freeze (1984).

**Dissolution:** $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$

**Precipitation:** $ZnCl^{2-} + H_2S_{aq} \leftrightarrow ZnS_{solid} + 2H^+ + Cl^-$

$$\mathrm{pH} = -\log_{10}(a_{\mathrm{H}^+})$$

# A second possible precipitation mechanism: sulfate reduction

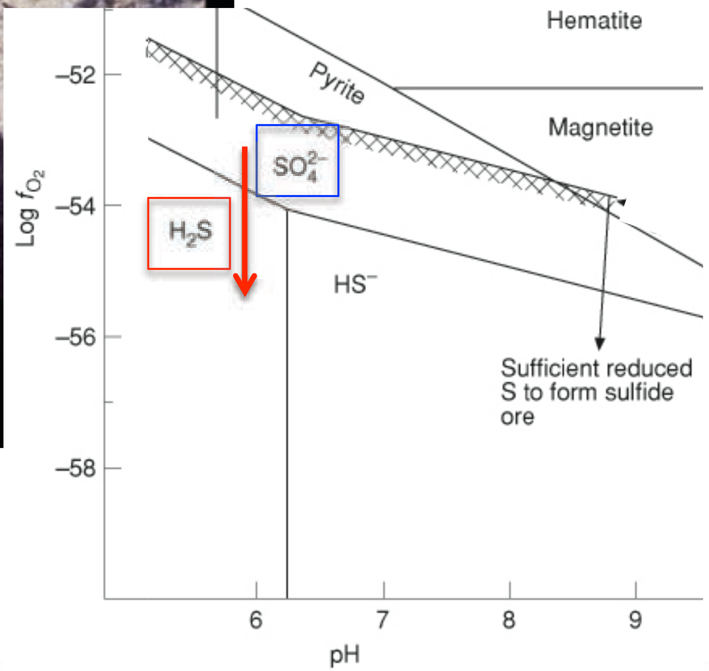



**From Hannigan (2007); Fig. 12:** Soft sticky bitumen in carbonate boulders, Pine Point mine-site. Bitumen starts to flow during hot summer days.

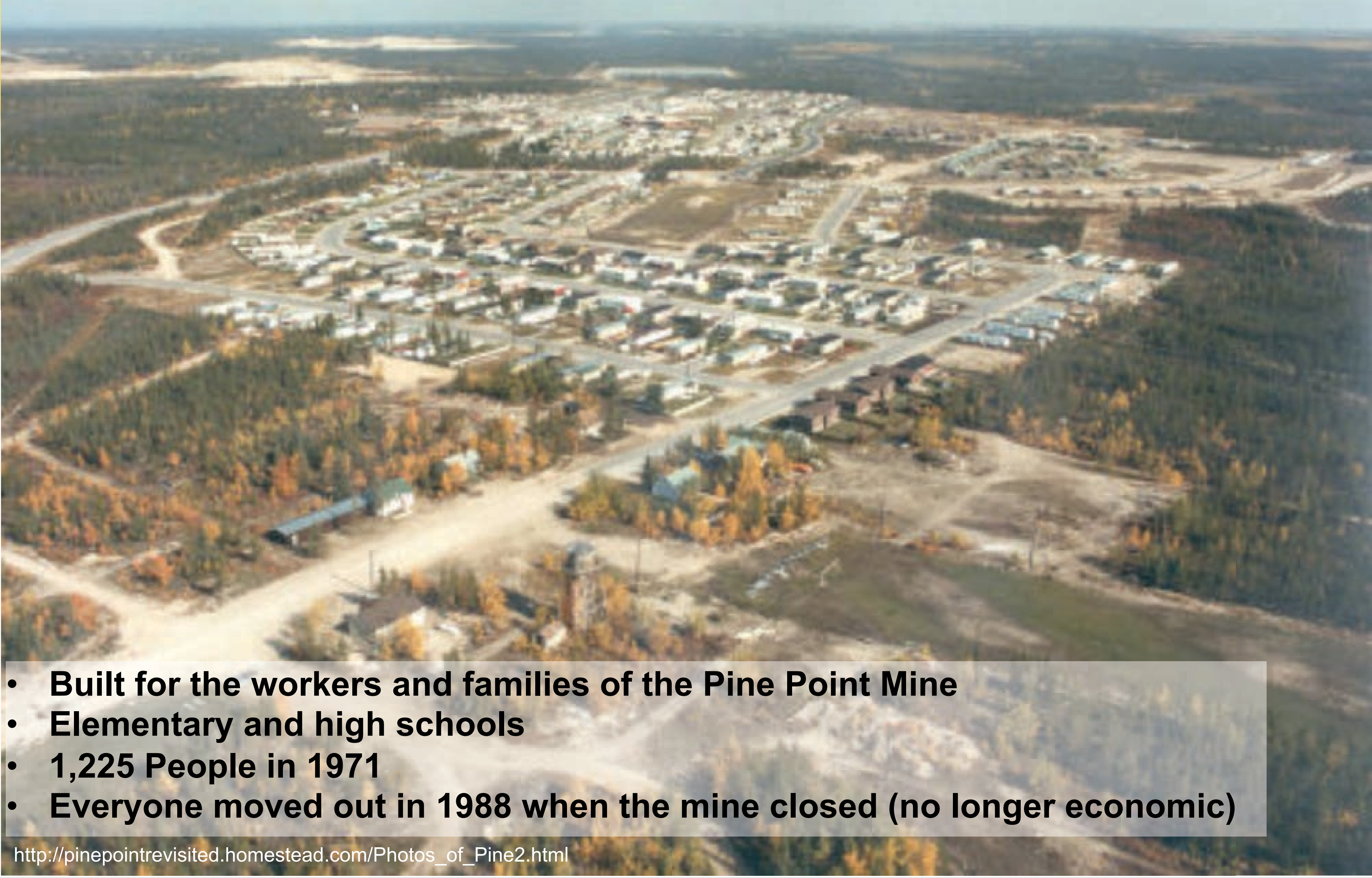
If fluid interacts with reduced organic matter (e.g. petroleum) sulfate reduction may occur

$SO_4^{2-} + 2CH_2O \rightarrow H_2S + 2HCO_3^-$

$ZnCl^{2-} + H_2S_{aq} \leftrightarrow ZnS_{solid} + 2H^+ + Cl^-$



# Town of Pine Point – (Cominco & Govt Canada joint venture)



- **Built for the workers and families of the Pine Point Mine**
- **Elementary and high schools**
- **1,225 People in 1971**
- **Everyone moved out in 1988 when the mine closed (no longer economic)**

http://pinepointrevisited.homestead.com/Photos_of_Pine2.html




http://pinepointrevisited.homestead.com/Photos_of_Pine.html

# A real mining town!

http://pinepointrevisited.homestead.com/Photos_of_Pine.html

Old open pit

Stockpile in distance

Core – lots of core

http://pinepointrevisited.homestead.com/Photos_of_Pine.html

# National Film Board of Canada – Interactive Documentary on Pine Point

http://interactive.nfb.ca/#/pinepoint

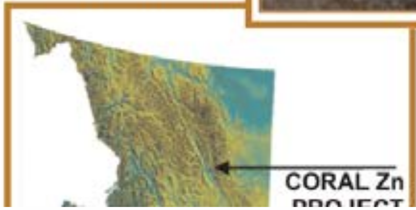
# MINFOCUS

DISCOVERING THE NEEDED METALS

| SHARE CAPITALIZATION (As at January 15, 2017) | |
|---|---|
| Trading Symbol | MFX: TSX-V |
| 52 Week High | $0.065 |
| Low | $0.005 |
| Recent Share Price | $0.02 |
| Shares Outstanding | 59,240,592 |
| Market Capitalization | $ 1,000,000 |

## CORAL ZINC PROJECT, BRITISH COLUMBIA

Coral Zinc Project is a Mississippi Valley Type (MVT) high grade zinc discovery that, based on soil geochemistry, covers an area at least 600 x 300 metres (almost 20 ha; equivalent to 20 soccer pitches). Very limited 1980's and 2016 drilling discovered Zn intersections at shallow depths over an area of 300 x 150 metres and more drilling is needed to extend the open ended drilled mineralization and to localize areas with potential for high grade breccia pipe hosted mineralization. Three more target areas have showings or anomalies and need detailed follow-up.




### CORAL HIGHLIGHTS

- A "Pine Point" look-alike with Mississippi Valley Type (MVT) mineralization with dominant Zn in carbonates

# MVT summary

- Epigenetic
- Stratabound
- Mineralization is ‘replacement’ or ‘massive’
- Basinal chloride- and metal-rich fluids are transported into carbonate units where ZnS and PbS precipitates

Fluid: connate water ($Cl^-$ ligands)

Source of metals: sedimentary rocks during transport

Transport: hydrothermal fluid flow driven by topography

Trap: mixing of saline, metal-rich and acidic waters with meteoric water OR sulfate reduction due to interaction with organic matter