ES3210 - Sediment-Hosted Zn-Pb (SEDEX) Deposits (aka Sedimentary Exhalative or Clastic Dominated Zn-Pb deposits)

Stephen J. Piercey

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ES 3210 ECONOMIC MINERAL DEPOSITS

- Relevant Chapter in Mineral Deposits of Canada:

⇒ SEDEX Deposits, Goodfellow & Lydon

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SEDEX – DEFINITIVE CHARACTERISTICS

- Occur in marine sedimentary sequences of intracontinental rifts – or similar environments
- Spatially associated (interbedded) with (clastic) basinal sedimentary rocks

⇒ ore often stratiform, at least in part

- Ores deposited on seafloor in tectonically controlled second or third order basins
- ⇒ another class of definitively submarine deposits

after Lydon, 2004 and Goodfellow & Lydon 2007

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SEDEX – DEFINITIVE CHARACTERISTICS

- Main ore metals are Zn, Pb & Ag

⇒ usually in sphalerite and galena

- Cu is minor or subsidiary
- Ore is interbedded with Fe sulphides (pyrite or pyrrhotite)
- Typically tabular or wedge-shaped bodies

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after Lydon, 2004 and Goodfellow & Lydon 2007

SEDEX – DEFINITIVE CHARACTERISTICS

- Genetic Model
  - Deposited on the seafloor, and in associated sub-seafloor vent complexes, from hydrothermal fluids vented into reduced sedimentary basins
  - Analogous to modern "Red Sea" environment

after Lydon, 2004 and Goodfellow & Lydon 2007

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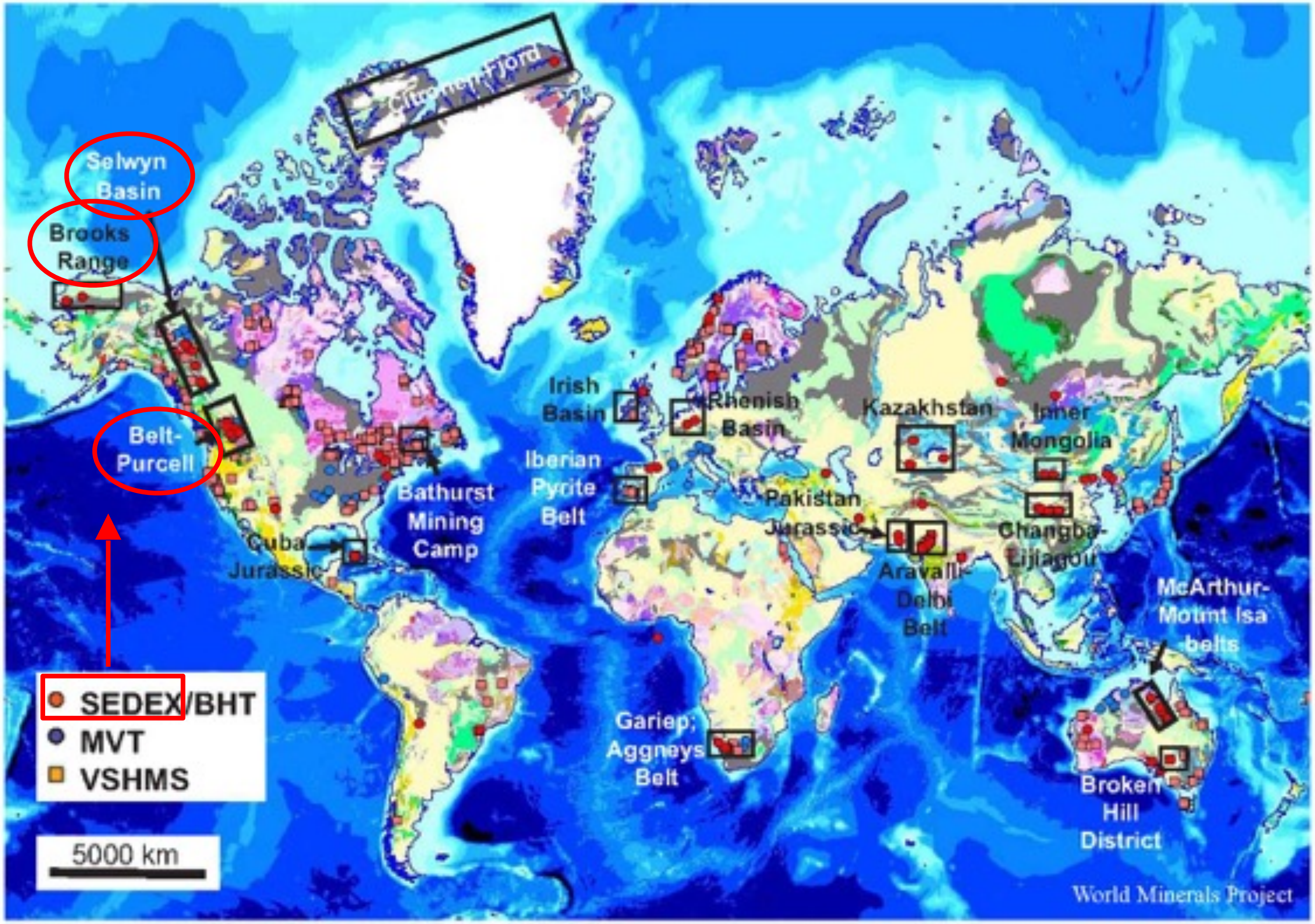

FIG. 1. SEDEX, BHT, VHMS and MVT deposits plotted on a simplified geological map of the world (World's Minerals Project). Irish-type deposits are included in the broad group of SEDEX deposits.

Note: BHT ("Broken Hill-Type") and VSHMS ("Volcanogenic Sediment-Hosted MS") categories include many deposits in the Besshi-Type Class of VMS

Goodfellow & Lydon, 2007

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VMS - SEDEX - MVT

- VMS
  - Occur in submarine volcanic-sedimentary belts
  - Formed from convective hydrothermal fluids (seawater-derived) driven by a sub-volcanic intrusion - driven by magmatic heat.
  - Fluids are generally reduced.
  - Formed by hydrothermal systems that vented fluids onto the seafloor - age difference between ores and immediate host rocks is always small
  - Temperature of fluids 200°C-380°C.
- SEDEX
  - Occur within (or on the platform margins of) a thick sedimentary basin as a result of migration of (connate) basinal saline fluids – sub-volcanic heat source implied. Normal geothermal gradient can drive fluid flow (not always need for magmatism).
  - Sediments are usually clastic.
  - Brines are oxidized.
  - Formed by hydrothermal systems that vented fluids onto the sea floor - age difference between ores and immediate host rocks is always small
  - Temperature of fluids <250°C.

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VMS - SEDEX - MVT

- SEDEX
  - Occur within (or on the platform margins of) a thick sedimentary basin as a result of migration of (connate) basinal saline fluids – sub-volcanic heat source implied. Normal geothermal gradient can drive fluid flow (not always need for magmatism).
  - Sediments are clastic.
  - Brines are oxidized.
  - Formed by hydrothermal systems that vented fluids onto the sea floor - age difference between ores and immediate host rocks is always small (i.e., syngenetic)
  - Temperature of fluids >250°C.
- MVT
  - Occur within (or on the platform margins of) a thick sedimentary basin as a result of migration of (connate) basinal saline fluids.
  - Sediments are mostly carbonates.
  - Brines are oxidized.
  - Formed in the (continental) subsurface - age difference between ores and host rocks can be very large (i.e., epigenetic).

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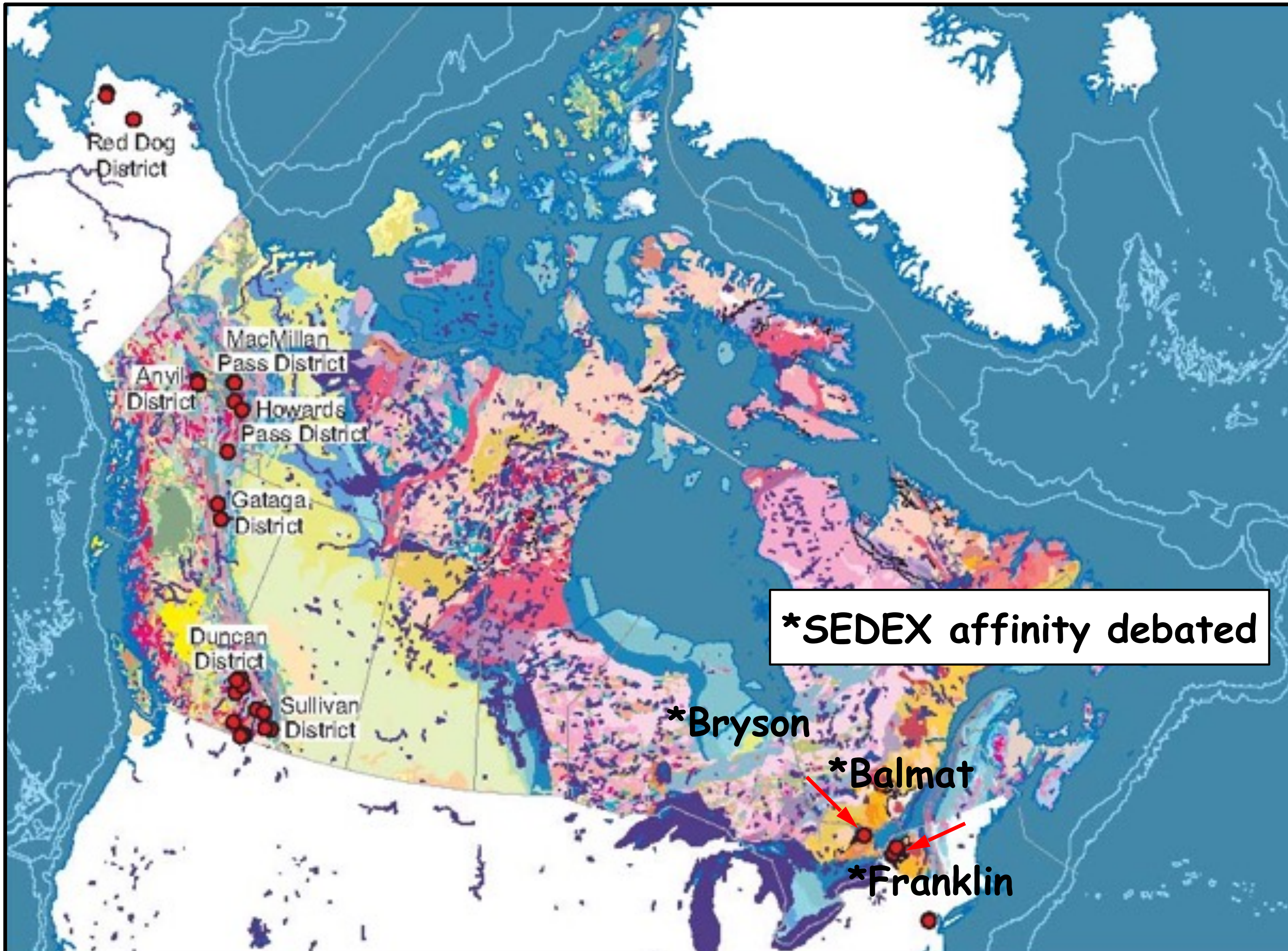

Known SEDEX Deposits in N. America

Goodfellow & Lydon, 2007

Table 3. Grade and Tonnage of Canadian SEDEX Deposits brought into Production

Deposit Name	Province/ Territory	Latitude degrees	Longitude degrees	Age	Date (Ma)	Total Production					
						Cu (%)	Zn (%)	Pb (%)	Ag (g/t)	Au (g/t)	Mt
Sullivan	British Columbia	49.7083	-116.0056	Mesoproterozoic	1470		5.8	6.7			116
Faro	Yukon	62.3583	-133.3667	Cambrian	514		5.7	3.4	36		?
Vangorda	Yukon	62.2528	-133.1833	Cambrian	514		4.9	3.8	54	0.79	?
Grum	Yukon	62.2694	-133.2222	Cambrian	514		4.9	3.1	49		?
Jersey	British Columbia	49.0986	-117.2208	Early Cambrian	525		3.49	1.65			7.68
H.B.	British Columbia	49.1467	-117.2000	Early Cambrian	525		4.1	0.77			6.45
Reeves-MacDonald	British Columbia	49.0200	-117.3708	Early Cambrian	525		3.42	0.98			5.8
Mineral King	British Columbia	50.3458	-116.4264	Neoproterozoic	370		4.12	1.76			2.1
Kootenay King	British Columbia	49.7431	-115.6111	Mesoproterozoic	1468		15.6	5.36			0.013

Key point: often big with lots of contained metal.

Faro	58 Mt
Grum	31 Mt
Vangorda	7.5 Mt

Goodfellow & Lydon, 2007

SEDEX – GRADE AND TONNAGE

- The proportion of world primary production of Zn and Pb from SEDEX deposits is 31% and 25%, respectively (2006)
- The size (in tonnes of Pb + Zn metal) of SEDEX deposits is on average an order of magnitude greater than that of VMS deposits (Goodfellow et al., 1993)

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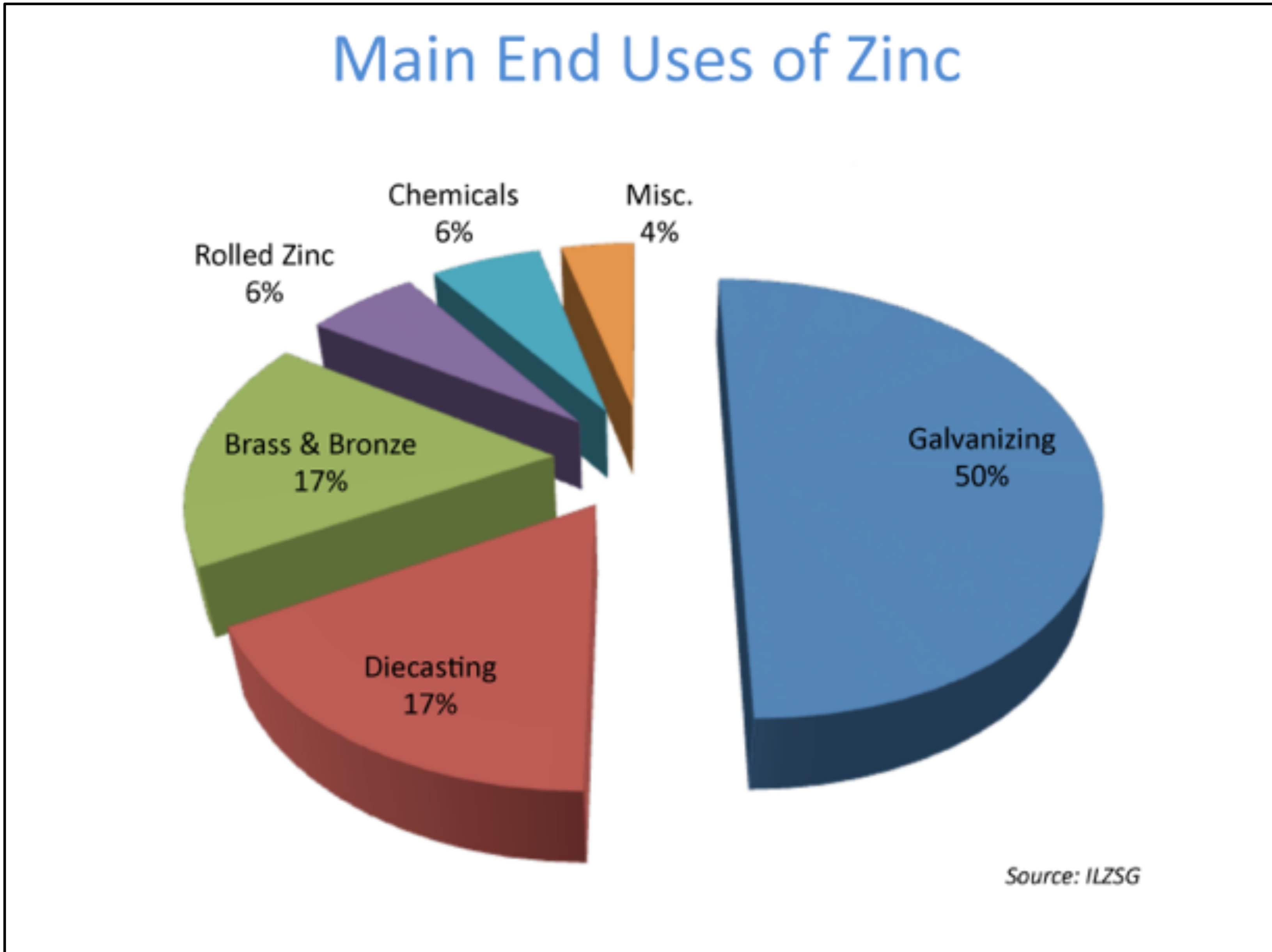
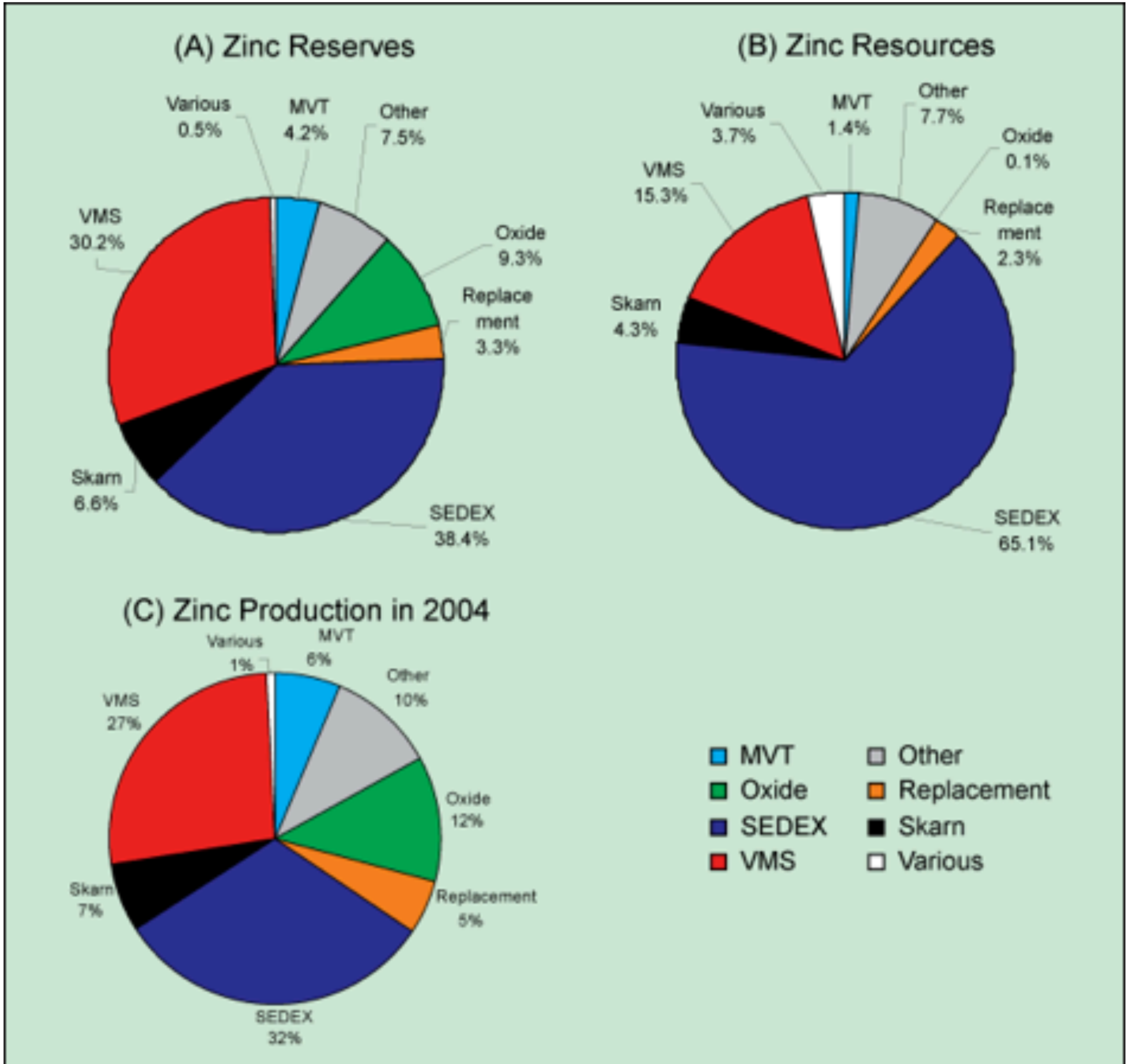
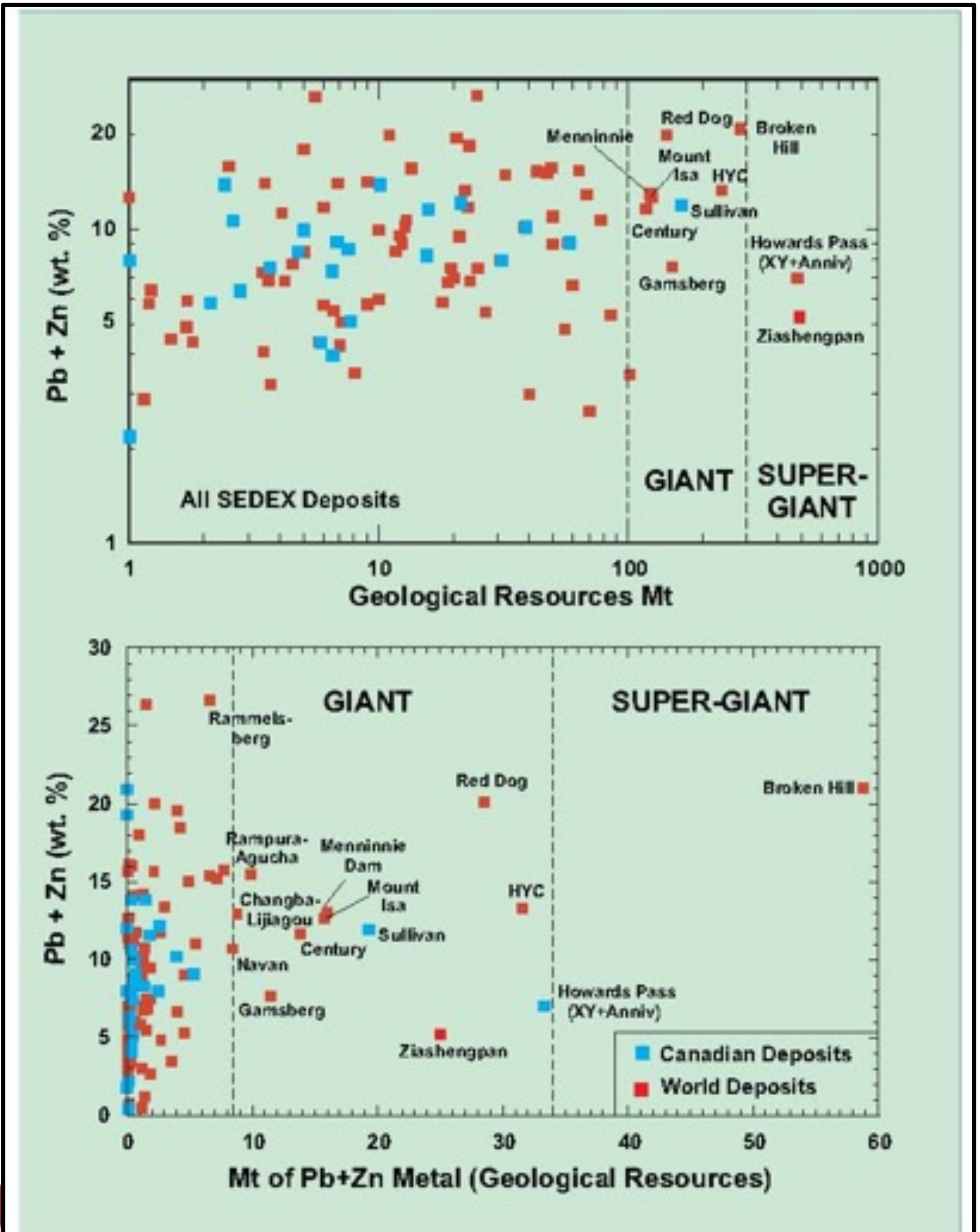


International Zinc Association, 2011

Goodfellow & Lydon, 2007



Zinc reserves (A), Zinc resources (B) & Zinc production (C) in 2004.
Broken down by deposit-type.
(From "Zinc and Lead Costs – Mines and Projects to 2018", Brook Hunt, 2004)



Grade vs. Tonnage Plots

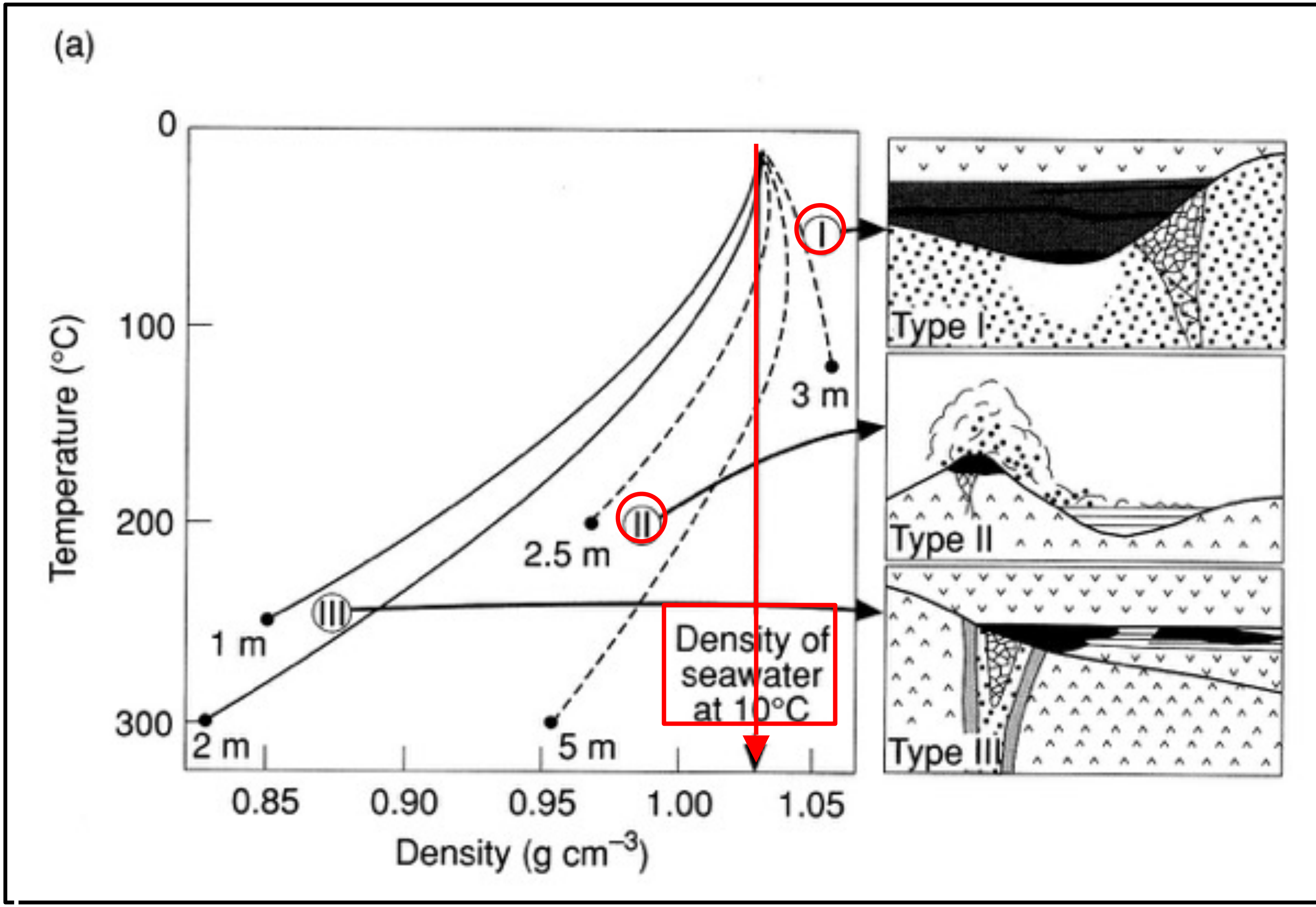
SEDEX - Including Irish-type & BHT deposits worldwide

Big deposits - lots of metal = attractive targets for mining and exploration companies

Goodfellow & Lydon, 2007

VENT-PROXIMAL VS VENT-DISTAL

- Morphology of SEDEX deposits is controlled by the proximity of seafloor sulphide deposition to fluid discharge vents + temperature and salinity of fluids.
  - Vent-proximal deposits typically form from buoyant hydrothermal fluids
  - Vent-distal deposits form from fluids that are denser than seawater and pool in remote depressions



Sato buoyancy models for VMS (and hydrothermal fluids, in general)

Robb (2005); Figure 3.23a; after Sato (1972)

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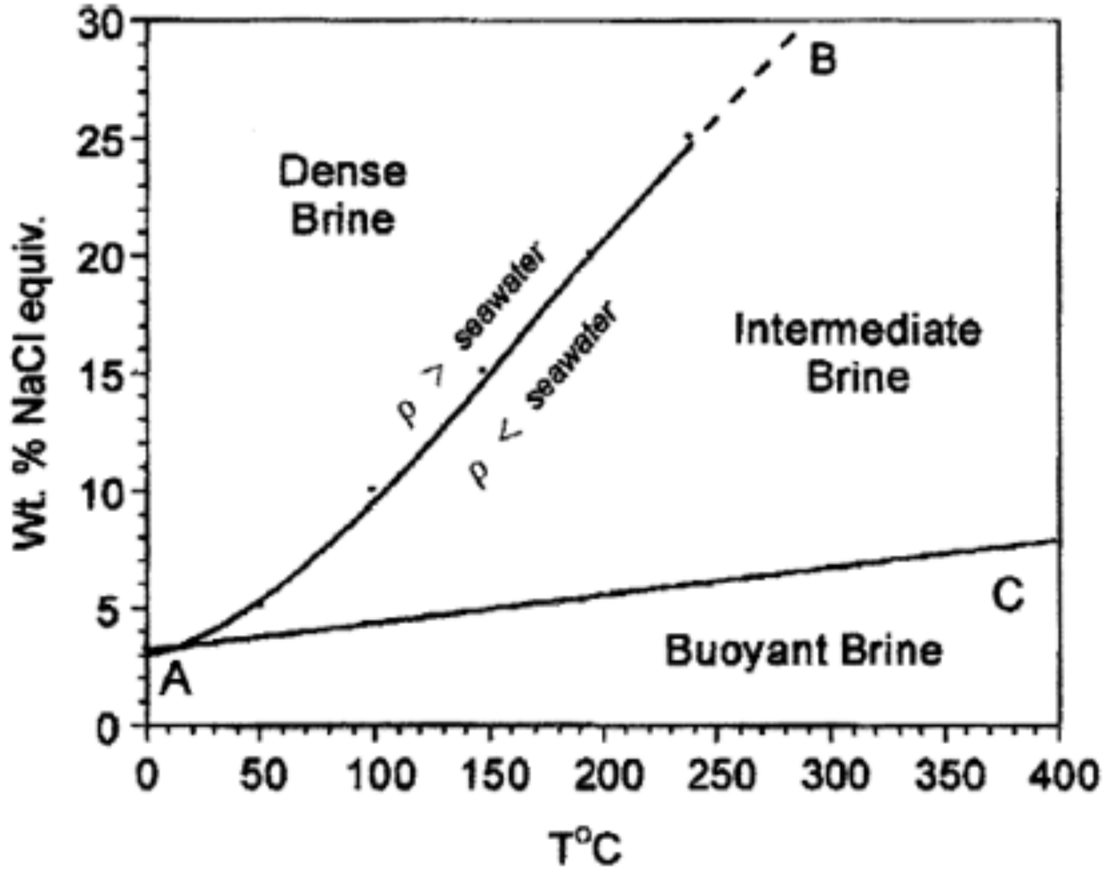

Fig. 1 Temperature versus salinity plot. Point "*A*" is the position of seawater at 2 °C. *Line AB* is the seawater isodensity line; *points* on this line have the same density as seawater at 2 °C ($\rho = 1.028$ g/cm^3). Ore fluids that plot below this line are less dense than seawater; fluids plotting above the line are denser than seawater. Data from Haas (1976). *Line AC* defines the lower limit of the field of buoyancy reversal (data from Turner and Campbell 1987). The field between AB and AC is one in which a discharging fluid is initially less dense than seawater and rises as a buoyant plume. After mixing with seawater, the fluid becomes heavy, the plume then collapses, and the fluid collects on the seafloor as a dense brine

From

Sangster (2002)

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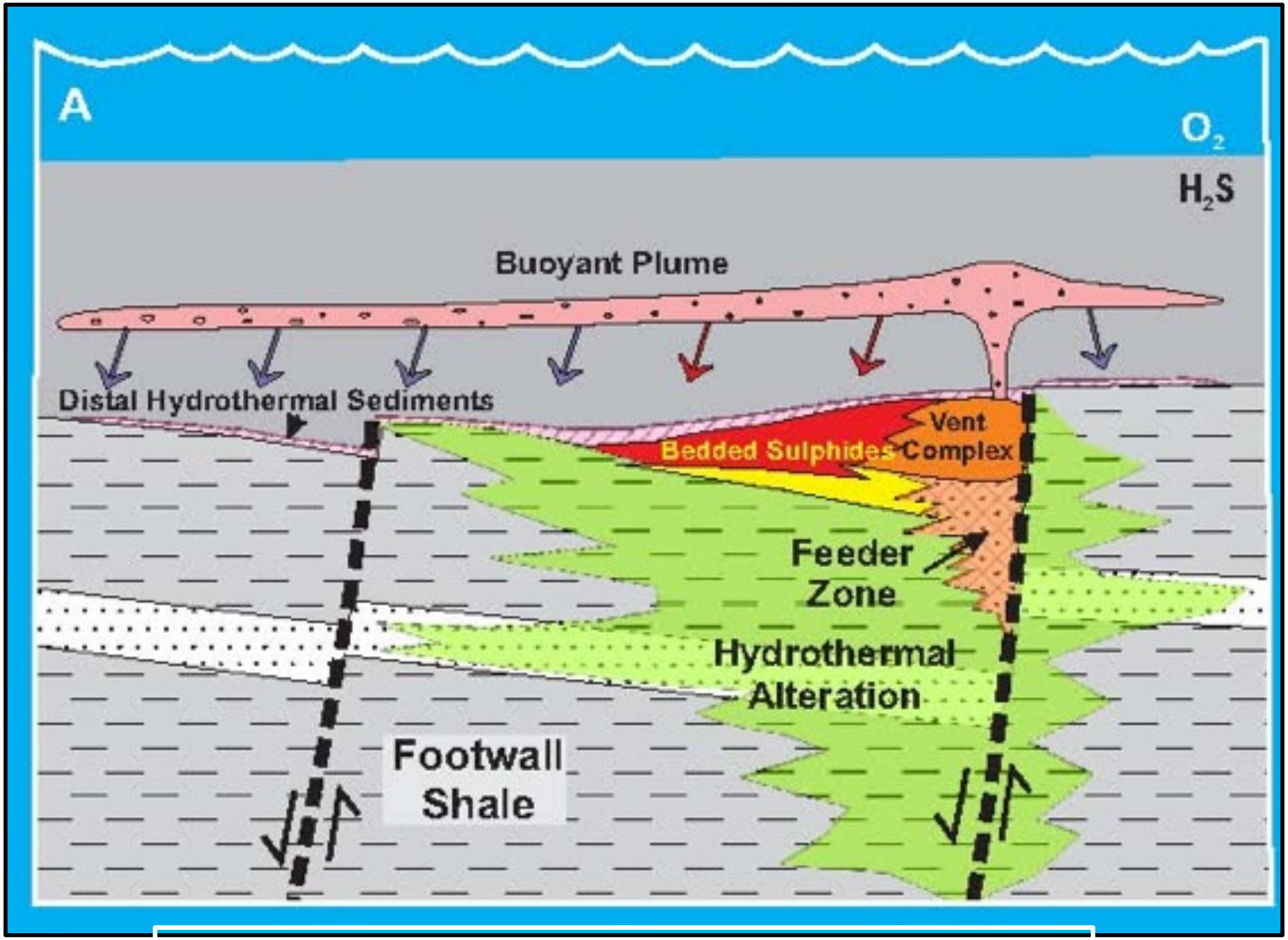

Vent-Proximal SEDEX Deposit

(e.g., Tom, Jason - MacMillan Pass)

Goodfellow & Lydon, 2007

VENT-PROXIMAL DEPOSITS

- Characterized by four distinct facies:
  - 1) Bedded sulphides
  - 2) Vent complex
  - 3) Sulphide stringer zone (feeder zone)
  - 4) Distal hydrothermal sediments

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after Goodfellow & Lydon, 2007

VENT-PROXIMAL DEPOSITS

- Near the center of fluid up-flow represented by the stringer zone, the bedded sulphides are characteristically infilled, veined & replaced by a high-T mineral assemblage

⇒ producing the vent complex (Goodfellow et al., 1993)

- Distal hydrothermal sediments probably represent plume fallout dispersed by bottom currents - or clastic sulphides from reworked/eroded bottom deposits

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after Goodfellow & Lydon, 2007

VENT-PROXIMAL DEPOSITS

- Characteristically zone-refined due to the reaction of hot hydrothermal fluids with pre-existing stratiform sulphides overlying the vents
- An increase in the Zn:Pb ratio away from the vent complex is the most pronounced and consistent evidence of zone-refining

⇒ e.g., Tom (Goodfellow and Rhodes, 1990), Jason (Turner, 1990), Cirque (Jefferson et al., 1983), Sullivan (Hamilton et al.,1982), Red Dog (Moore et al., 1986)

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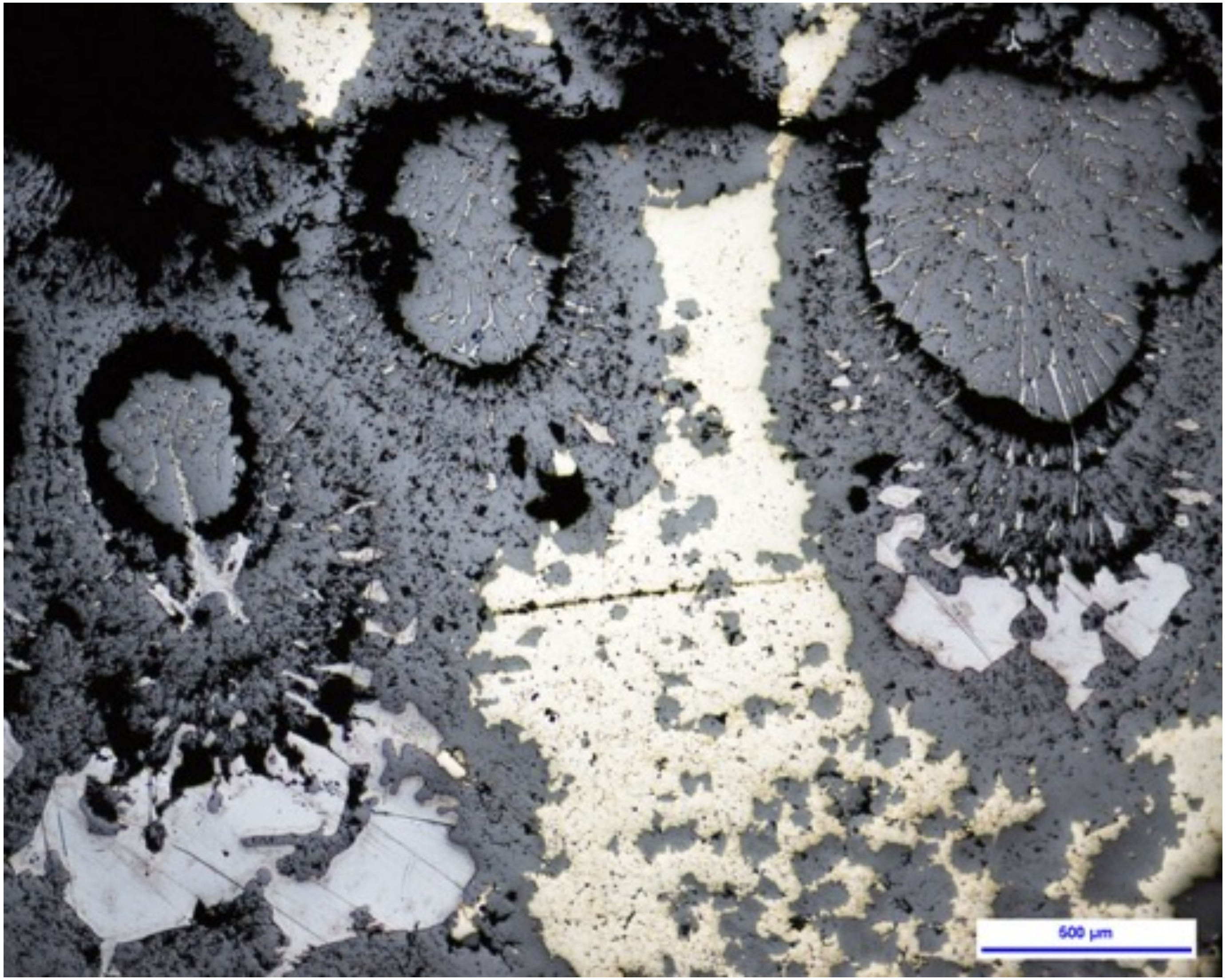
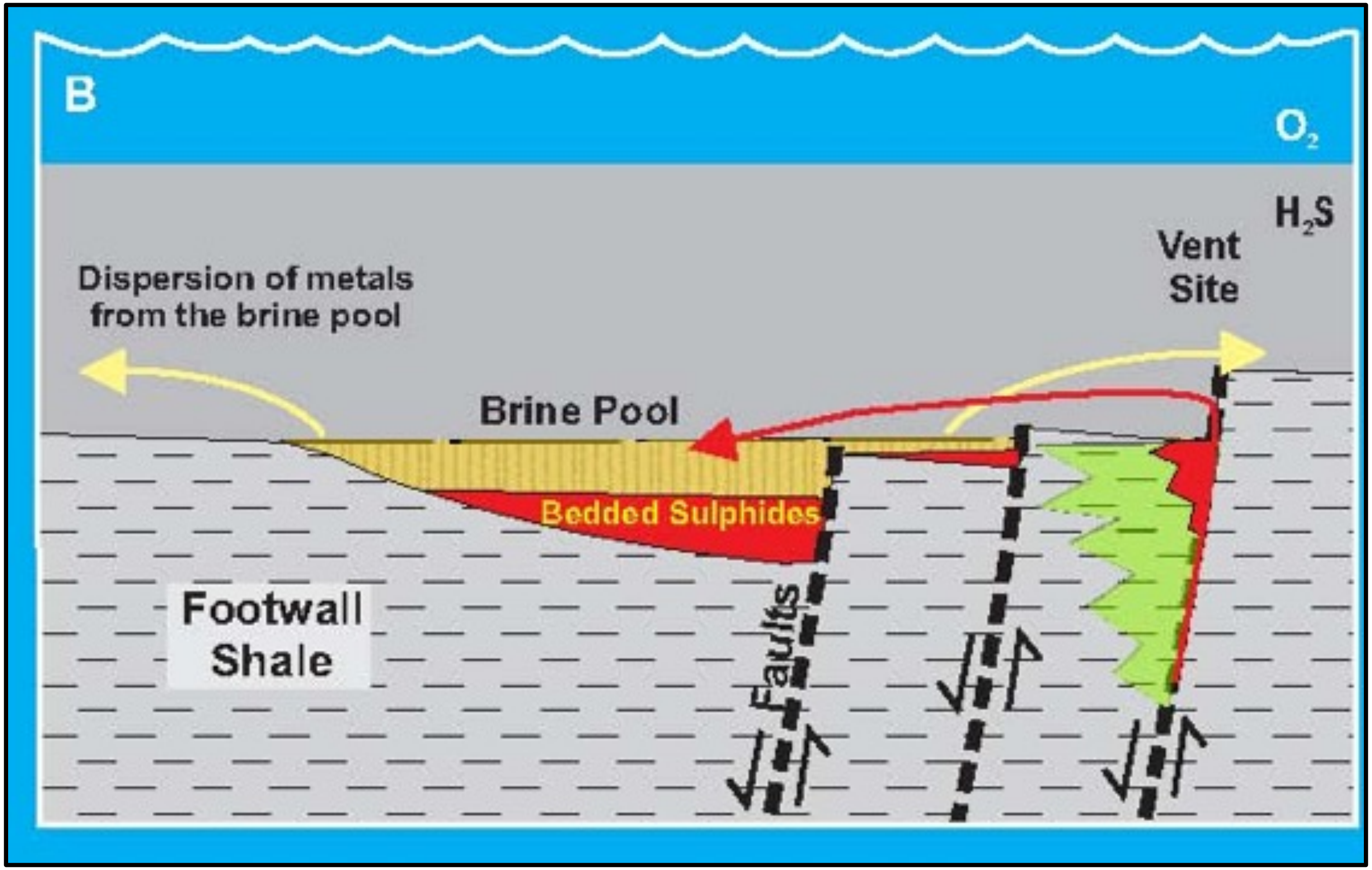
after Goodfellow & Lydon, 2007

Zone Refining: Photographic Evidence





Vent-Distal SEDEX Deposit

after Goodfellow & Lydon, 2007

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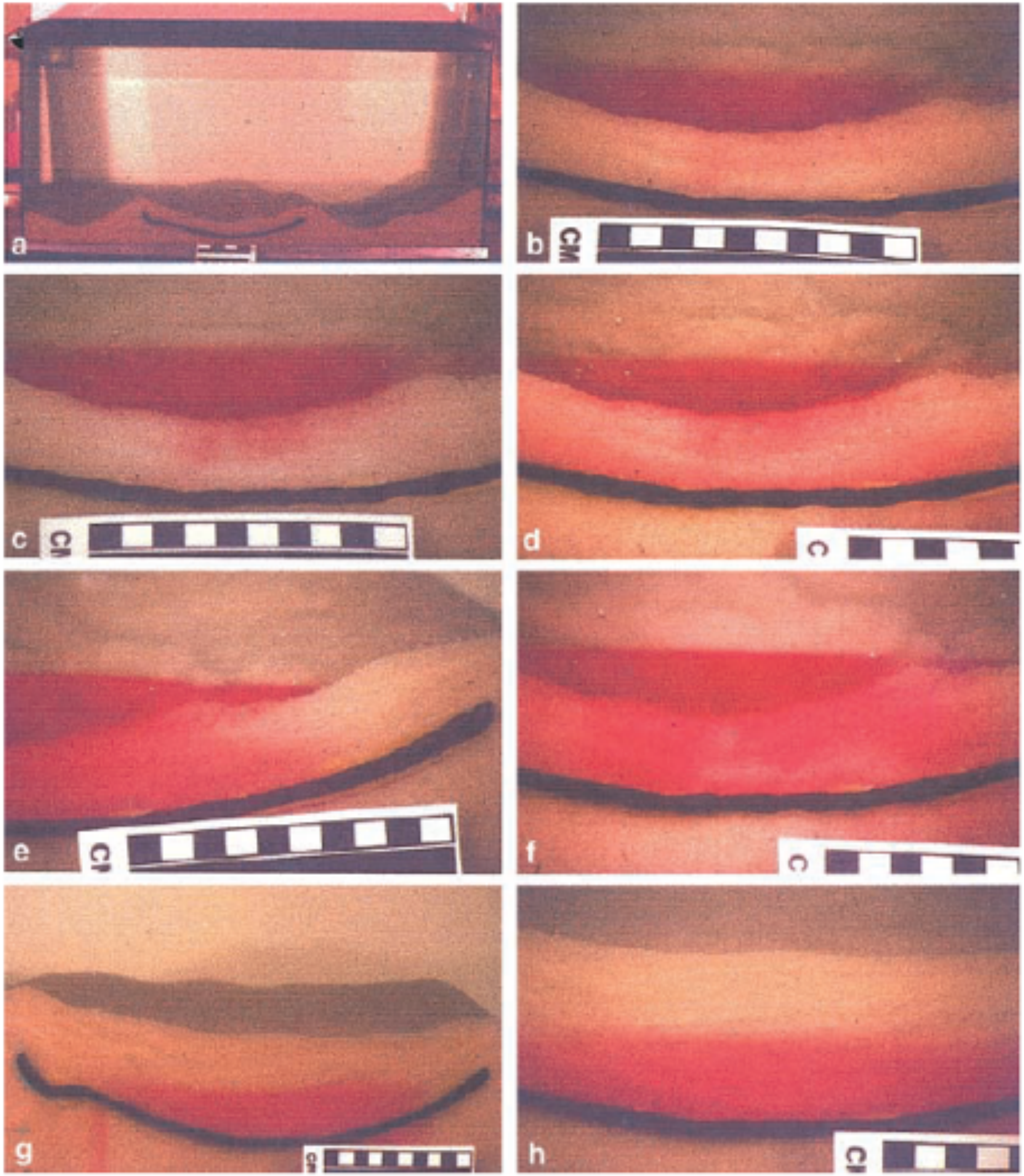
Fig. 2 Laboratory experiment to illustrate the role of a "sinking brine". **a** Water-filled aquarium with a small hollow in quartz sand floored with a ~1-cm-thick layer of modeling clay (*black layer*) tightly attached to the viewer's side of the aquarium and overlain with more sand. **b** Dye-colored saline solution ("ore fluid") placed in hollow immediately begins to sink into the underlying sand. **c** Irregular, downward-projecting "ore fluid" extensions below the brine pool. **d** The first increment of "ore fluid" has ponded against the clay, ambient "seawater" has again filled the sand pores, and a second increment of fluid has been added to the pool. **e, f** As more fluid is added to the brine pool, it continues to sink and eventually to accumulate above the impermeable clay layer. **g, h** The brine pool has been allowed to deplete itself, the "ore fluid" has collected on the clay layer and a layer of quartz sand has been added above the "ore layer". The *small vertical stripe* below the clay in 2G is caused by a small leak between the clay and aquarium glass



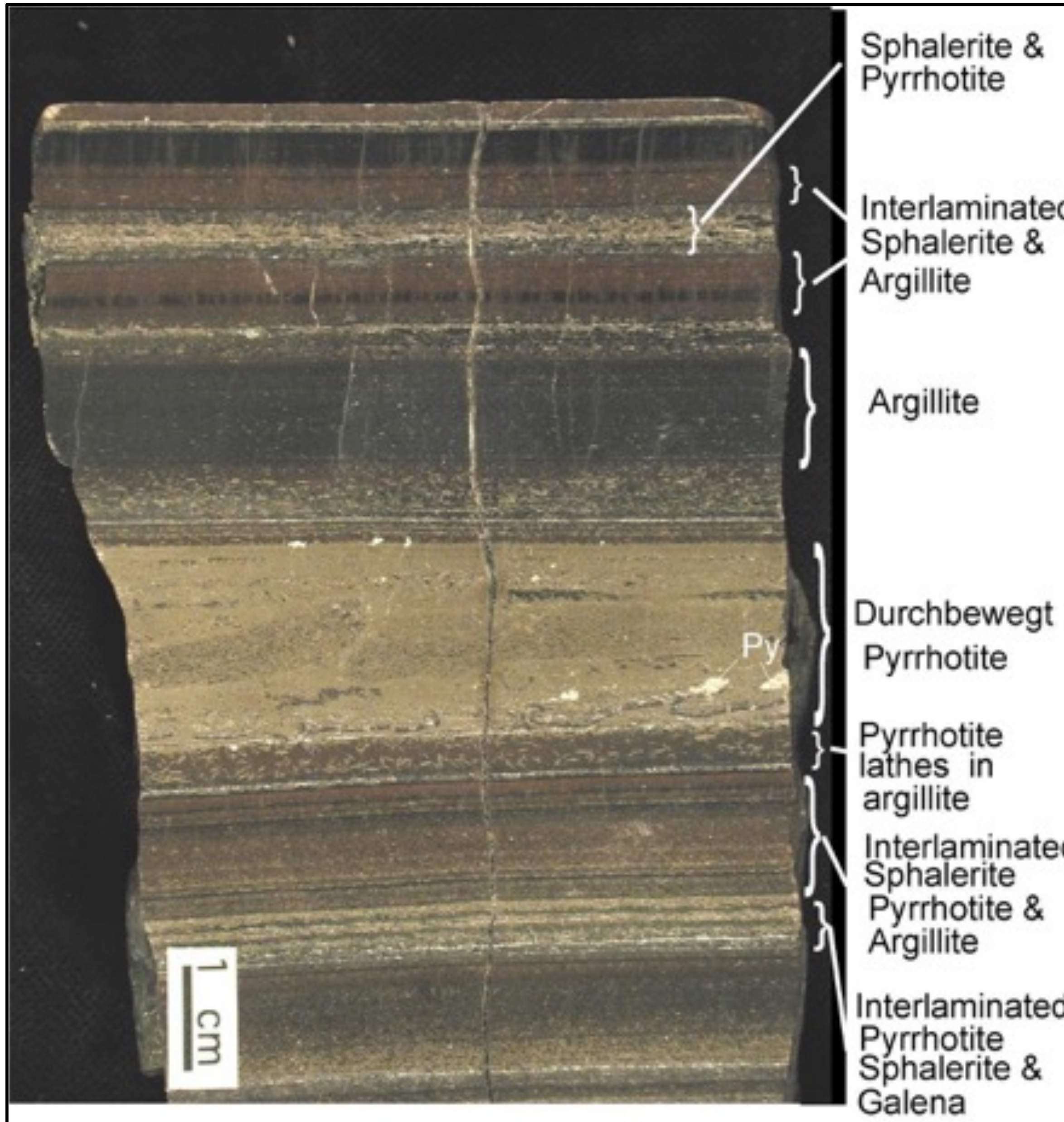
From Sangster (2002)

VENT-PROXIMAL VS VENT-DISTAL

- Vent-distal deposits, however, are typically weakly zoned, well bedded and conform to the basin morphology
- There is no evidence of the type of zone refining that accompanies veining, infilling and replacement of bedded sulphides by a typically higher temperature assemblage that characterizes vent-proximal deposits

Polished slab of ore from the “B-Band”, 3200SE Crosscut, Sullivan Mine.

Illustrating the typical laminated nature of pyrrhotite-rich bedded ores.
From Lydon and Reardon, 2000.



Lydon, 2007 MDD; Lydon & Reardon, 2000

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Lydon, 2007 MDD

High grade, galena-rich, relatively un-reworked layered ore from the upper part of the main sulphide body in the Vent Complex, Sullivan Mine

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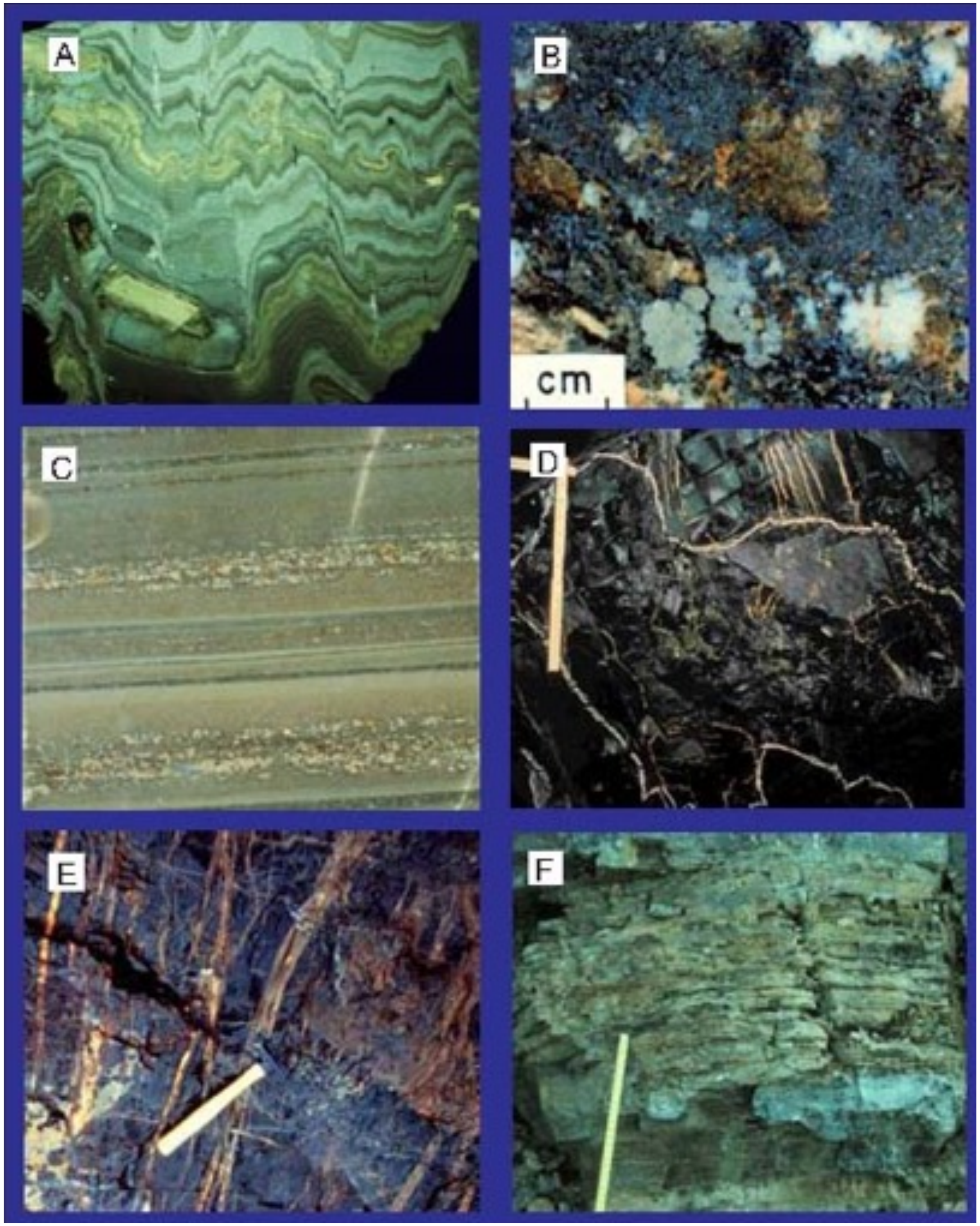

FIG. 8. Photographs of SEDEX and barite deposits. A. Bedded facies: sphalerite and galena interlaminated with pyrite, hydrothermal carbonate and carbonaceous chert, Howards Pass (XY) deposit, Yukon and NWT; B. Distal hydrothermal sediments: Pyrrhotite and pyrite containing disseminated sphalerite interlaminated with fine-grained turbiditic sedimentary rocks, Concentrator Hill, Sullivan deposit, B.C.; C. Vent Complex: pyrite, sphalerite, galena and ferroan carbonates replacing bedded sulphide facies, Tom Deposit, Selwyn Basin, Yukon; D. Vent Complex: tourmalinized breccia infilled with pyrrhotite, sphalerite and chalcopyrite, Sullivan Deposit, B.C.; E. Sulphide Stringer Zone: Black silicified shale cut by a network of brown sphalerite veins, Red Dog deposit, Alaska; F. Well bedded barren barite deposit, Gataga District, northeastern B.C.

Goodfellow & Lydon, 2007

SEDEX – OTHER COMMON CHARACTERISTICS

- Bulk of sulphide mineralization in most SEDEX deposits resides in bedded ore facies

- Other associated hydrothermal sediments:
  - Mn- & Ca-carbonates
  - Calcium phosphate
  - Silicate-oxide-carbonate facies iron formations

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SEDEX – OTHER COMMON CHARACTERISTICS

- Dominant sulphide mineral in most deposits is pyrite

⇒ In some deposits (e.g., Sullivan and Mt. Isa) it is pyrrhotite

- Barite, when present, occurs in significant amounts (i.e., >25% of the hydrothermal product) and is present in ~25% of Proterozoic and ~75% of Phanerozoic SEDEX deposits (Goodfellow et al., 1993).

- Silica (usually chert), is ubiquitous in most stratiform ores and is, in part, hydrothermally derived

SEDEX – VENT COMPLEX

- In contrast to the regularly layered appearance of the bedded ore facies, the vent complex is extremely heterogeneous
- Can contain massive zones, replacement patches, irregular veins and/or disseminations of sulphides, carbonates, & silicates (mostly quartz)
- Mineral assemblage dominated by pyrite, pyrrhotite, galena, sphalerite, ferroan carbonate, dolomite, quartz, tourmaline
- Lesser muscovite, chlorite, chalcopyrite, arsenopyrite, and sulphosalt minerals

SEDEX – FEEDER ZONE

- Feeder zone underlying vent complexes is a discordant zone composed of sulphide, carbonate & silica veins, impregnations & replacements that transects the footwall sedimentary sequence
- Feeder zone at many deposits appears rooted in a syn-sedimentary fault zone
- Fault-scarp breccias, debris flows, & abrupt facies changes associated with SEDEX deposits indicate that faulting was active before, during, and/or after sulphide formation (e.g. Jason and HYC deposits, Large et al., 1998; Turner,1990)

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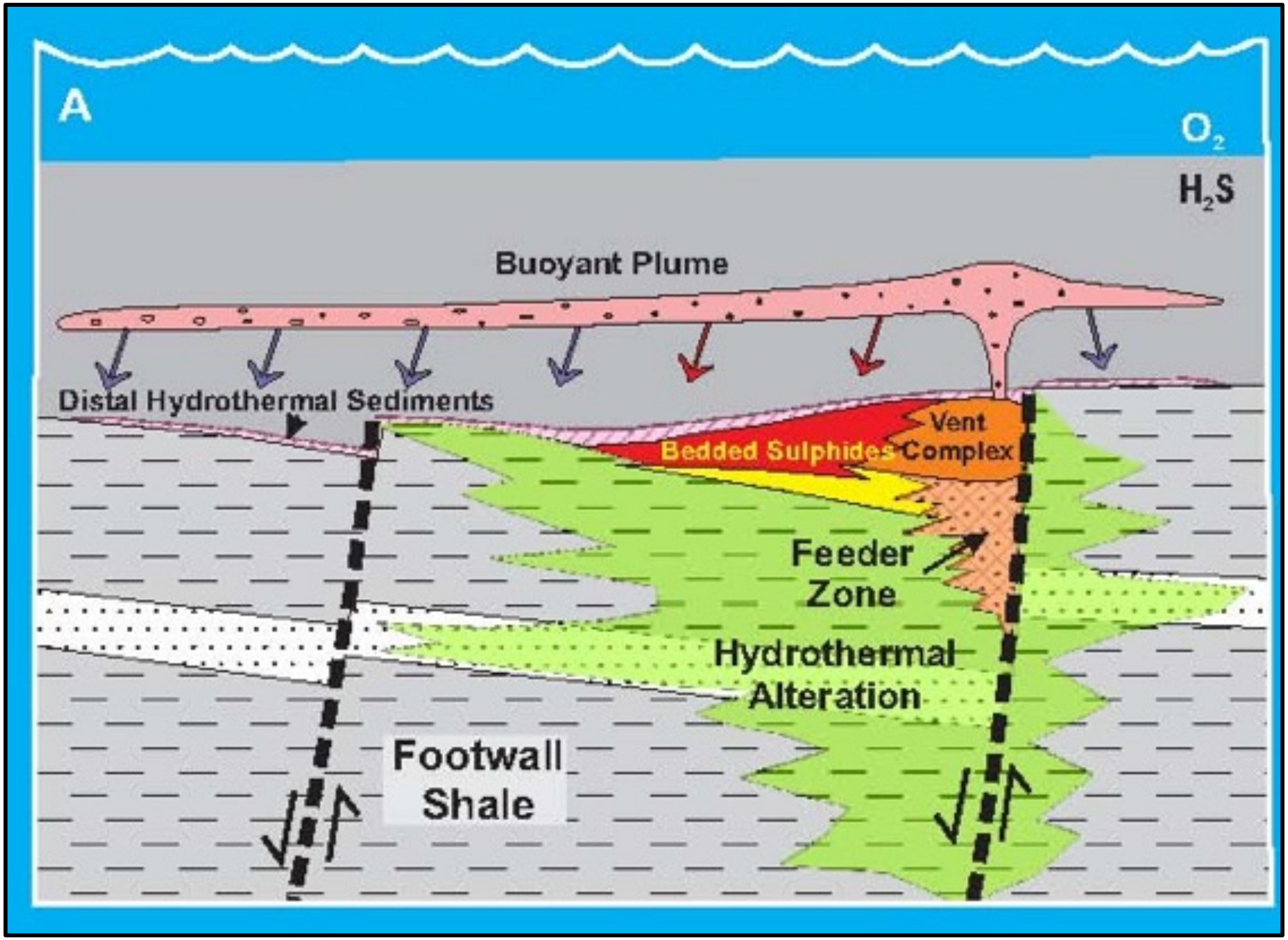
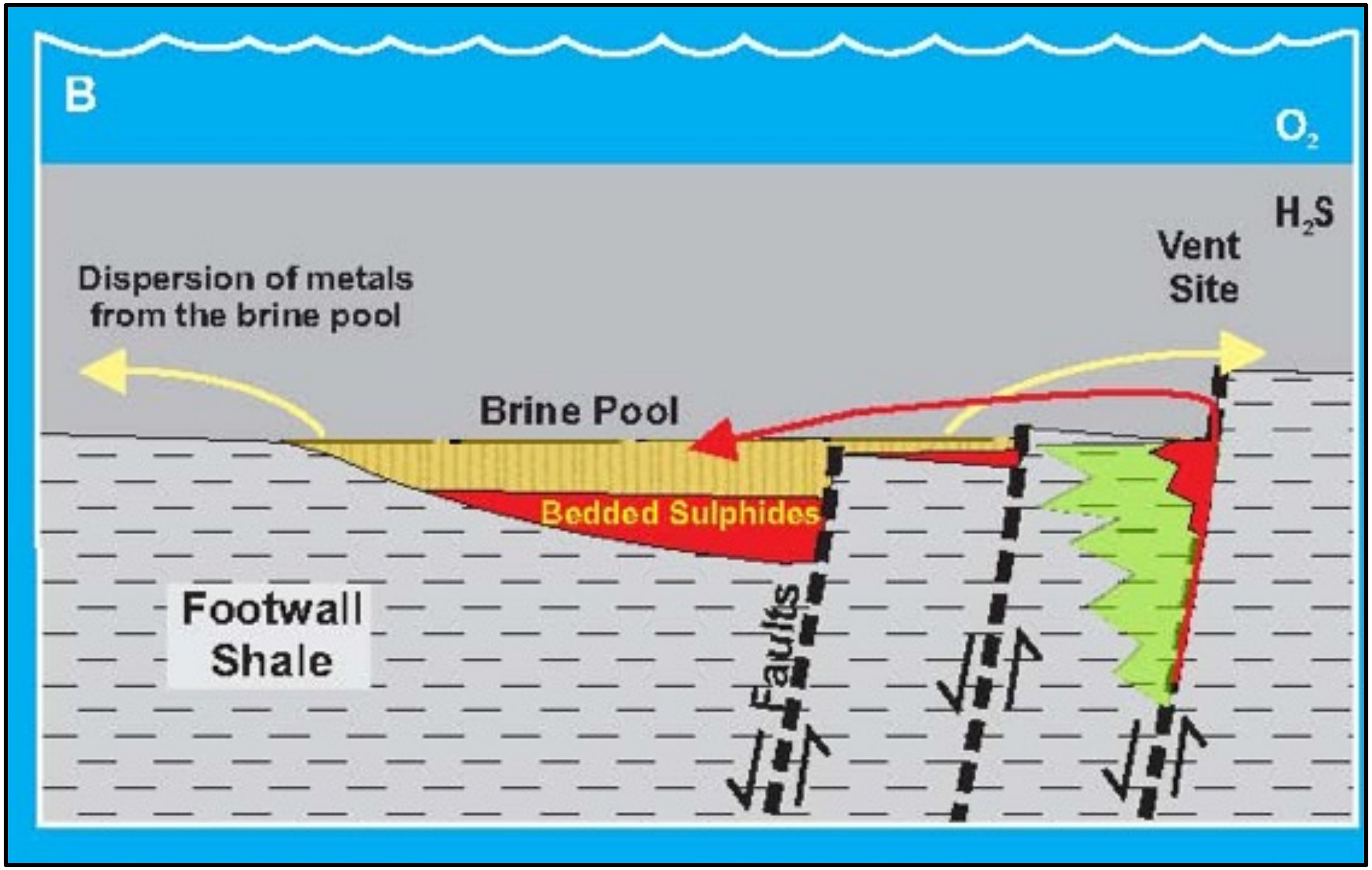


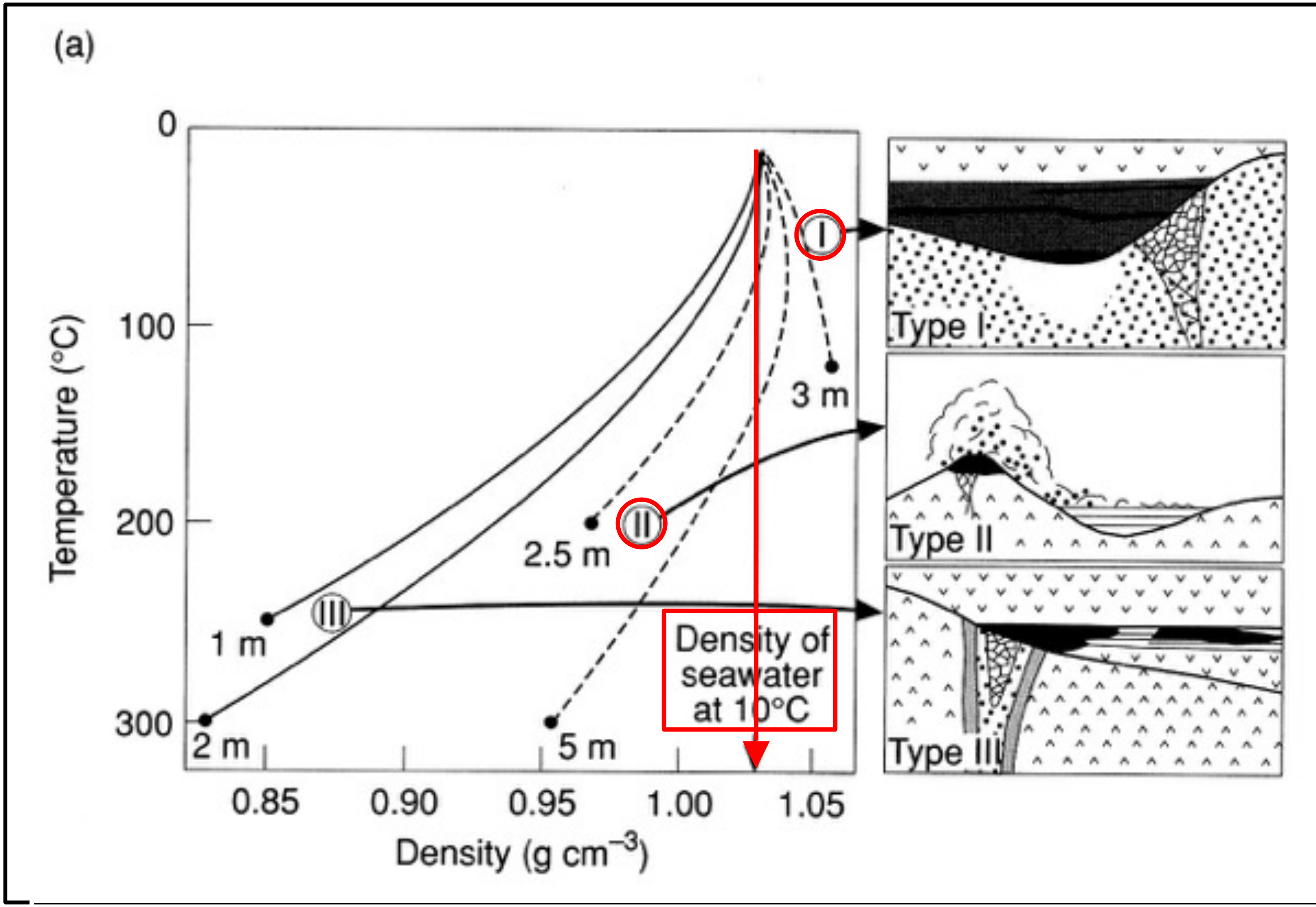
Vent-Proximal SEDEX Deposit

Goodfellow & Lydon, 2007



Vent-Distal SEDEX Deposit

Goodfellow & Lydon, 2007



Sato Buoyancy Models – developed for VMS

Robb (2005); Figure 3.23a; after Sato (1972)

VENT-PROXIMAL VS VENT-DISTAL

- Further to the Sato models, behaviour changes somewhat between VMS deposits and SEDEX deposits
- Due to the presence of a reactive, H_2S-rich, anoxic ambient bottom water.
  - Vent-proximal deposits typically form from buoyant hydrothermal fluids.
  - Vent-distal deposits form from fluids that are denser than seawater and pool in remote depressions.

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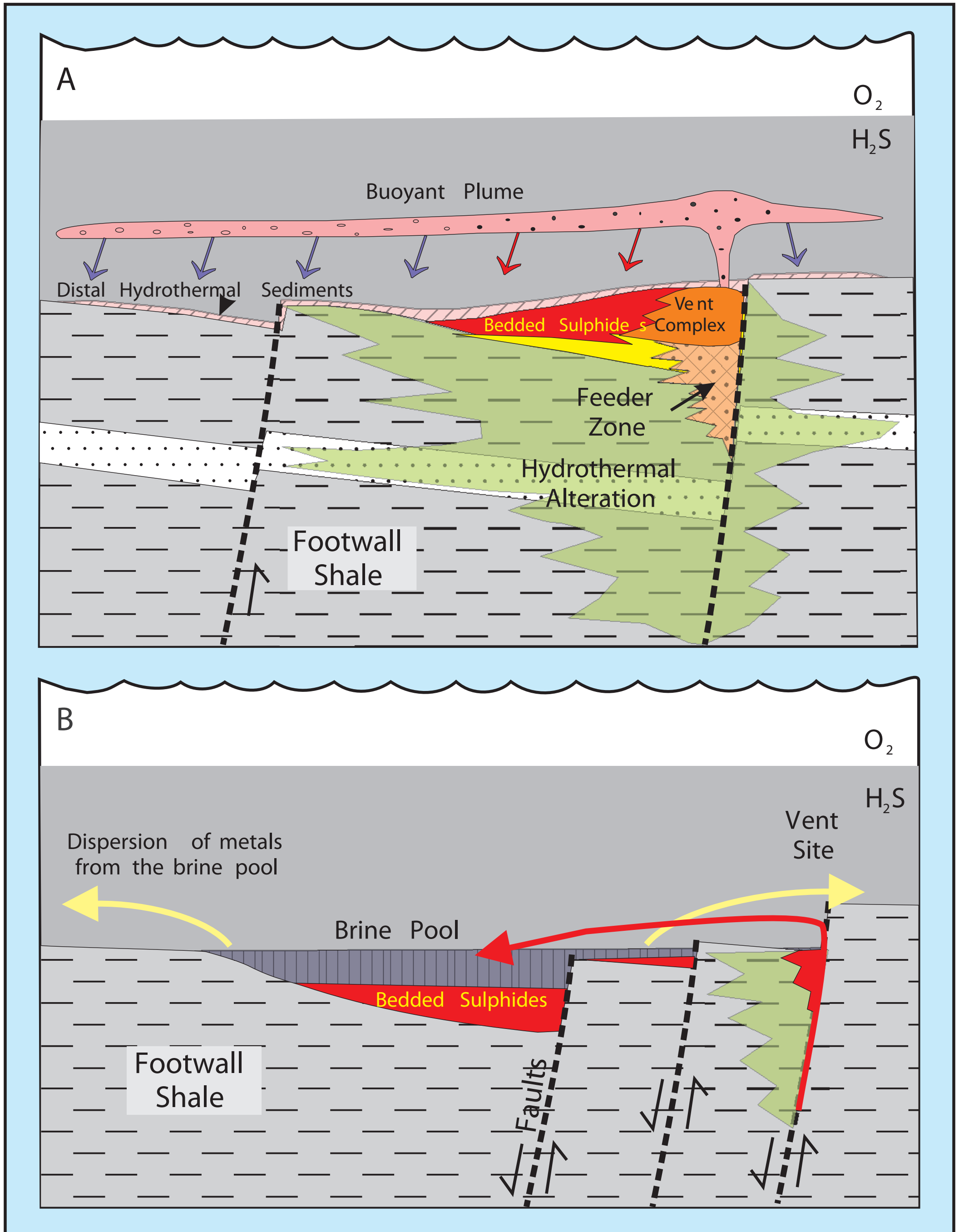
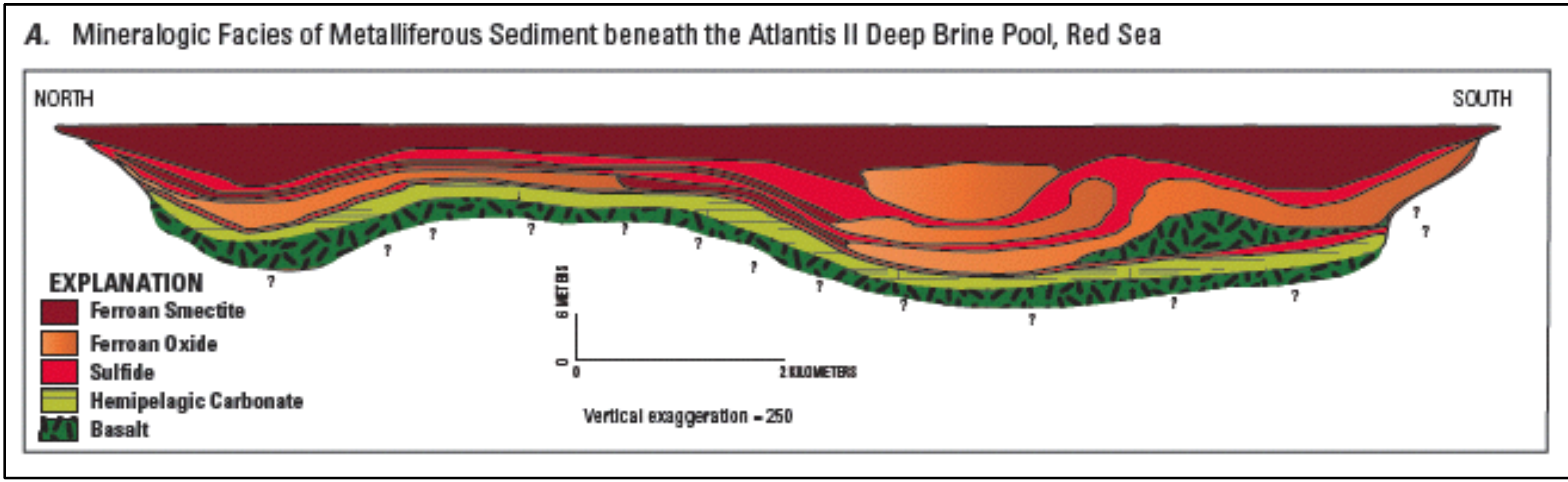


Goodfellow & Lydon, 2007

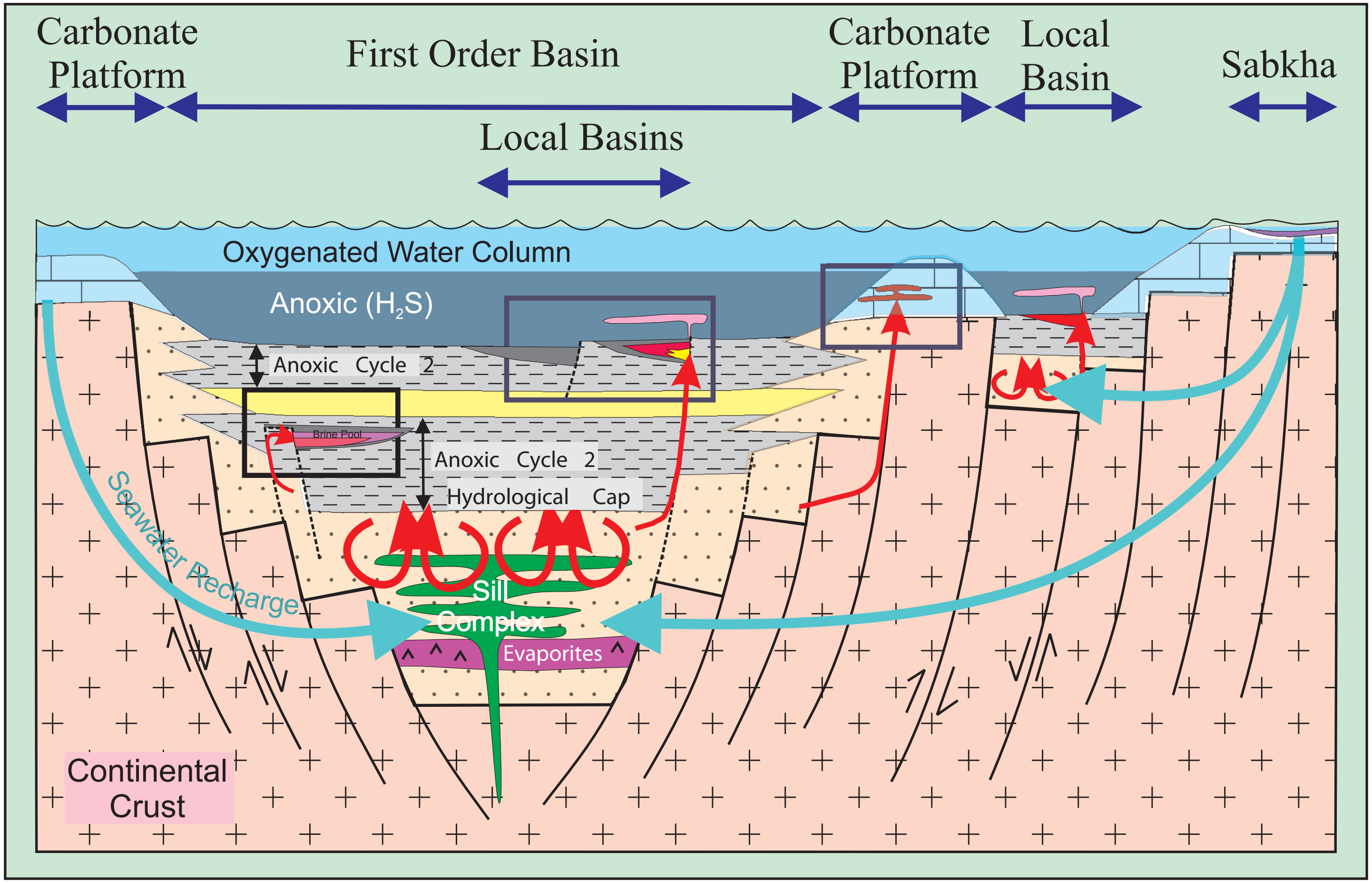


Cross-section of Metalliferous Mud Facies, Atlantis II Deep, Red Sea

Based on this cross-section - does the Atlantis II Deep appear to represent a proximal, or distal, SEDEX deposit?

Hackett & Bischoff, 1973

SEDEX Model



We have brines. We have metals. But how do we induce precipitation?

Goodfellow and Lydon (2007)

ORE PRECIPITATION – SEDEX ENVIRONMENTS

$$ZnCl_2 + H_2S(aq) = ZnS_{sphalerite} + 2H^- + 2Cl^-$$

$$PbCl_2 + H_2S(aq) = PbS_{galena} + 2H^- + 2Cl^-$$

⇨ Metals (Zn, Pb) arrive as chloride complexes in the exhaled hydrothermal fluid

⇨ They react with H_2S in the anoxic bottom waters of the rift basin to precipitate sulphide ores

⇨ H_2S originates from the bacterial reduction of (seawater) sulphate common in these environments

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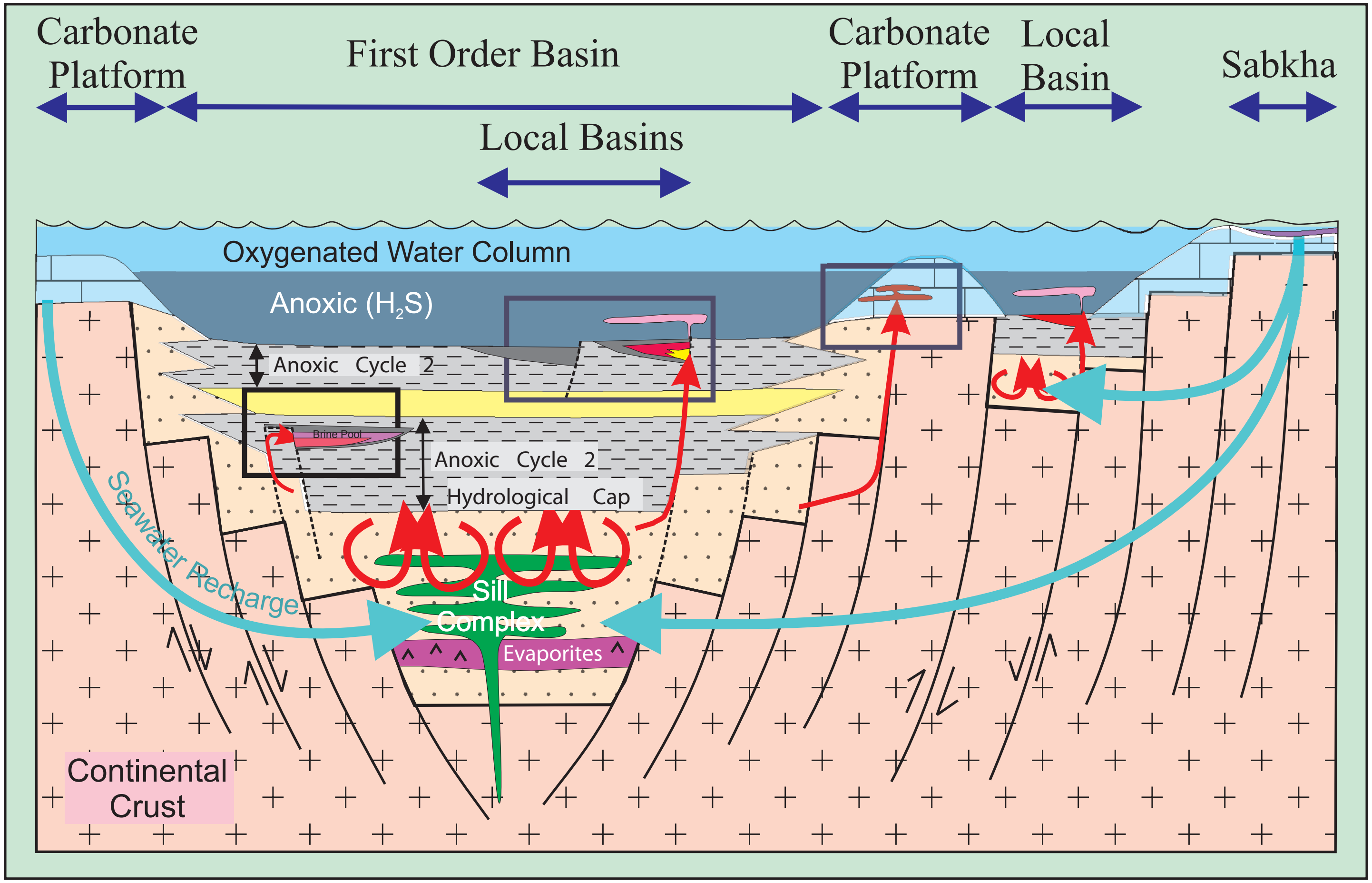
SEDEX Model



Goodfellow and Lydon (2007)

SEDEX – AGE SIGNIFICANCE

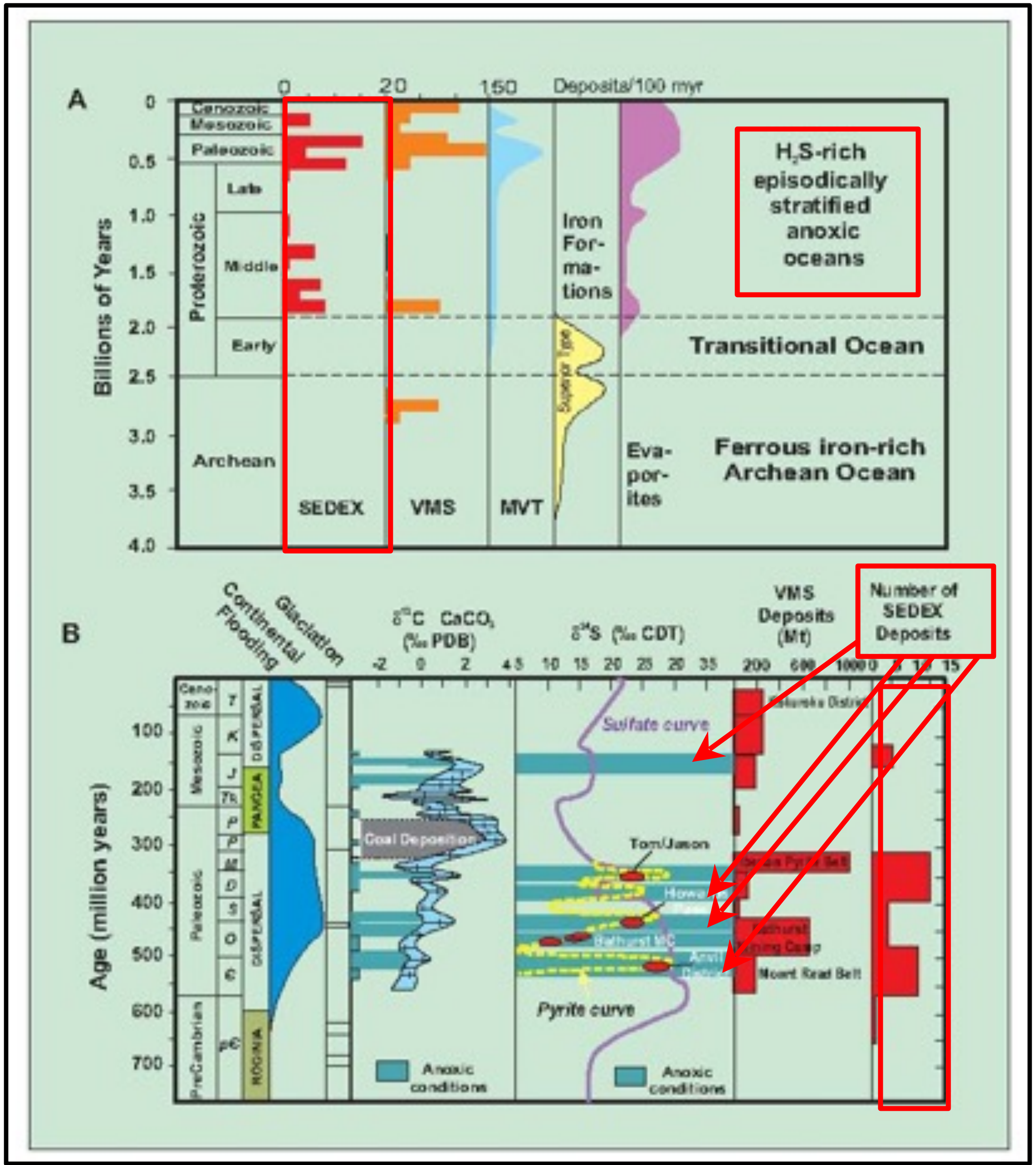


FIG. 11. A. Secular distribution of SEDEX , VMS and MVT deposits, iron formation, evaporites, and H_2S-rich anoxic periods (Goodfellow, 2004). B. Late Proterozoic and Phanerozoic tectonic (continent accretion and dispersion) (Fischer, 1984) and glacial (Baker, 1997) events, continental flooding (Vail et al., 1977), and sulfur isotope secular curves for evaporites (Claypool et al., 1980), carbonates (Arthur and Sageman, 1994) and pyrite (Goodfellow, 1987). Also shown are global (Arthur and Sageman, 1994) and Selwyn Basin (Goodfellow, 1987) anoxic periods, and the temporal distribution of volcanic-associated massive sulfide (Mosier et al., 1983) and SEDEX (Goodfellow et al., 1993) deposits. BMC = Bathurst Mining Camp.

Note coincidence of SEDEX deposits with periods of stratified anoxic ocean basins

Goodfellow & Lydon, 2007

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FLUID INCLUSION TEMPERATURES

- Good fluid inclusion studies are sparse

⟹ Since SEDEX material is often fine-grained

- Tom, Jason Deposits (Gardner & Hutcheon, 1985; Ansdell et al, 1989)
    - Thavg=260 °C 9 wt.% NaClequiv
- Sullivan (Leitch, 1992)
    - Th= 150-320 °C 8-36 wt.% NaClequiv
- These temperatures generally compatible with inferred values for modern Red Sea system
    - >200-250 °C up to 26 wt.% NaClequiv

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SEDEX Ore Deposit

SINK
(deposition)

+

Post-Depositional
Processes

TRANSPORT
(of metals)

SOURCE
(of metals)

Layne, 2007

Summary so far

- SEDEX - sediment-hosted Zn-Pb
  - Vent proximal (descriptive info knowledge required)
  - Vent distal (descriptive info knowledge required)
- Extensional basins - convective hydrothermal circulation.
- Basinal brines (oxidized, SO_4-rich, Cl-rich) - 150-250^oC.
- Need H_2S at the site of deposition - anoxic/euxinic basins.

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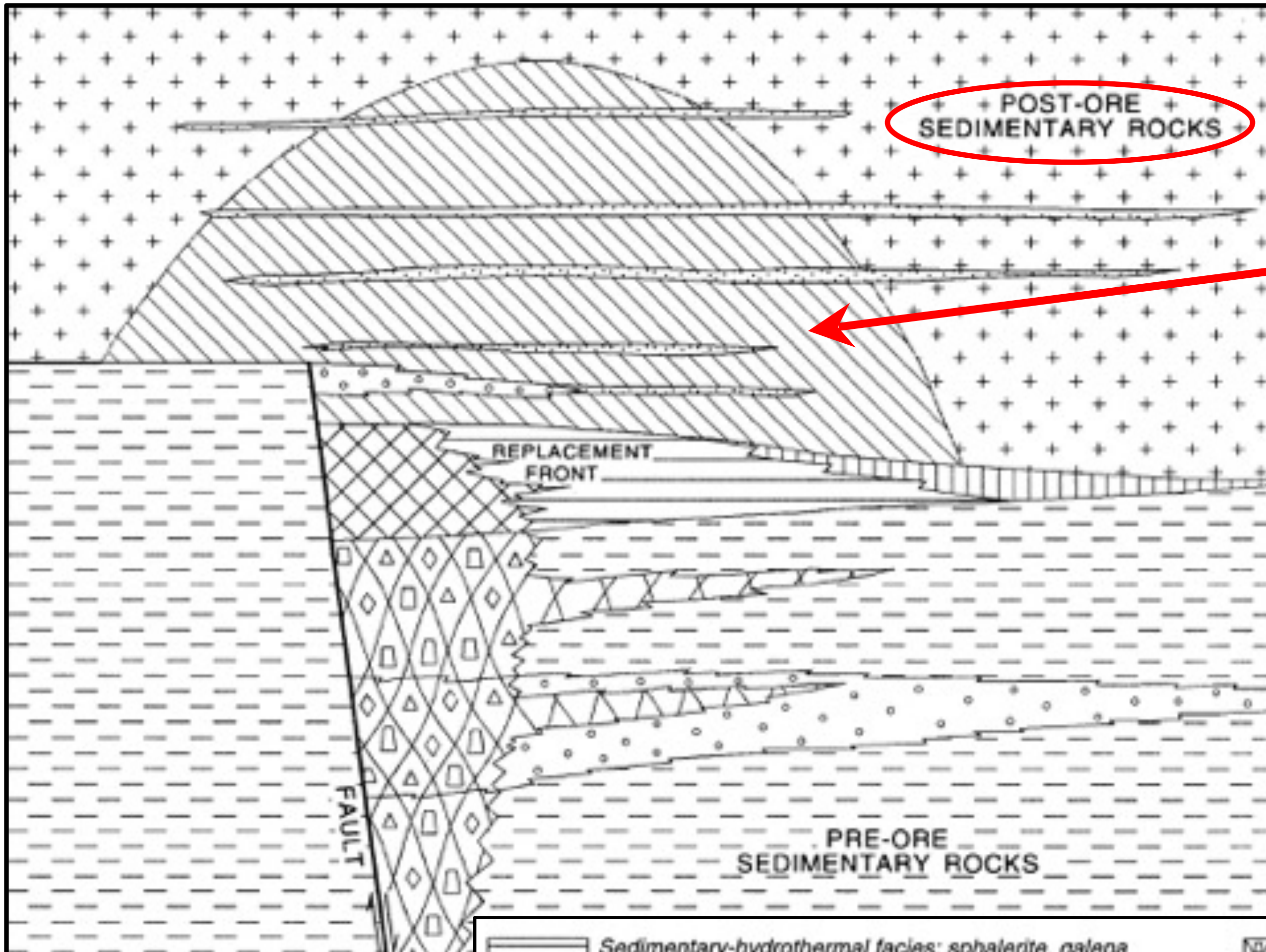
ALTERATION

- Hydrothermal alteration associated with SEDEX deposits commonly extends for 100s of m into the pre- and post-ore sedimentary sequence and up to several km laterally from the deposit.

Goodfellow et al, 1995



Post-Ore Hydrothermal Alteration

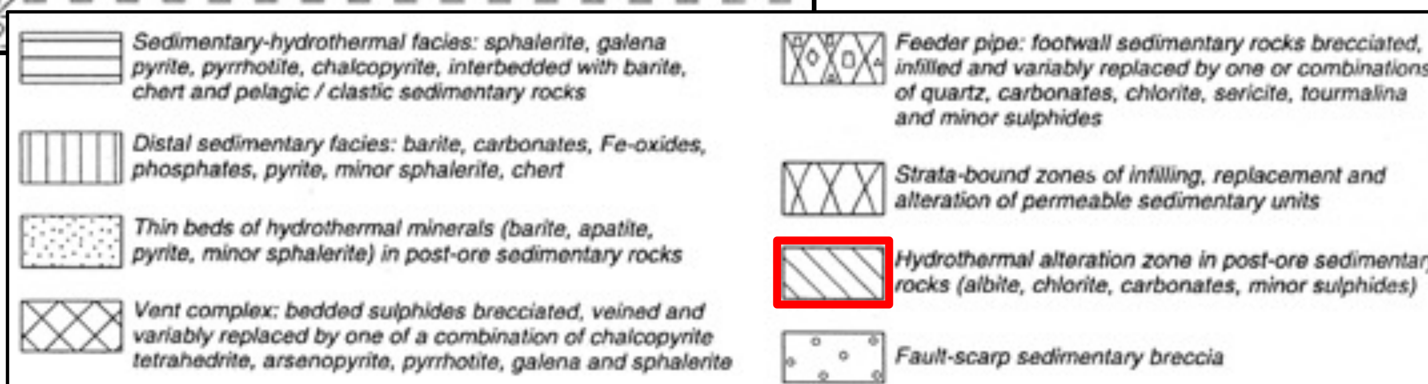


Figure 1. *Idealized section showing the principal attributes of most SEDEX deposits, including synsedimentary faults and associated fault-scarp breccias, a vent complex and underlying feeder pipe, the bedded ore and distal hydrothermal-sedimentary facies, and the overlying hydrothermal sediments and alteration zone.*

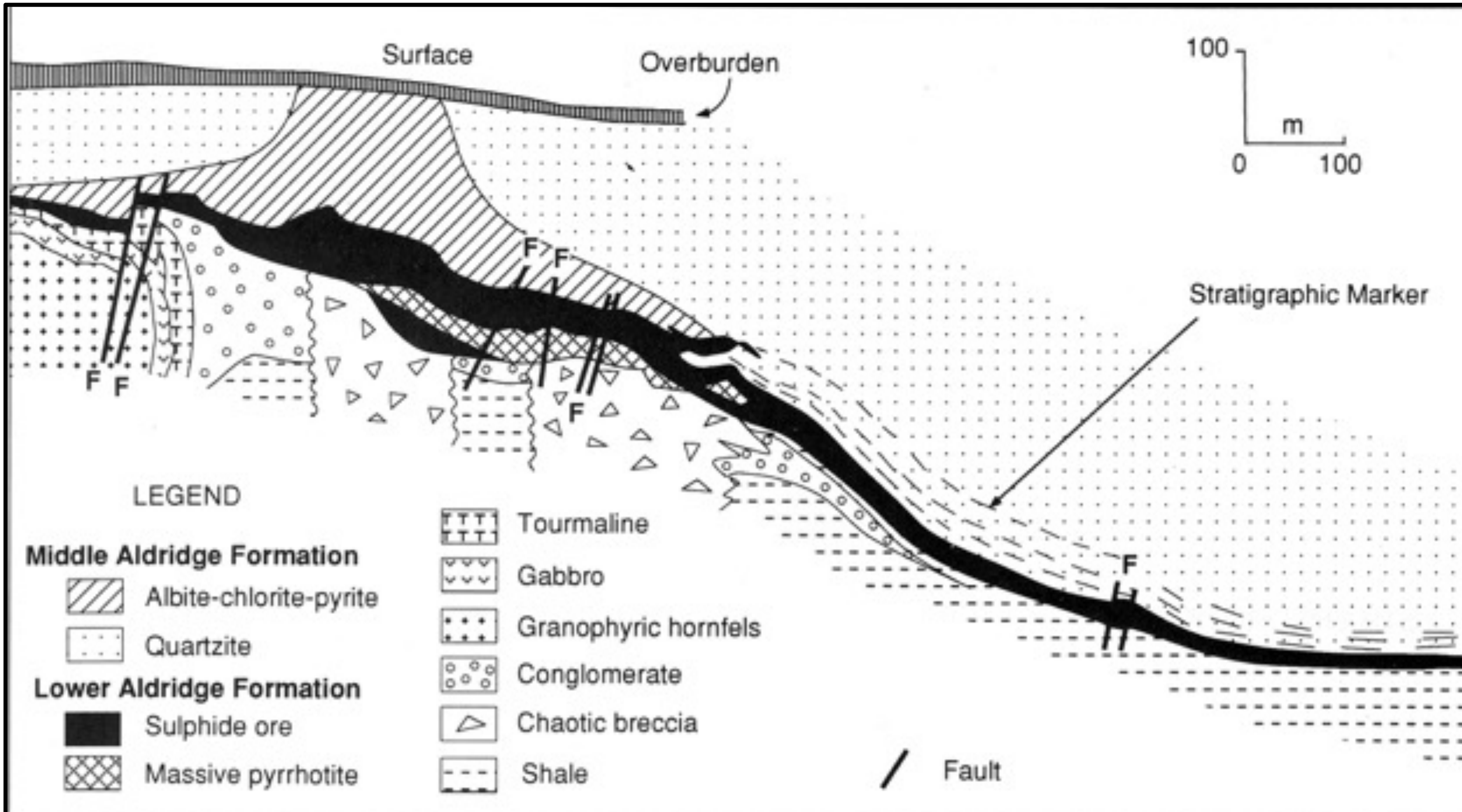


Figure 7. *Cross-section of the Sullivan deposit, British Columbia, showing the relationship between sulphide ore and massive pyrrhotite, footwall chaotic tourmalinized breccia, and the overlying zone of albitization (modified from Hamilton et al., 1983).*

Sullivan SEDEX Deposit Cross-Section

Goodfellow et al, 1995

ALTERATION

- HOWEVER, compared to VMS deposits, feeder pipes and associated alteration underlying SEDEX deposits are relatively subtle/harder to detect:
  - Lower volume of deposited sulphide in pipe
  - Less reactive siliciclastic sediments vs glassy volcanic rocks ⟹ alteration less obvious
  - Limited shallow seawater recharge through the low permeability hemi-pelagic mud hosting most deposits ⟹ alteration less laterally extensive
  - Diagnostic hydrothermal assemblages - such as clay alteration minerals - easily obscured by later metamorphism ⟹ alteration more cryptic

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ALTERATION

- Nevertheless, alteration can extend over great distances from the deposit itself
- Sericite alteration at Sullivan extends more than 200 m below the ore, ~4 km E-W along the Kimberley Fault, and ~6 km S along the Sullivan-North Star corridor.

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Sullivan SEDEX Deposit Map View of Major Alteration Facies

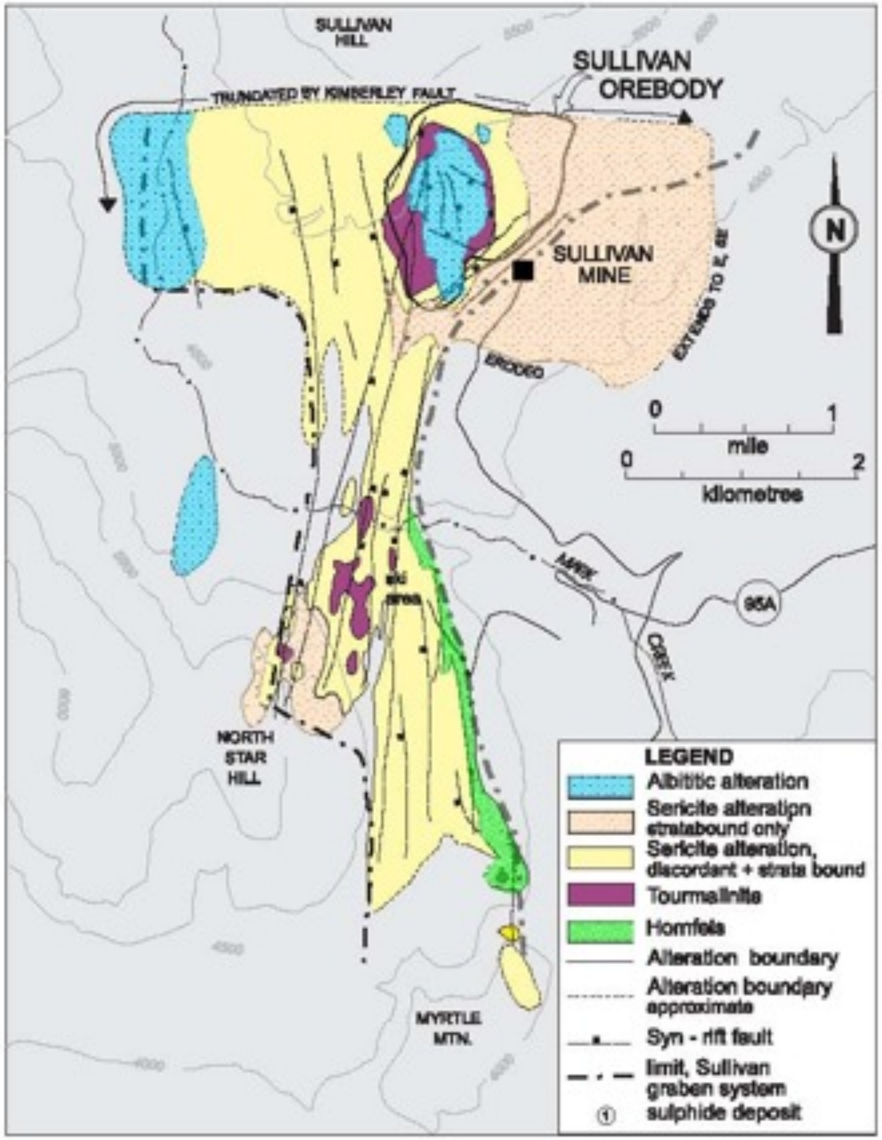

FIG 9. Map of the distribution of major alteration facies within the Sullivan graben system (from Turner et al., 2000).

Goodfellow & Lydon, 2007

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ALTERATION

- The best documented example of post-ore hydrothermal alteration anywhere is the albite-chlorite alteration of turbiditic sedimentary rocks overlying the Sullivan deposit (Hamilton et al, 1982; Turner et al, 2000).
- Late albitization of the vent complex and feeder zone is also apparent - clear evidence that post-ore hydrothermal fluids utilized the same conduits as the ore-forming fluids

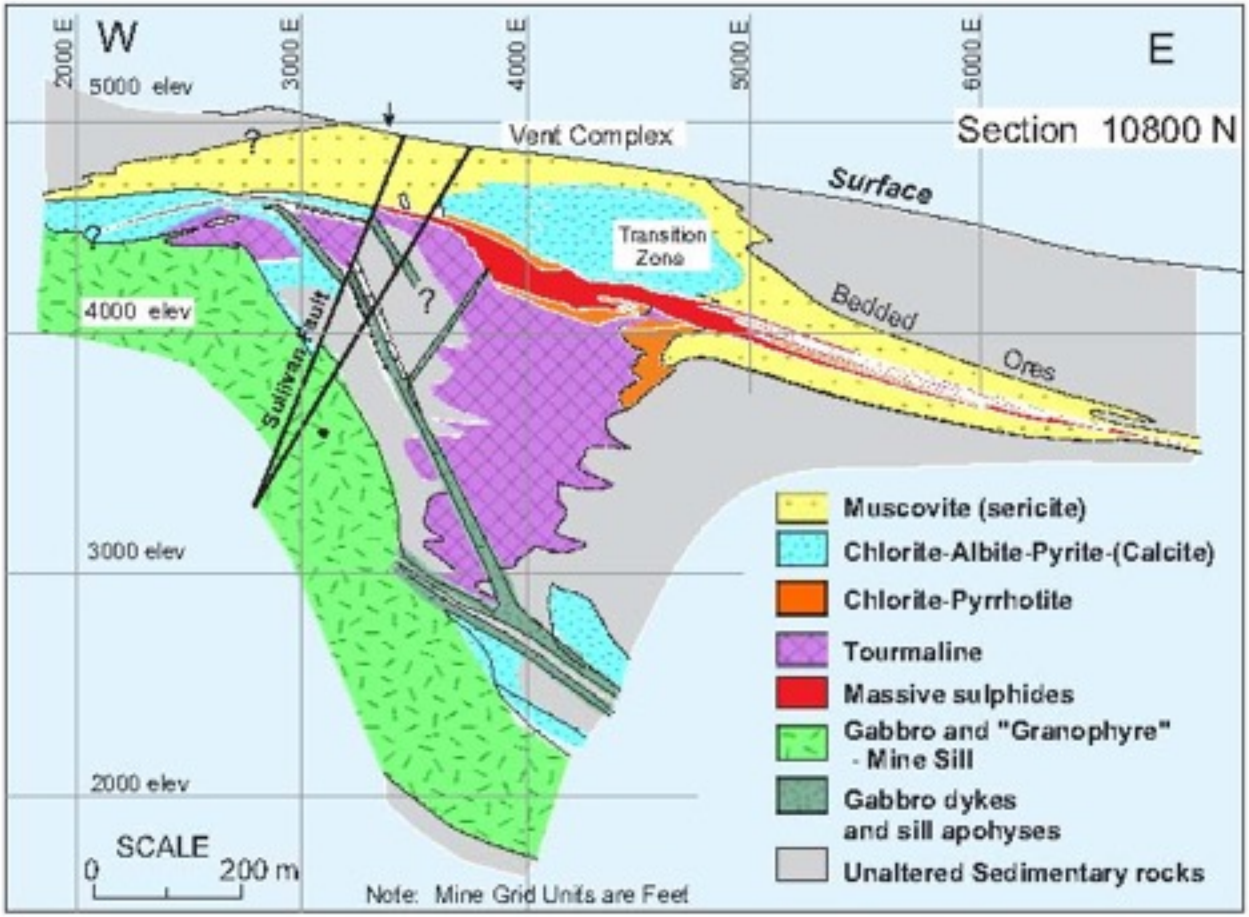

FIG. 5. Geological cross-section of the Sullivan deposit (from Lydon et al 2000a).

Sullivan SEDEX Deposit Cross-Section

Goodfellow & Lydon, 2007

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NON-ORE MINERALIZATION

- Post-ore hydrothermal mineralization can also persist 100s of m into hanging wall stratigraphy (an important guide for mineral exploration), for example:
    - Laminated and disseminated barite and pyrite (e.g. Tom, Jason, Rammelsberg, Meggen)
    - Manganese and iron carbonates (e.g. Meggen, Silvermines, McArthur River (HYC))
    - Phosphatic and pyritic chert (e.g. Howards Pass, Anniv)
    - Metal-rich laminated pyrite (e.g. HYC, Mt. Isa, Tom, Jason)

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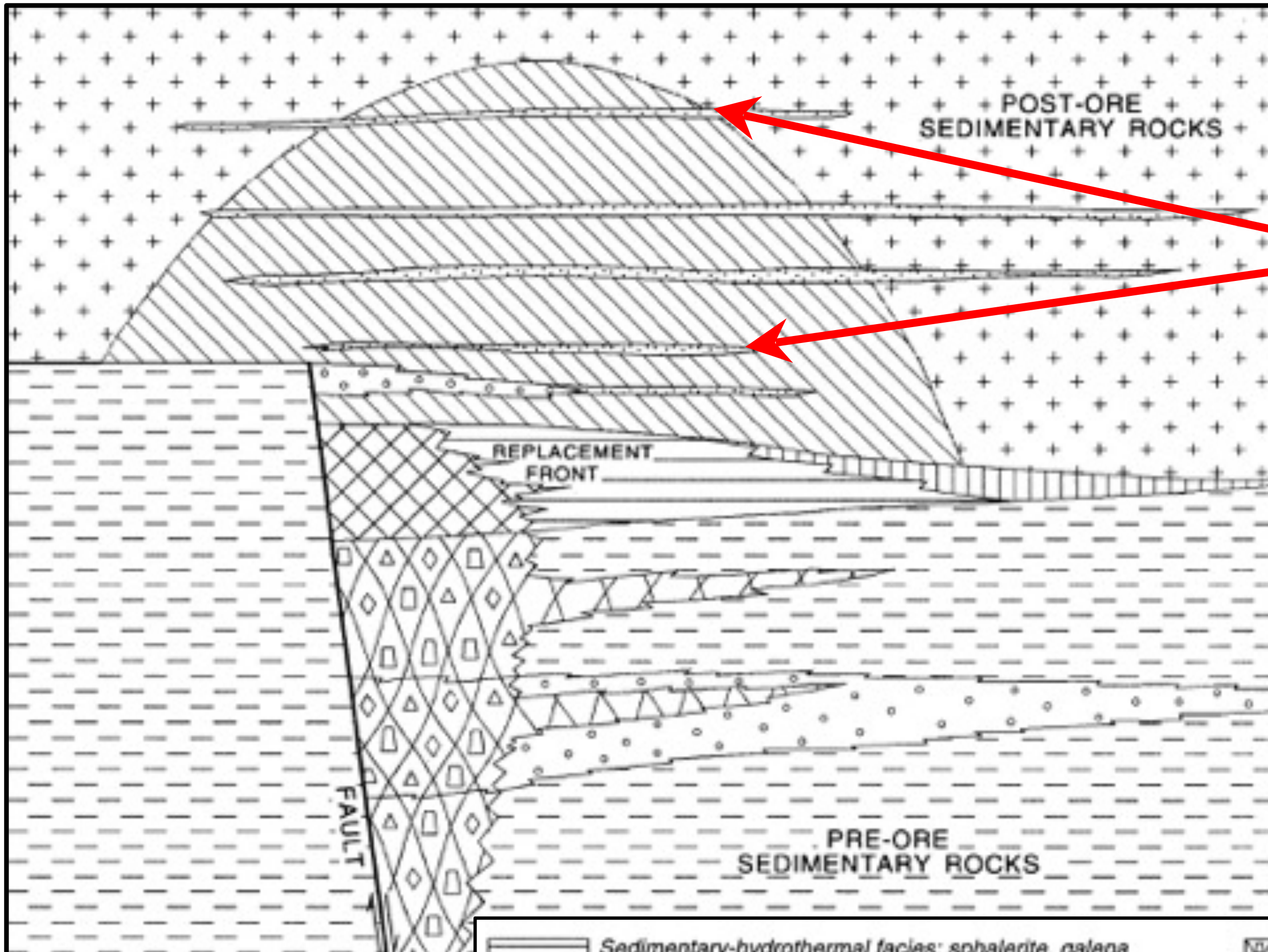
Goodfellow & Lydon, 2007

Goodfellow et al, 1995

Non-Ore Hydrothermal Mineralization



Sedimentary-hydrothermal facies: sphalerite, galena pyrite, pyrrhotite, chalcopyrite, interbedded with barite, chert and pelagic / clastic sedimentary rocks

Distal sedimentary facies: barite, carbonates, Fe-oxides, phosphates, pyrite, minor sphalerite, chert

Thin beds of hydrothermal minerals (barite, apatite, pyrite, minor sphalerite) in post-ore sedimentary rocks

Vent complex: bedded sulphides brecciated, veined and variably replaced by one of a combination of chalcopyrite tetrahedrite, arsenopyrite, pyrrhotite, galena and sphalerite

Feeder pipe: footwall sedimentary rocks brecciated, infilled and variably replaced by one or combinations of quartz, carbonates, chlorite, sericite, tourmalina and minor sulphides

Strata-bound zones of infilling, replacement and alteration of permeable sedimentary units

Hydrothermal alteration zone in post-ore sedimentary rocks (albite, chlorite, carbonates, minor sulphides)

Fault-scarp sedimentary breccia

Figure 1. *Idealized section showing the principal attributes of most SEDEX deposits, including synsedimentary faults and associated fault-scarp breccias, a vent complex and underlying feeder pipe, the bedded ore and distal hydrothermal-sedimentary facies, and the overlying hydrothermal sediments and alteration zone.*

NON-ORE MINERALIZATION

- These same styles of non-ore hydrothermal mineralization often also form aprons that extend several km laterally from the ore zone of vent-proximal deposits

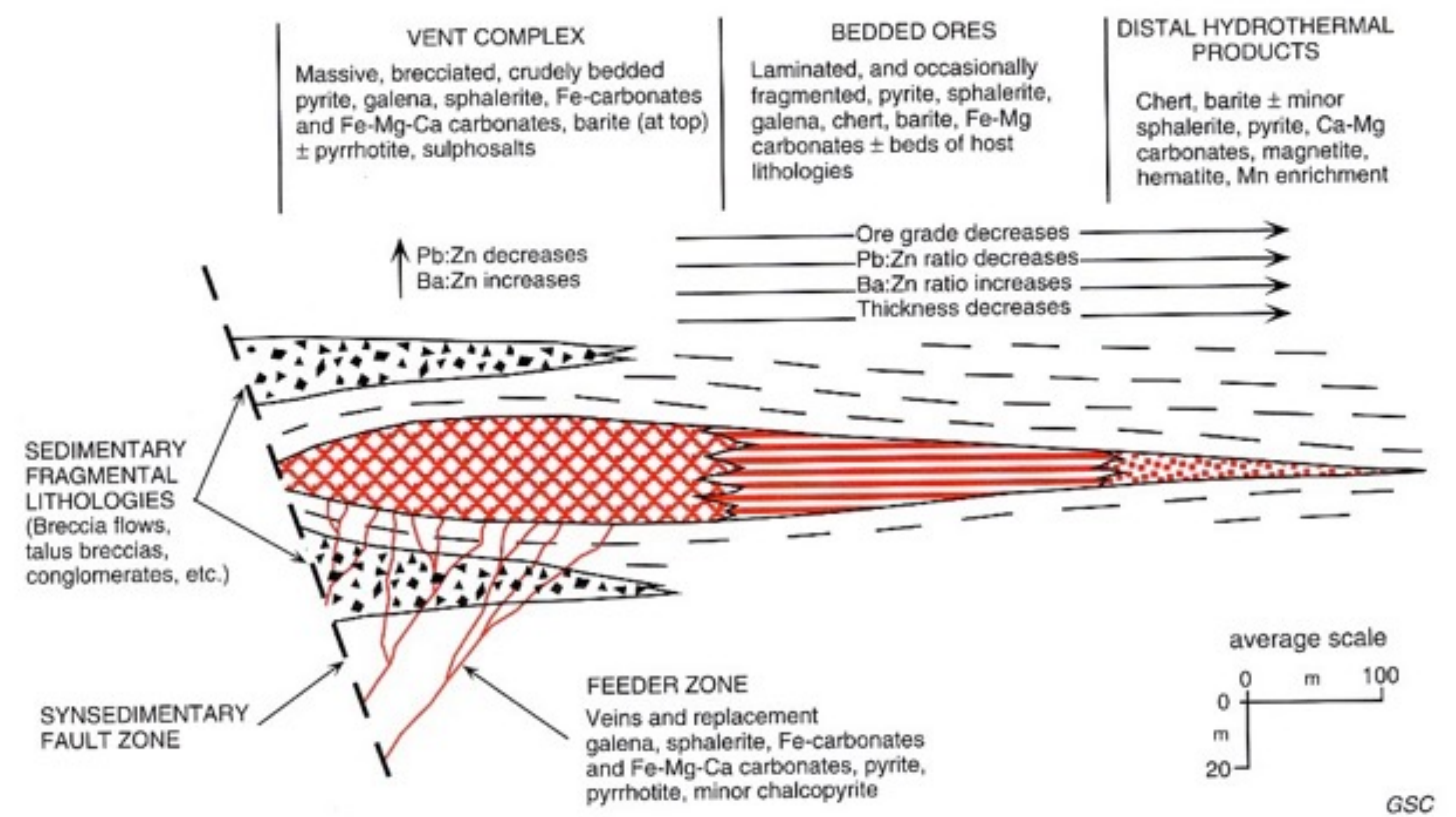


Figure 6.1-4. Schematic illustration of the characteristic features of the idealized Sedex deposit.

A Useful Plan-View Schematic of a SEDEX Deposit

Lydon, 1995

FAULTING & ORE LOCALIZATION

- SEDEX deposits typically occur in second-order or local third-order sedimentary basins.
  - Vent-proximal deposits are associated with active faults that commonly define the margins of local basins (and the deposit)
  - Vent-distal deposits form in bathymetric depressions on the seafloor

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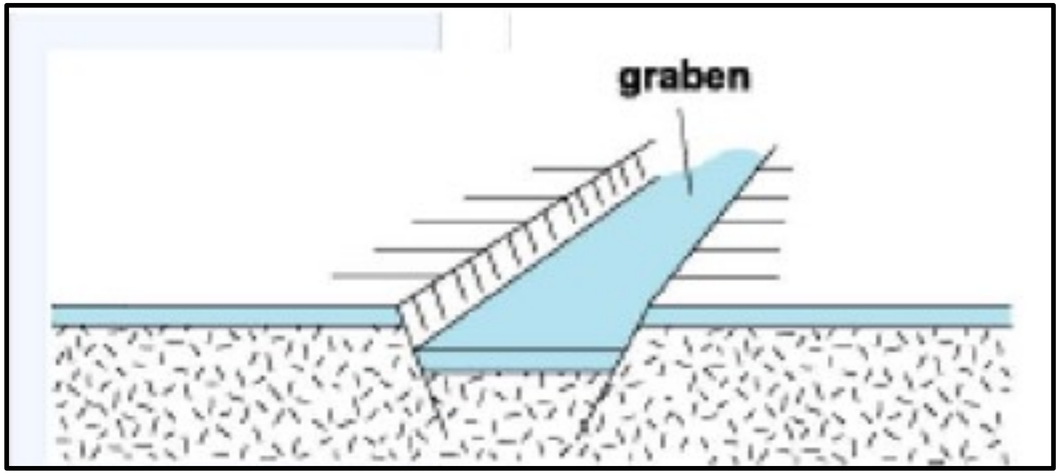
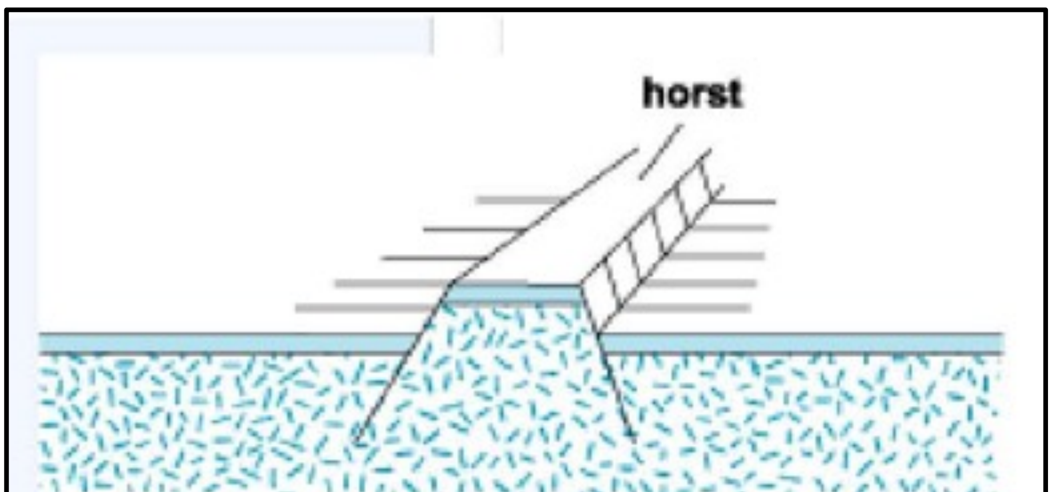
Graben: Dropped Fault Block



Horst: Upthrown Fault Block



after A.K. Lobeck, Geomorphology, McGraw-Hill, 1939

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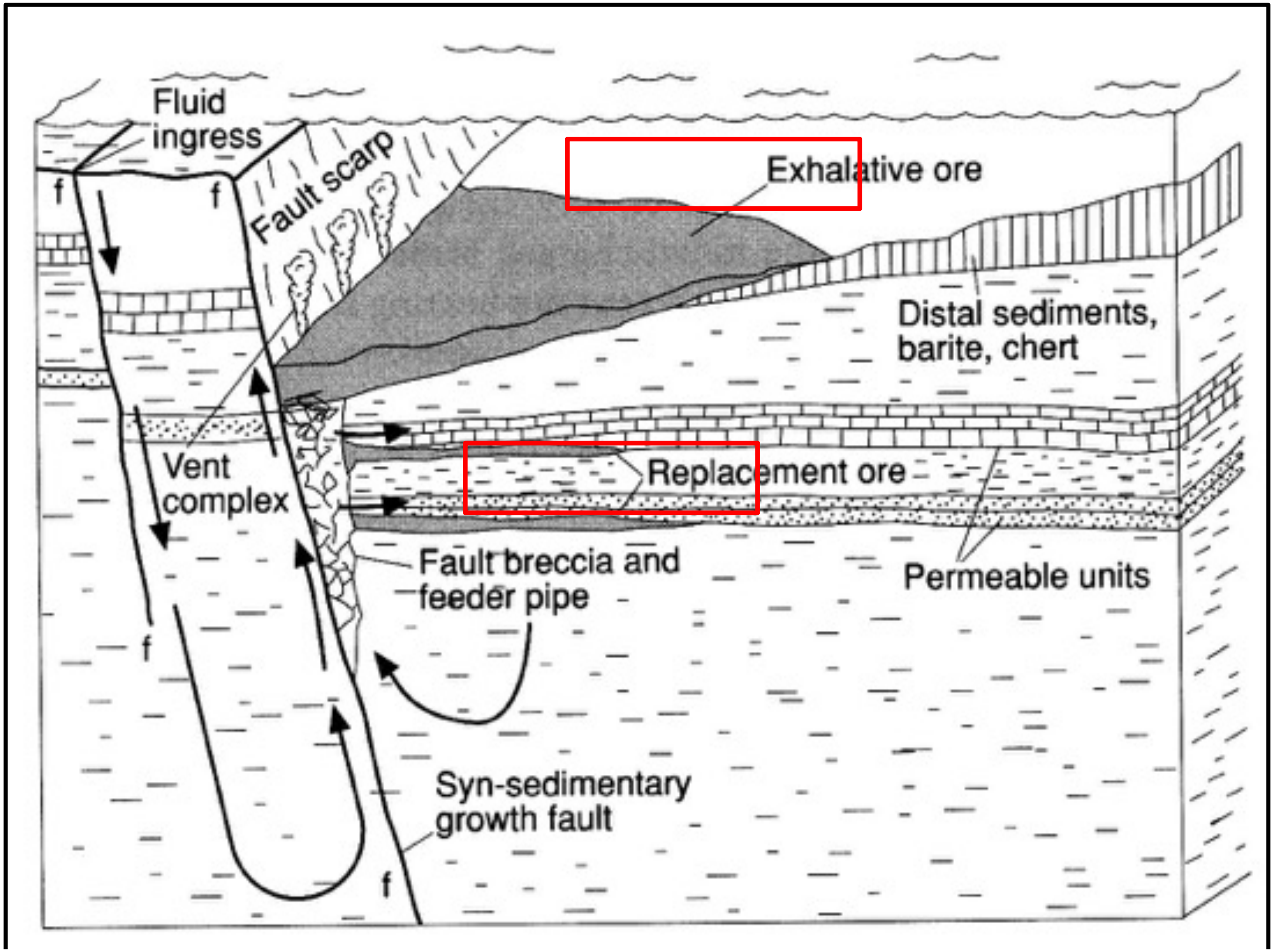

Setting(s) of SEDEX Pb-Zn Ore Formation

Robb (2005); Figure 3.25

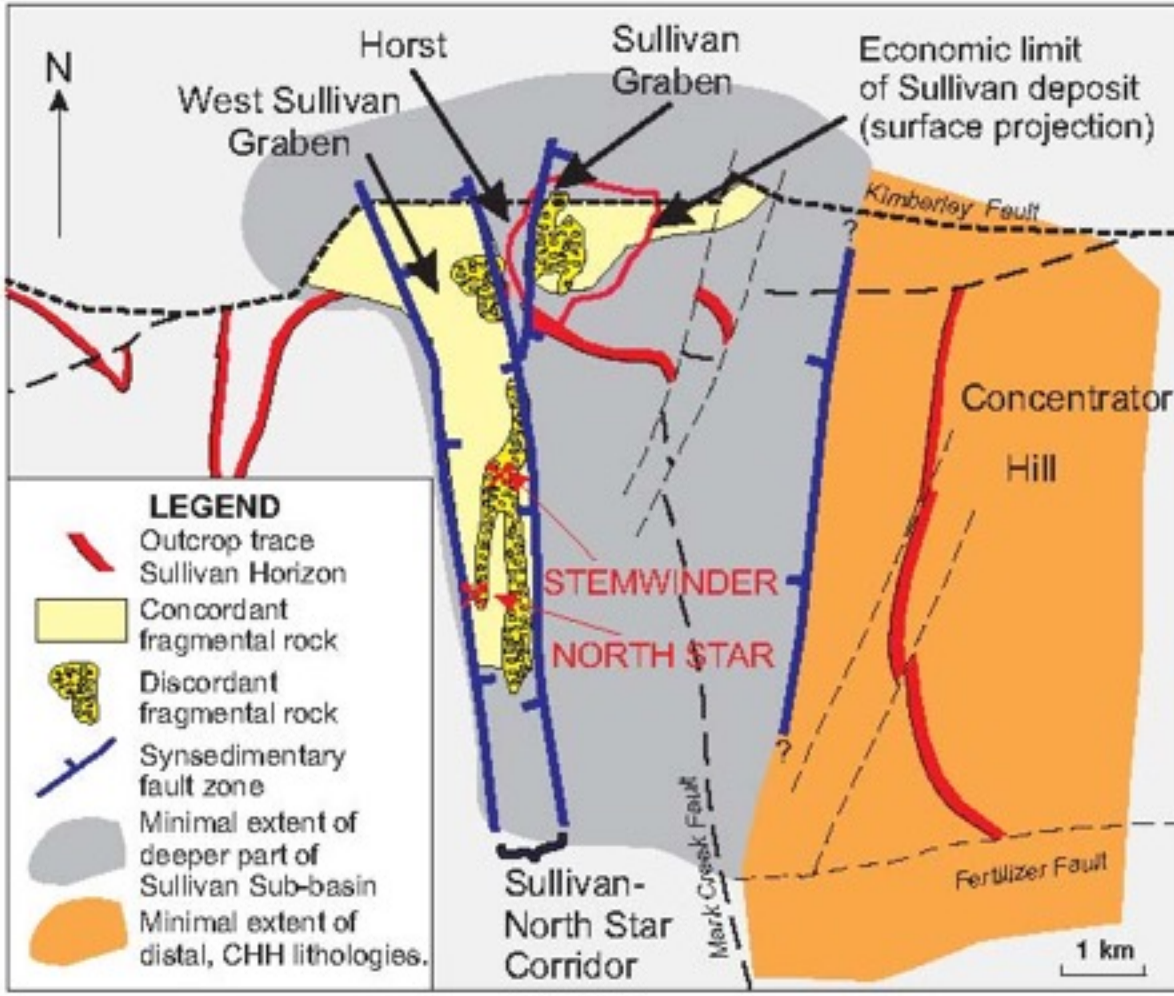

FIG. 15. Surface map of the Sullivan deposits showing the Sullivan and West Sullivan grabens or third-order basins and basin bounding faults (from Lydon et al., 2000a).

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Goodfellow & Lydon, 2007

SEDEX Summary

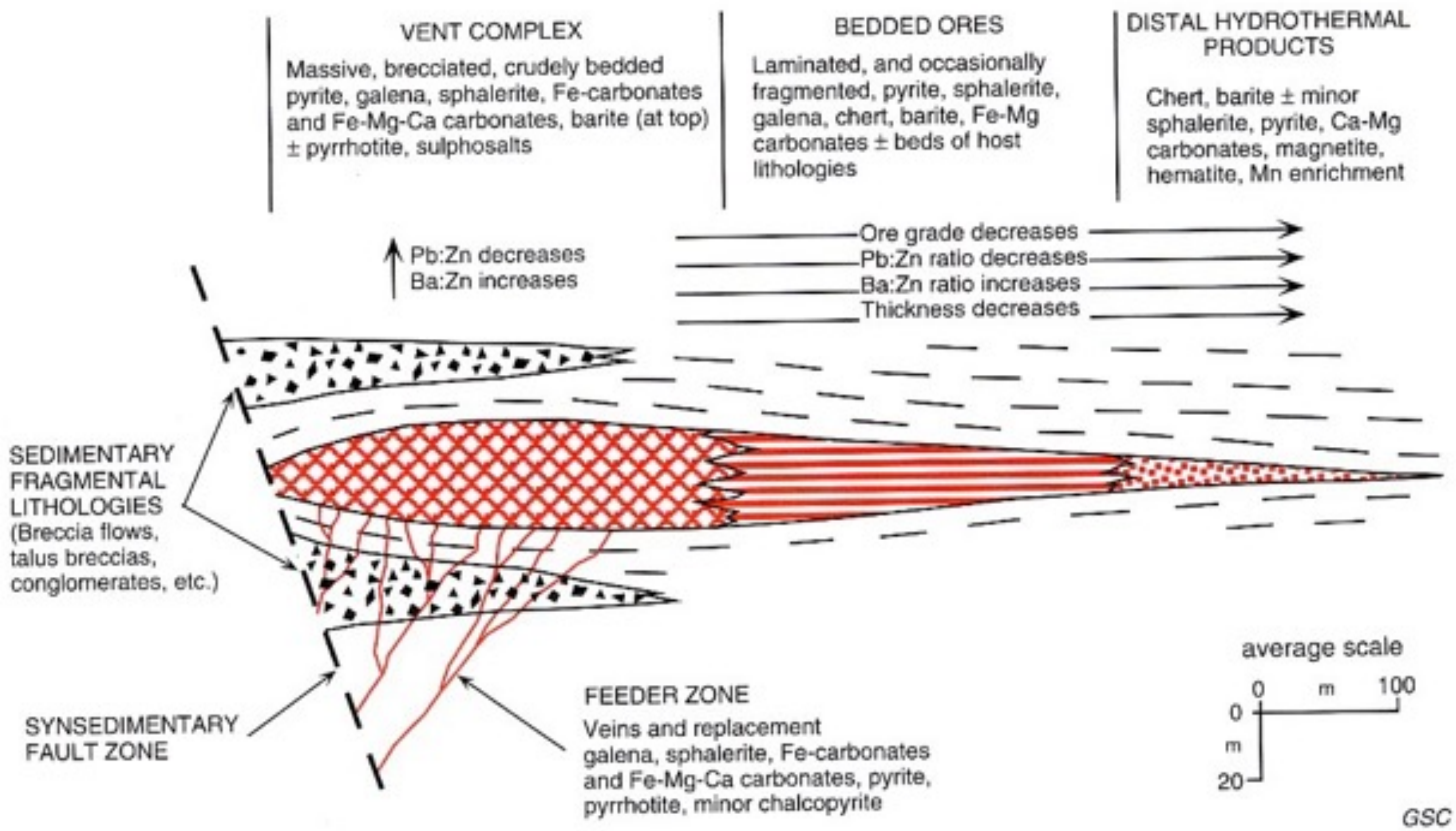

Figure 6.1-4. Schematic illustration of the characteristic features of the idealized Sedex deposit.

- Extensional sedimentary basins
- Control by faults
- Vent proximal vs. vent distal
- Zoning of ore facies (above)
- Alteration – footwall and hanging wall

SULLIVAN DEPOSIT

- The Sullivan Deposit has all of the definitive characteristics of a SEDEX class deposit
- However, it also has some (somewhat) unusual additional features and geological history

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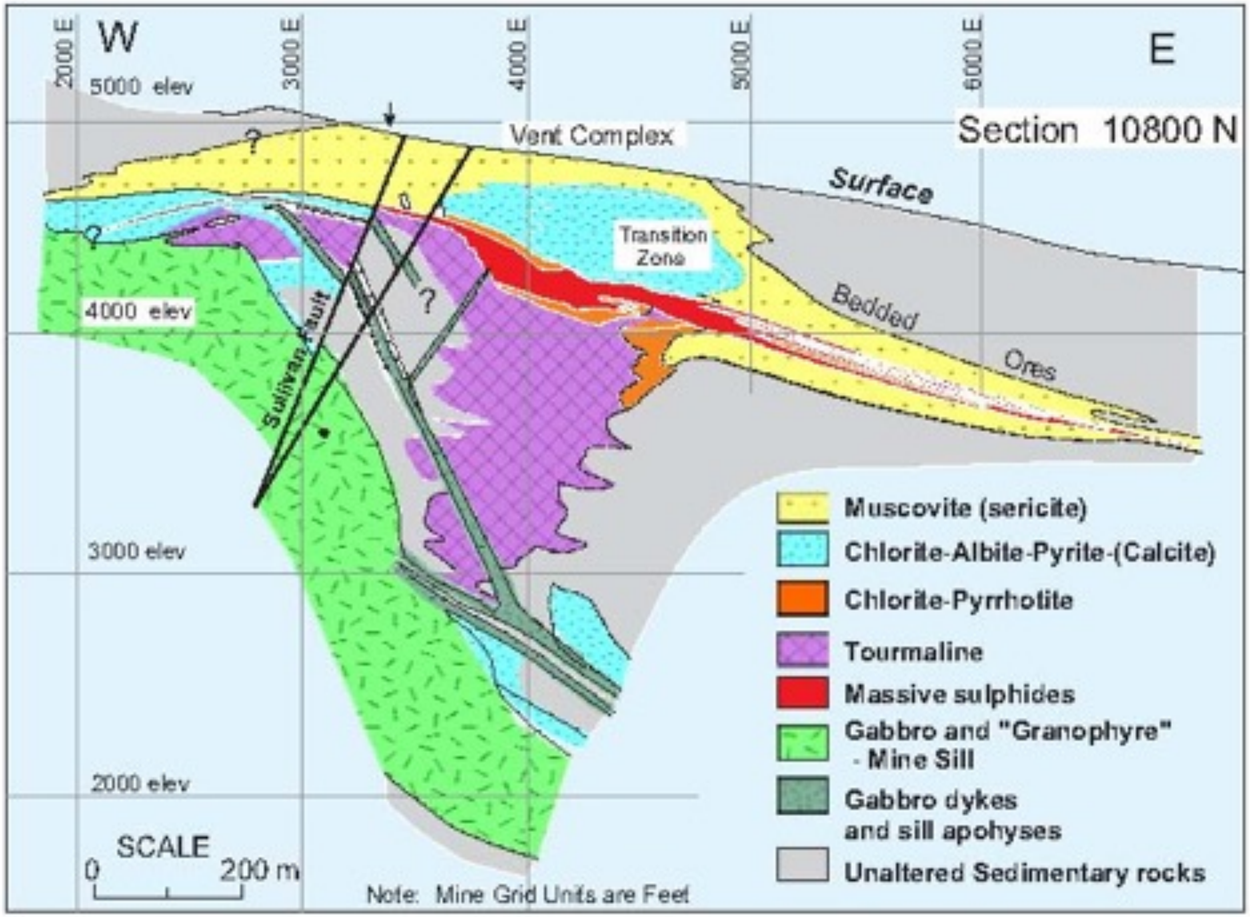

FIG. 5. Geological cross-section of the Sullivan deposit (from Lydon et al 2000a).

Sullivan SEDEX Deposit Cross-Section

Goodfellow & Lydon, 2007

SULLIVAN DEPOSIT

- It occurs quite early in the rift-fill sequence of an intracratonic rift – and there are proximal, coeval gabbroic sills in the host rock sequence.
- For next module - what VMS class does this resemble?
- Besshi-type or Bathurst-type setting (or BHT-type deposits)

SULLIVAN DEPOSIT

- Recent genetic models for Sullivan (e.g.,Lydon, 2004) propose that ore-deposition was preceded by a period of mud volcano activity.
- Mud volcanoes were provoked by the intrusion of the gabbroic sills in to wet, un-indurated soft sediments within the early rift basin
- Mud volcano activity – rather than typical scarp talus debris – was responsible for forming the footwall conglomerate and chaotic breccia units of Hamilton (1983).

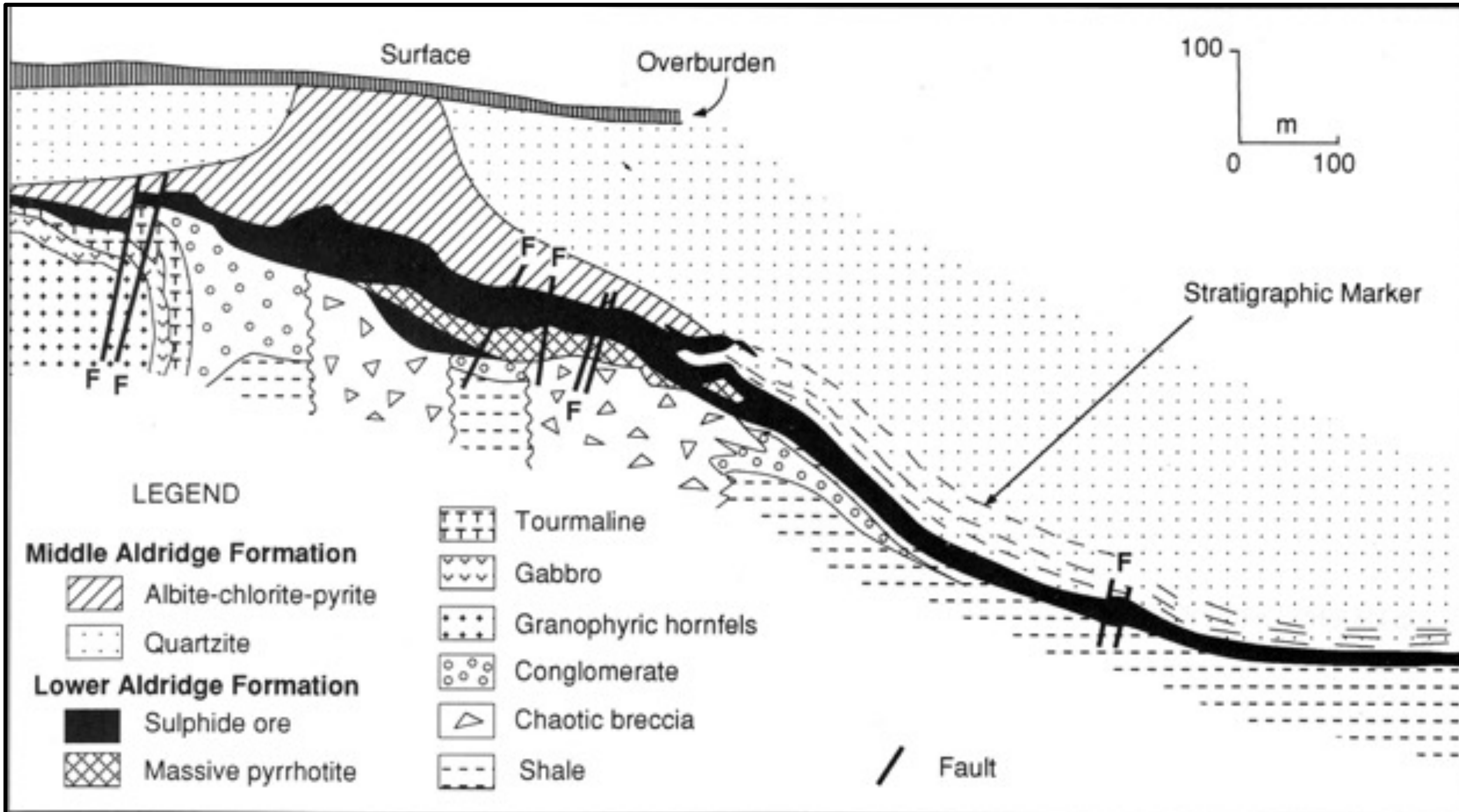

Figure 7. *Cross-section of the Sullivan deposit, British Columbia, showing the relationship between sulphide ore and massive pyrrhotite, footwall chaotic tourmalinized breccia, and the overlying zone of albitization (modified from Hamilton et al., 1983).*

Sullivan SEDEX Deposit Cross-Section

Goodfellow et al, 1995

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SULLIVAN DEPOSIT

- There is also a suggestion that the pronounced zone of tourmalinization below the deposit was also caused by pre-ore fluids related to mud volcano activity.
- However, once mud volcano activity ceased, subsequent hydrothermal activity utilized the same conduit(s), producing a classical vent-proximal SEDEX deposit.

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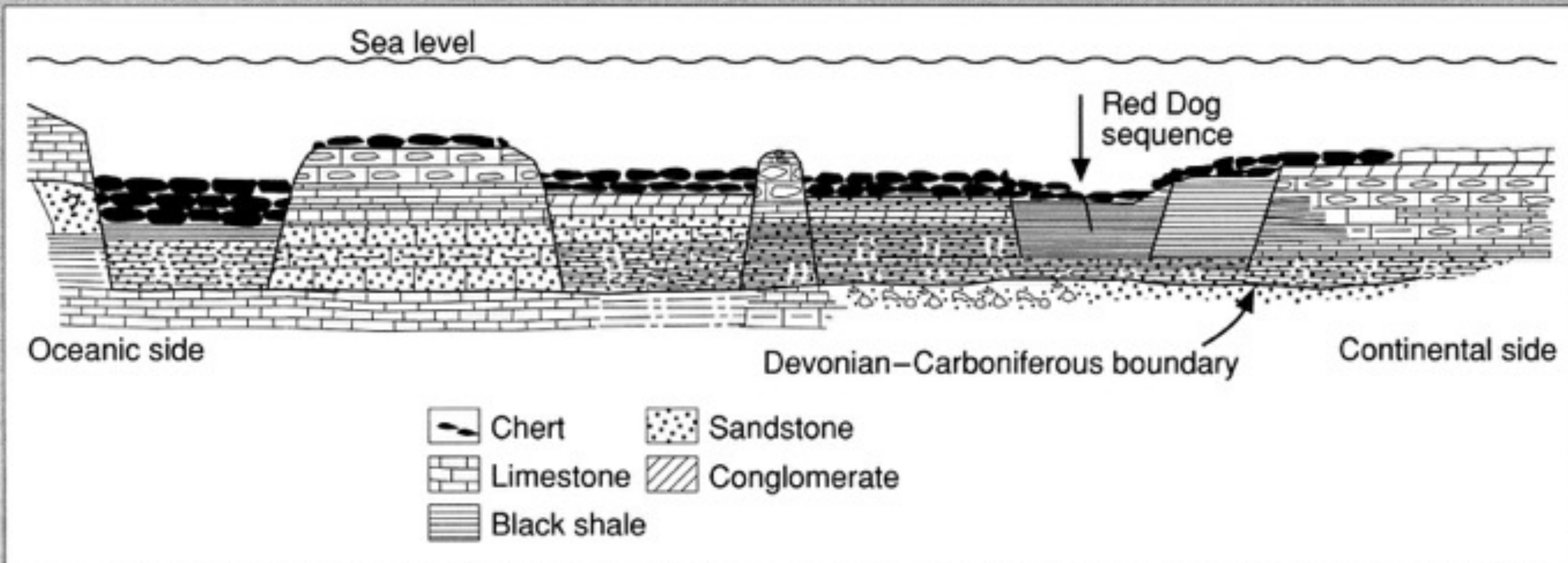

Figure 1 Interpretive, pre-thrusting, cross section through Devonian–Carboniferous sediments in the Brooks Range, illustrating the depositional setting of host rocks at the Red Dog mine. Syn-sedimentary growth faults and abrupt lateral facies variations are also a feature of the regional setting (after Moore *et al.*, 1986).

Robb (2005) Box 3.4 (p.188-189) on the Red Dog, AK example of a SEDEX deposit. It should make sense to you in terms of the Lecture discussions.

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Robb (2005); after Moore et al, (1986)

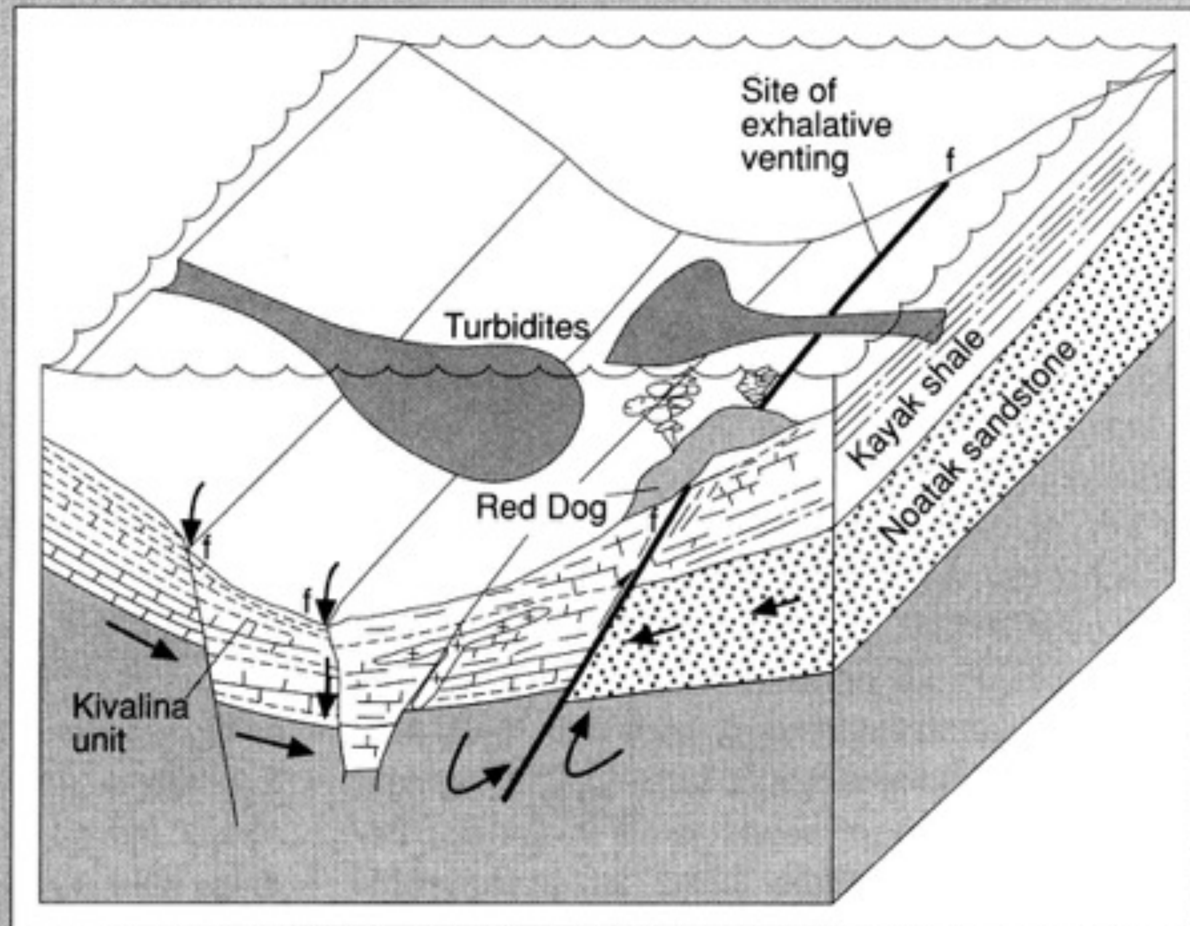

Figure 2 Simplified block diagram showing the environment of ore formation in the Carboniferous for the Red Dog deposit (after Moore *et al.*, 1986).

Robb (2005); after Moore et al, (1986)