

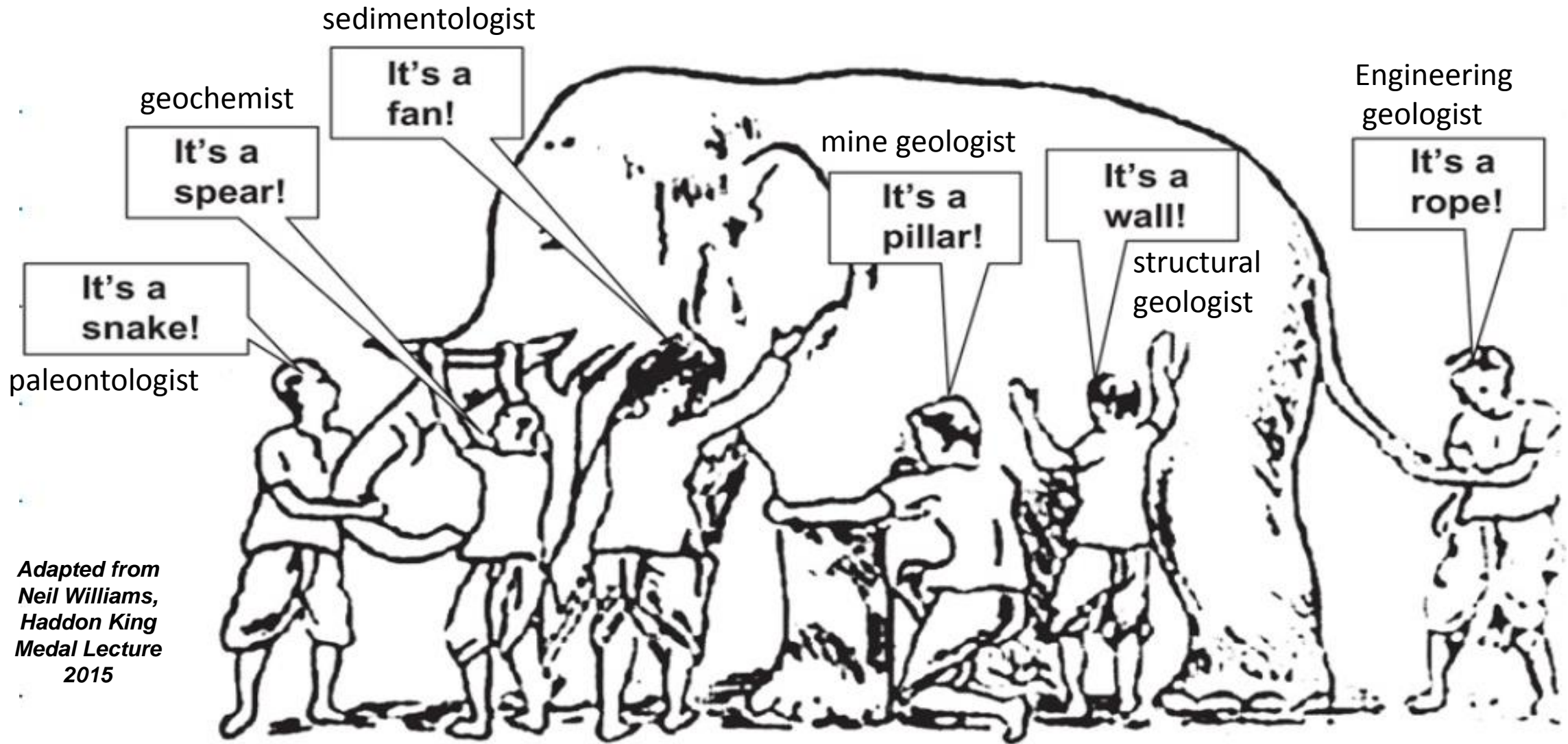
'Viewing the scene'

SMEDG
22nd October 2015

**Broken Hill Mineralisation -
Observations from Outside
the Box**

Ian Pringle

Six blind geologists and the Broken Hill elephant



*Adapted from
Neil Williams,
Haddon King
Medal Lecture
2015*

How about taking a look at the bigger picture – what does the surrounding environment tell us about this elephant?

Perspective of another geologist - a 'view of the scene'

'The Broken Hill Circus' – a picture puts it in perspective

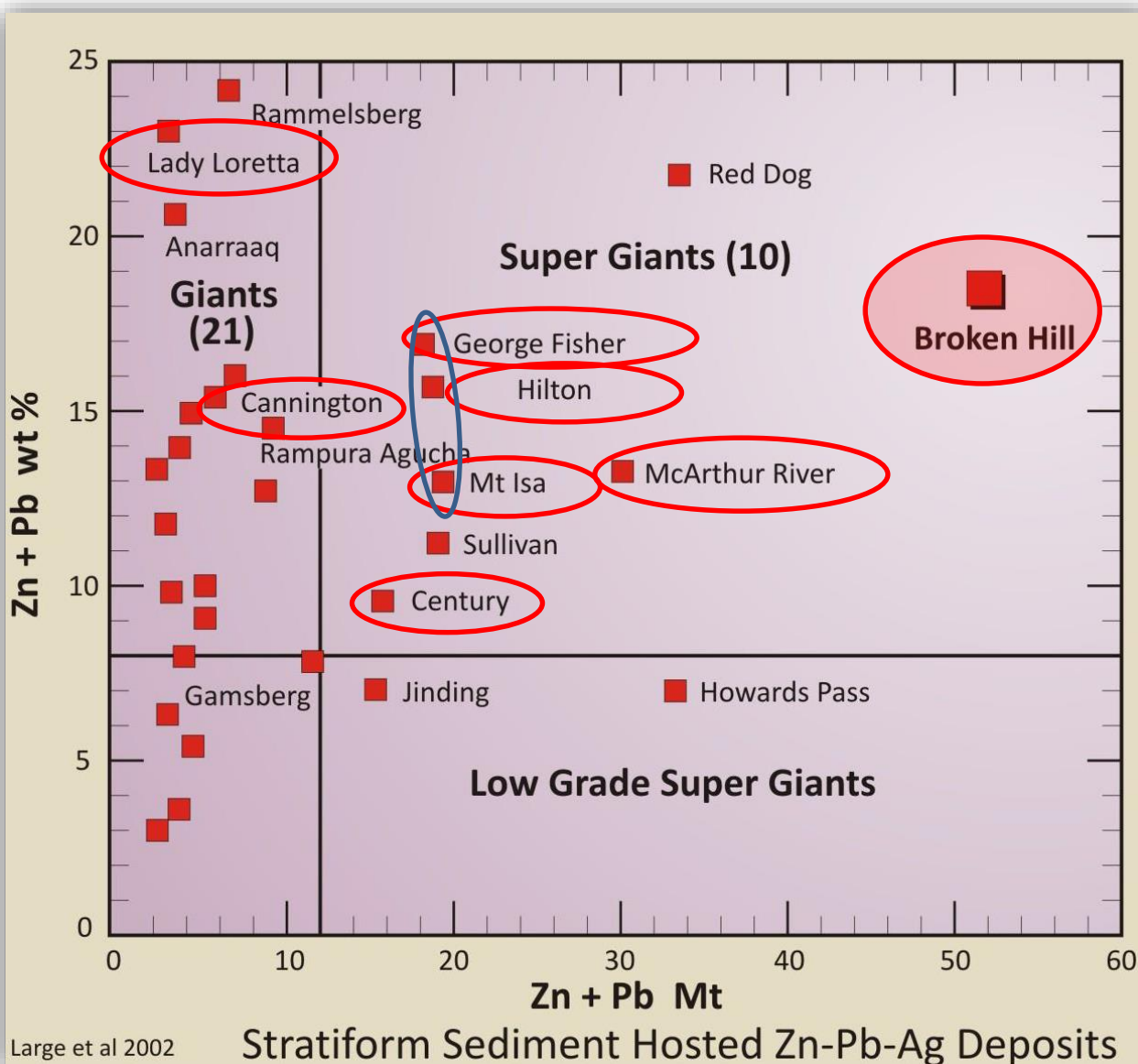


In this talk I plan to:

- provide a general description of the 'mammoth' Broken Hill orebody
- give 'viewing the scene' thoughts about possible formation of Broken Hill ore with particular note on the environment at the time of mineral deposition
- briefly outline my ideas on the formation of the Thackaringa cobalt-pyrite deposit, located not far from BH, and;
- Hopefully leave all of you with some thoughts to ponder



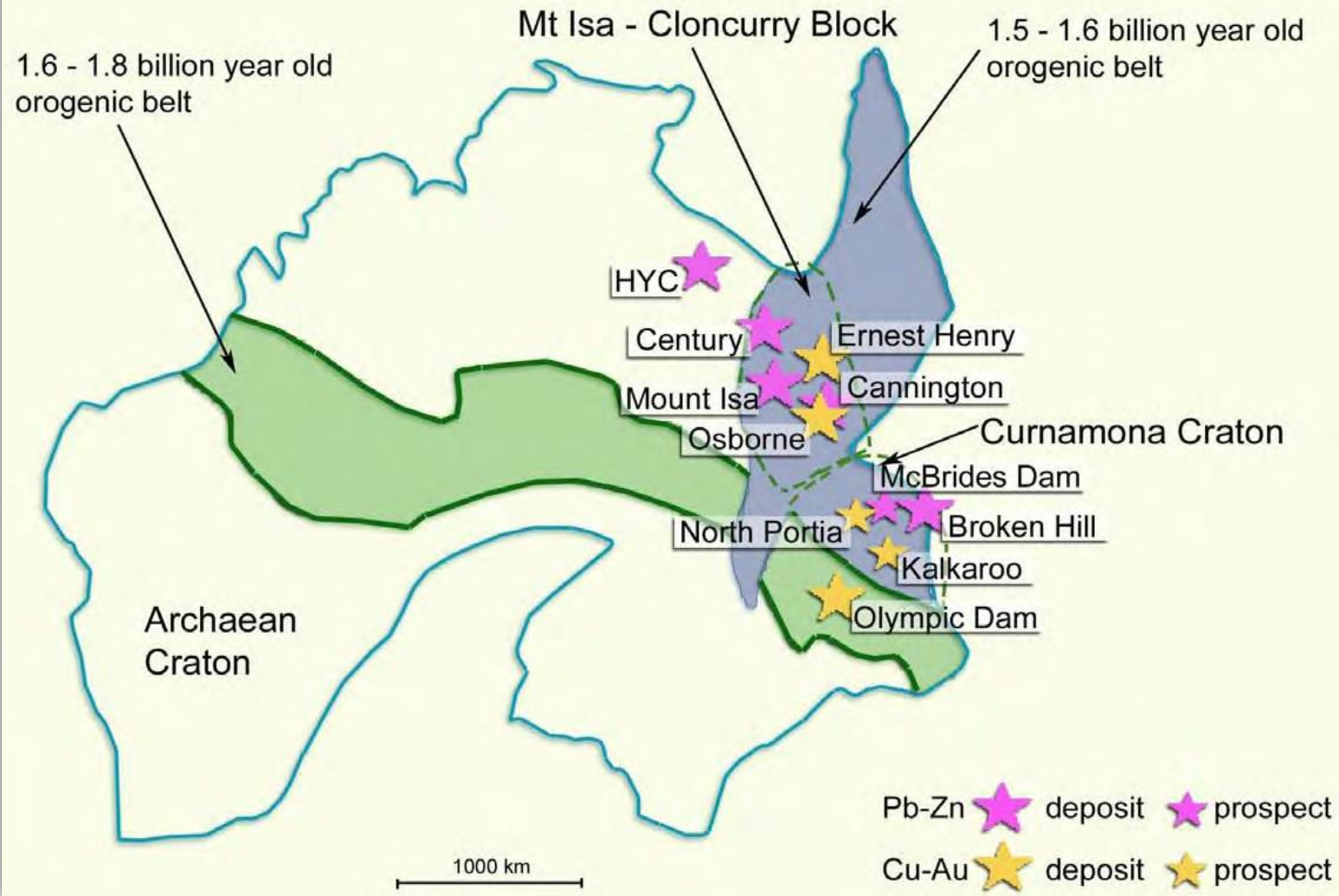
Broken Hill is the 'elephant' of lead and zinc!



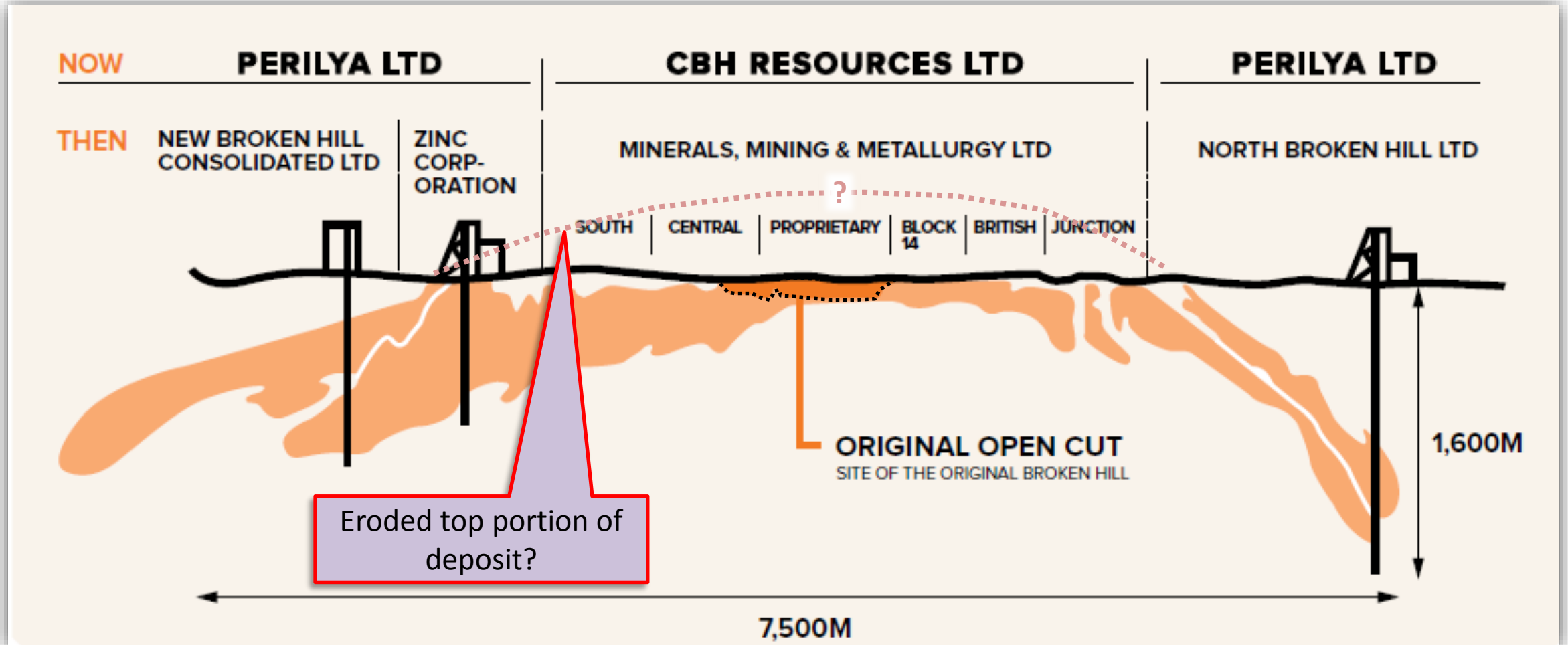
The best of the rest of the 'herd' are mostly located in eastern Australia

Located in a spectacular base metal province

SOURCES: David Giles (UofA), Havilah Resources NL

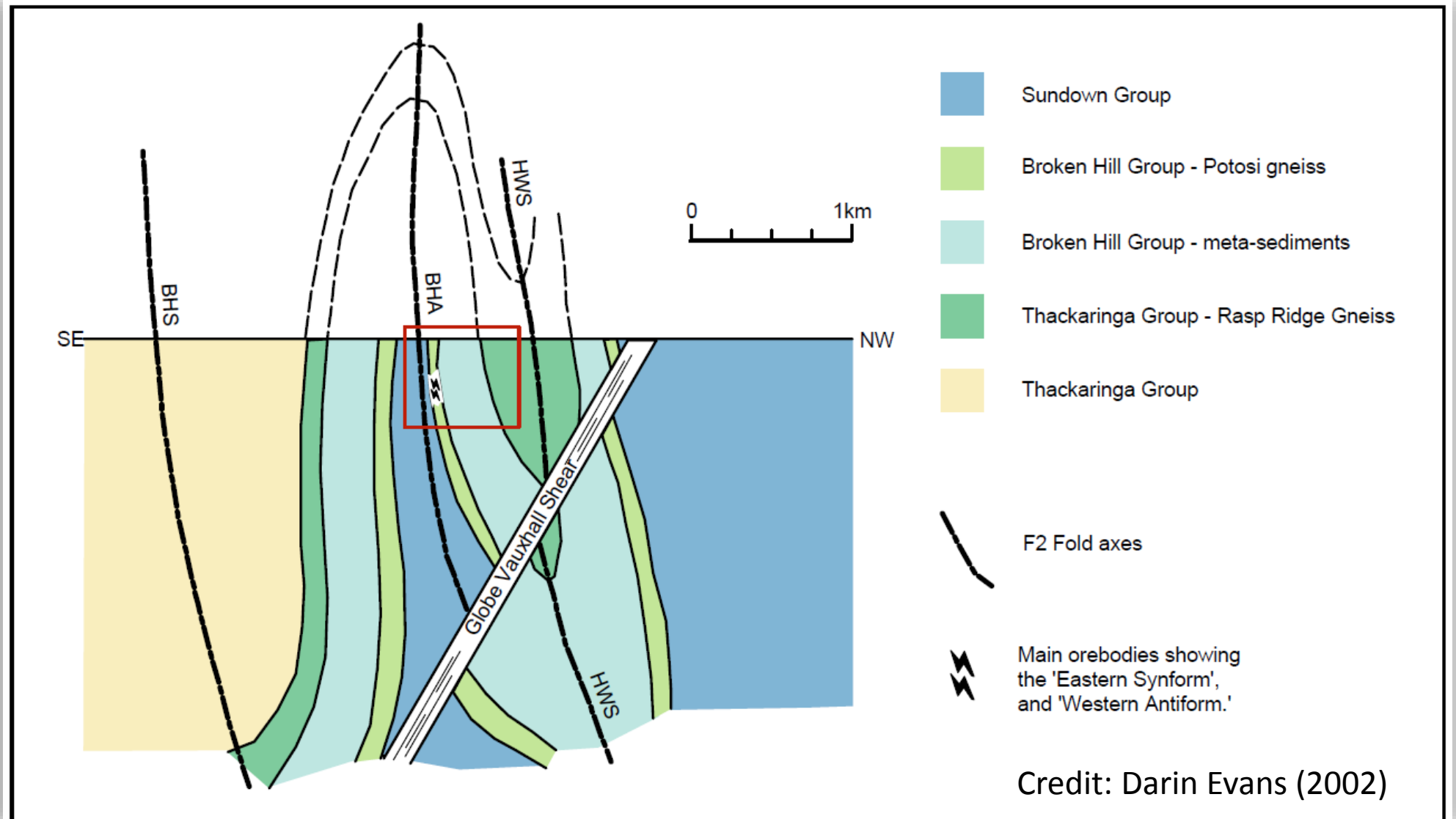


Line of Load – now and then



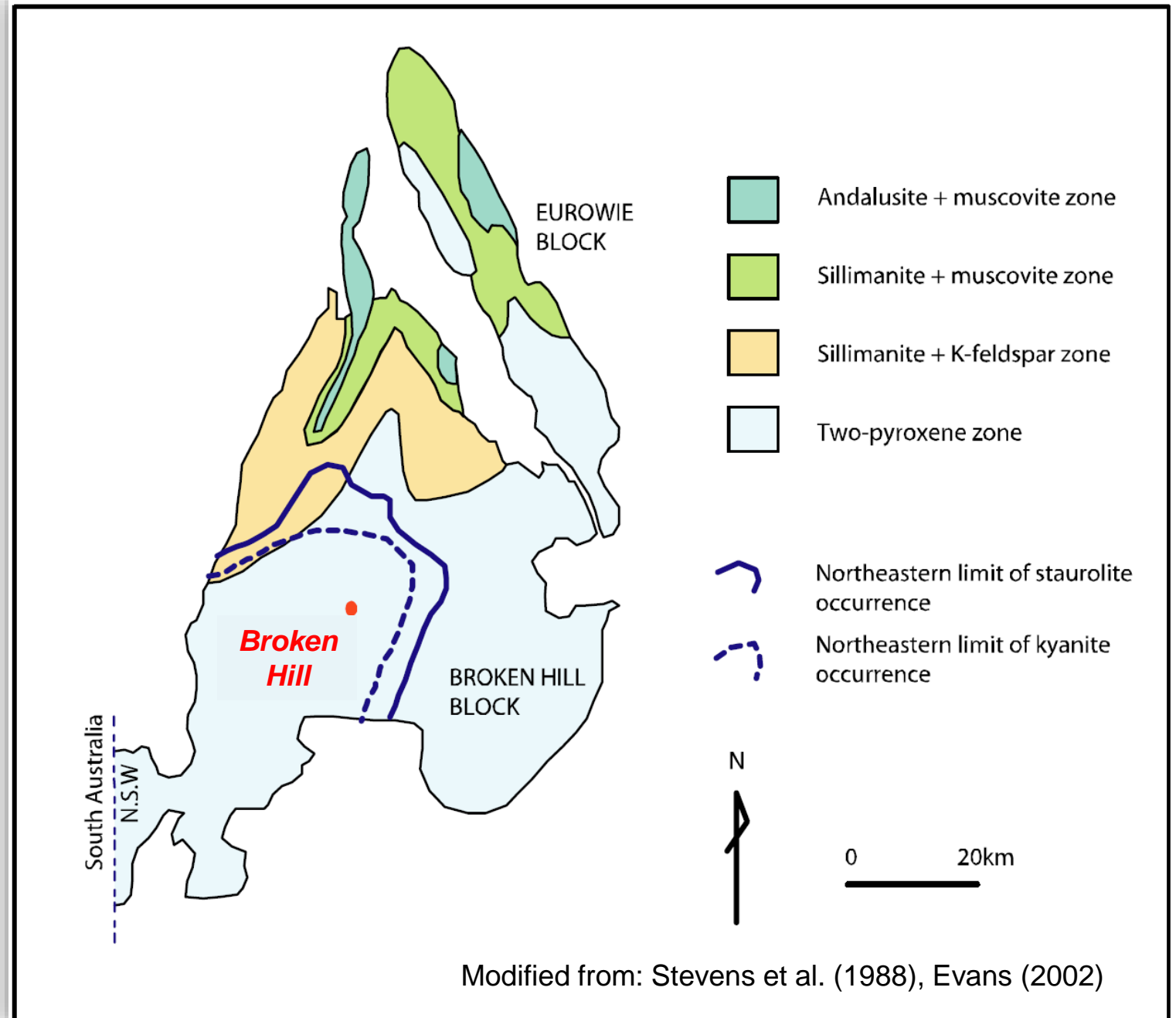
Source: www.brokenhillaustralia.com.au/about-broken-hill/local-factbook/the-ore-body/

Structurally complex



Regional Metamorphism

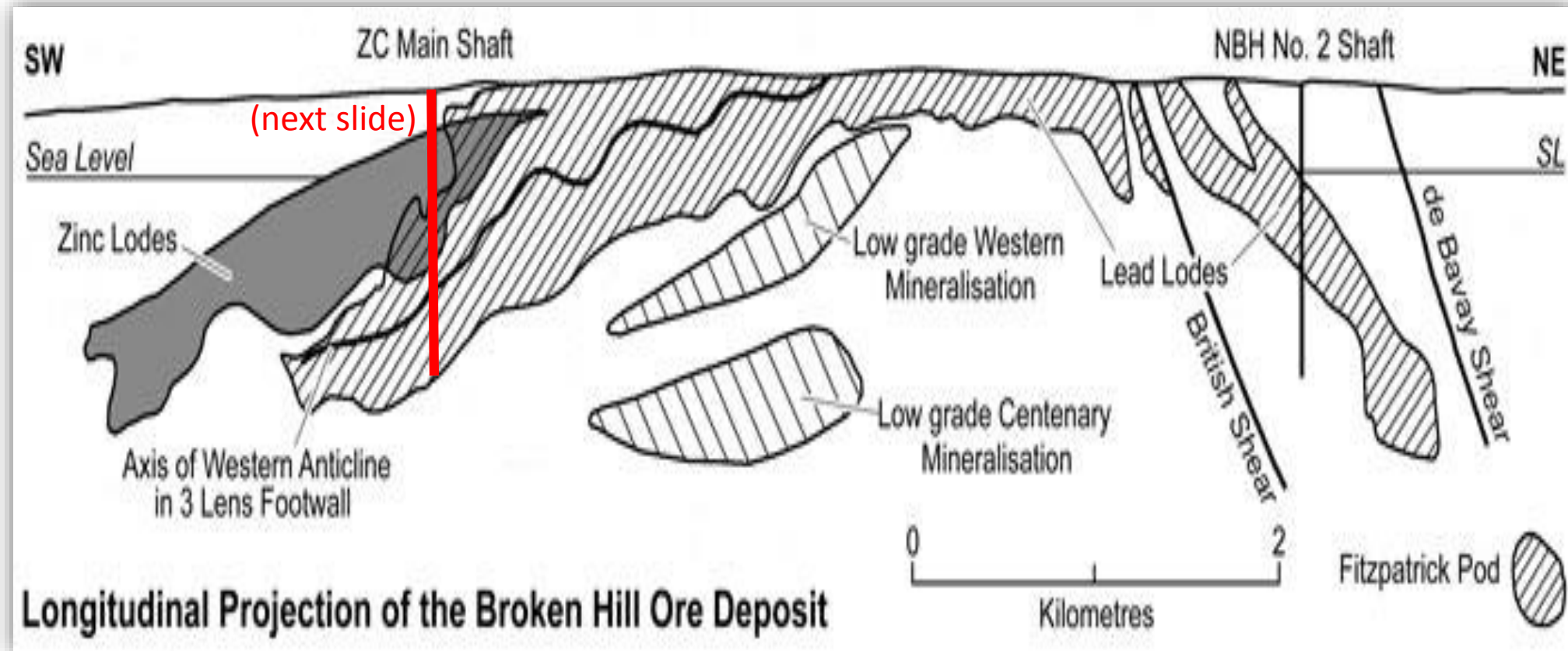
- Buried and folded during two periods; ~1Ga and 460Ma
- Metamorphism (Willyama Supergroup).



An impressive gossan....



The Broken Hill lead-silver-zinc deposit is the largest ever discovered.
A massive sulphide lode of >200mt with 50mt Pb and Zn and 20,000t Ag.



From Porter GeoConsultancy Pty Ltd

ZC Main Shaft Section

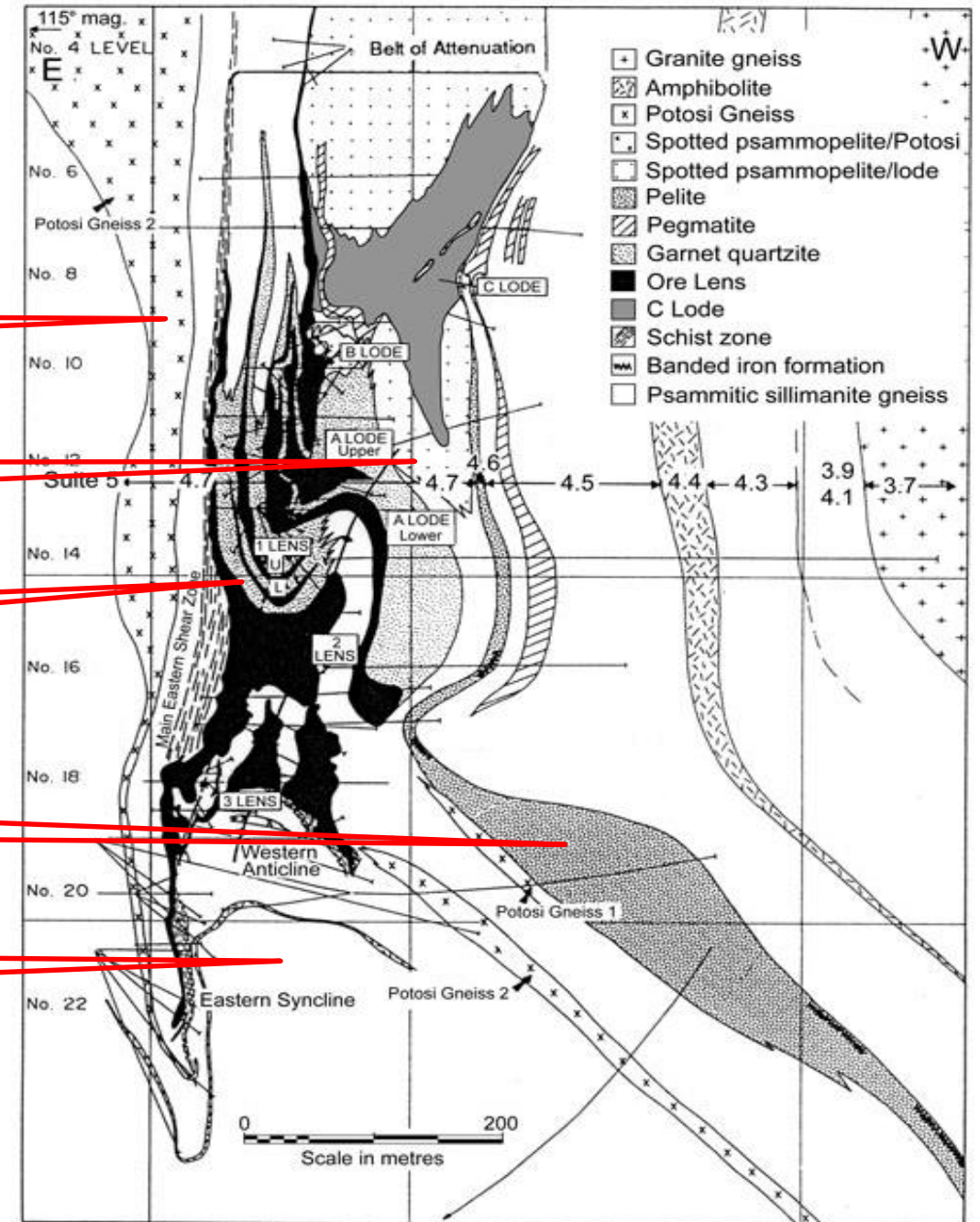
Potosi Gneiss

Spotted Psammopelite/lode

Garnet Quartzite

Pelite

Psammitic Sillimanite Gneiss



Some points of note re the BH ore body

- Broken Hill ore body (>1,500 related papers published)
- 'Deltaic' sediments deposited 1,685my ago
- Buried and folded during two periods; ~1Ga and 460Ma
- Metamorphism (Willyama Supergroup, Potosi Gneiss).
- 'Line of Load' associated with an horizon of manganiferous garnet (manganiferous chert) now garnetiferous gneiss – exhalative?
- Ore body 'exposed' ~30Ma & weathering
- >300 minerals identified
- Richest outcrop of ore occurred near "apex" where lode is narrow
- Is it a SEDEX deposit? ... or is there evidence of black smoker activity?

Models of origin

Recent proposals:

- syn-sedimentary 'exhalative' deposit (SEDEX) (e.g. Large et al);
- dominantly 'inhalative' processes (just below the seafloor), forming stacked ore lenses over a 5-6my and synchronous with, or shortly after, deposition of the host sediments (e.g. Parr et al).

Neither is consistent with the restricted range of $\delta^{34}\text{S}$ isotopic values from lode sulphides (cluster around 0) or magmatic S/Se values. These are homogeneous, mantle-like, and with minimal evidence for seawater-derived S, suggesting an igneous source for the sulphur in the deposit.

What is a SEDEX deposit?

©2005 Society of Economic Geologists, Inc.
Economic Geology 100th Anniversary Volume
pp. 931-963



Stratiform and Strata-Bound Zn-Pb-Ag Deposits in Proterozoic Sedimentary Basins, Northern Australia

ROSS R. LARGE,[†] STUART W. BULL, PETER J. MCGOLDRICK, STEVE WALTERS,

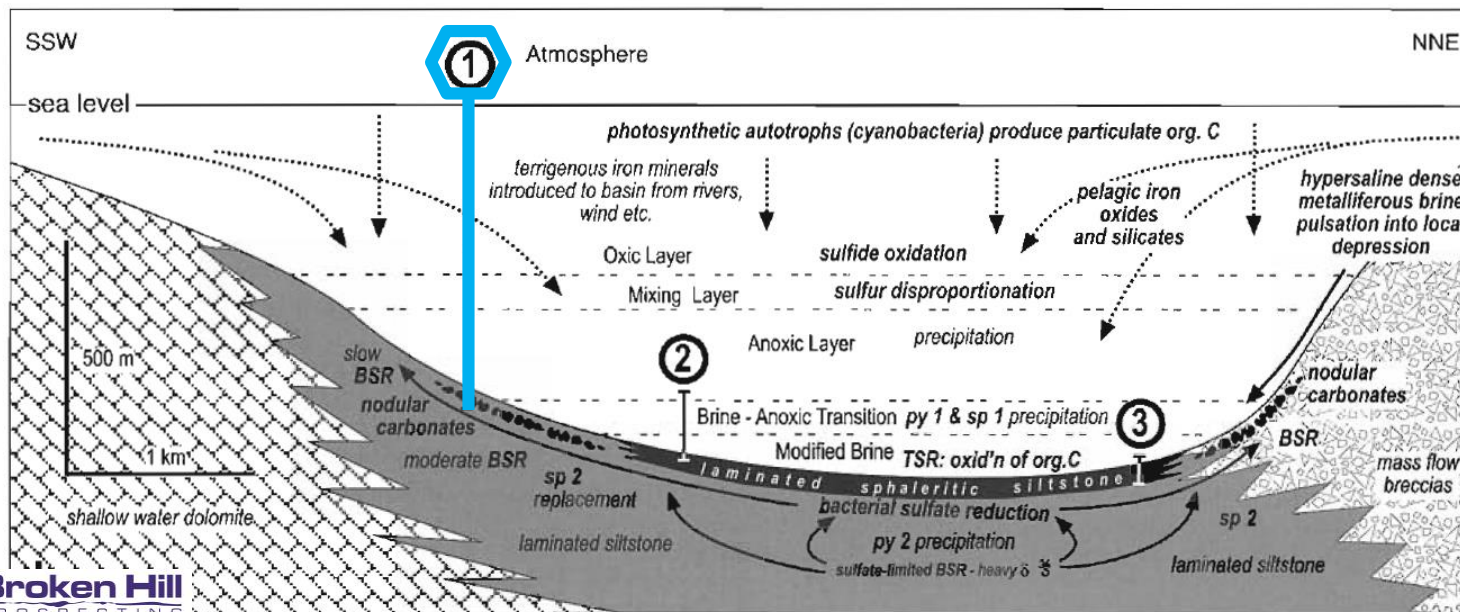
Centre for Ore Deposit Research, University of Tasmania, Private Bag 79, Hobart, Tasmania, Australia 7001

GEOFF M. DERRICK,

P.O. Box 184, Corinda, Queensland, Australia 4075

AND GRAHAM R. CARR

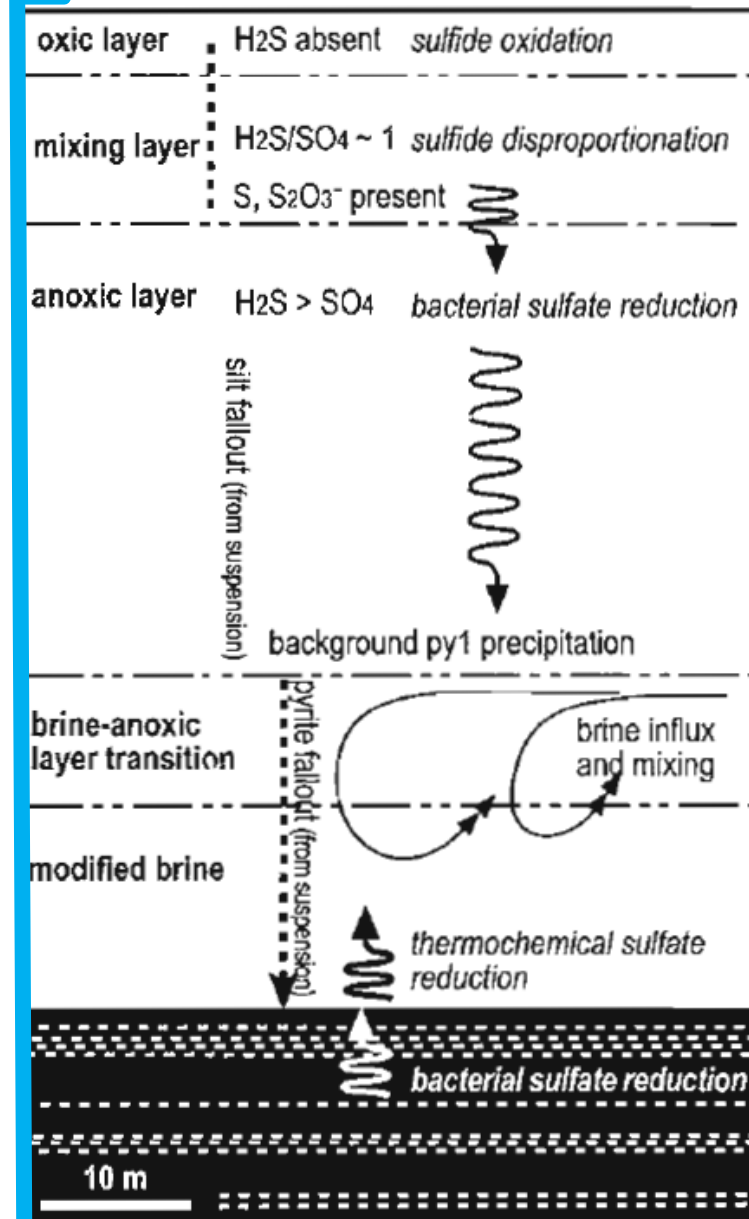
CSIRO Exploration and Mining, P.O. Box 136, North Ryde, NSW, Australia 1670



Broken Hill
PROSPECTING

1

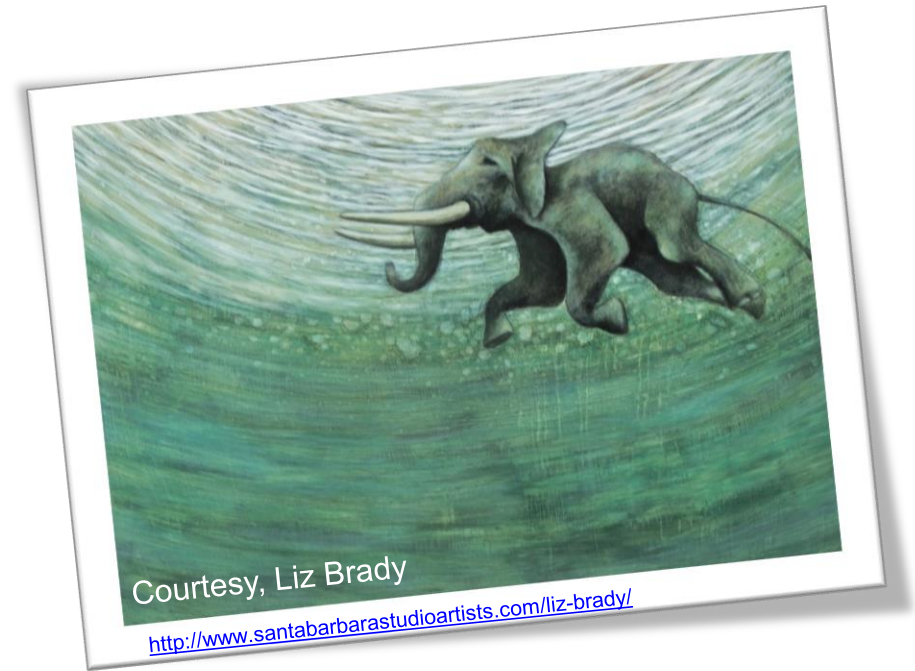
Brine Influx and Pelagic Sedimentation



How does the Broken Hill deposit shape up as SEDEX?

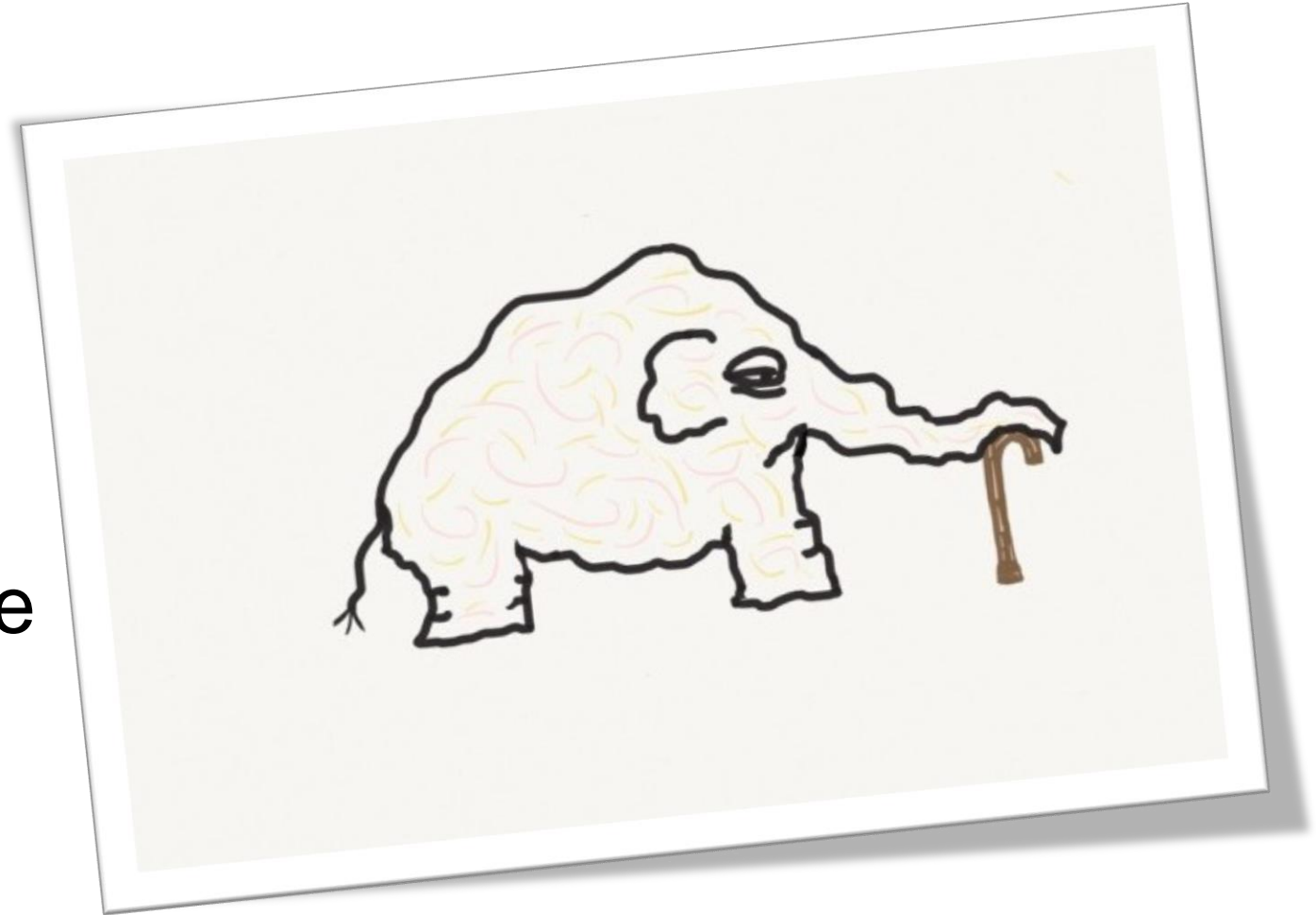
Six main features (very broadly) include:

- Age (**YES**)
- Lead, zinc, silver mineralisation (**YES**)
- Structural setting – rift/graben, active fault, marine basin (**? YES**)
- Assemblage of well laminated siltstones, fine grained, graded bedding (**?**)
- Formed from oxidised (reduced, sulphur poor) fluids (**?**)
- Sulphate reducing bacteria produced H_2S to allow metal formation (**?**)



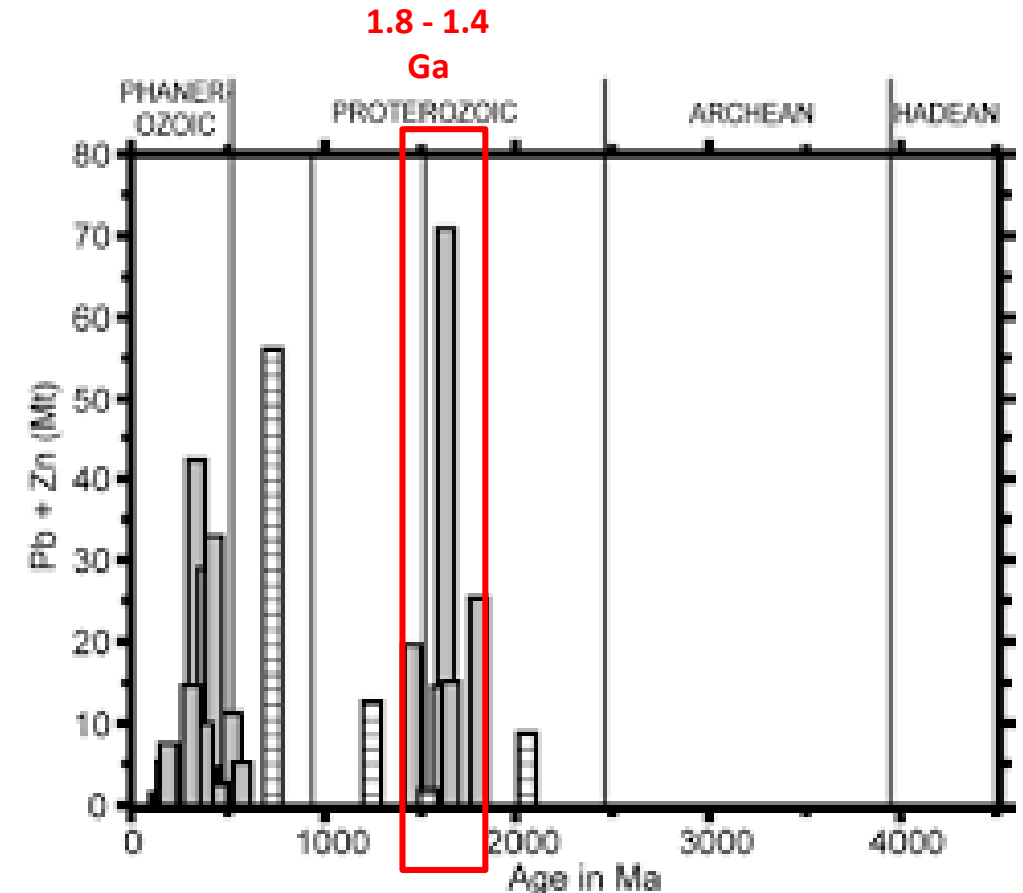
BH Ore body - Environment of formation

- Age
- Location
- Atmosphere
- Hydrosphere
- Environment, climate
- What about cobalt?



Age of BH and 'SEDEX-type' Deposits

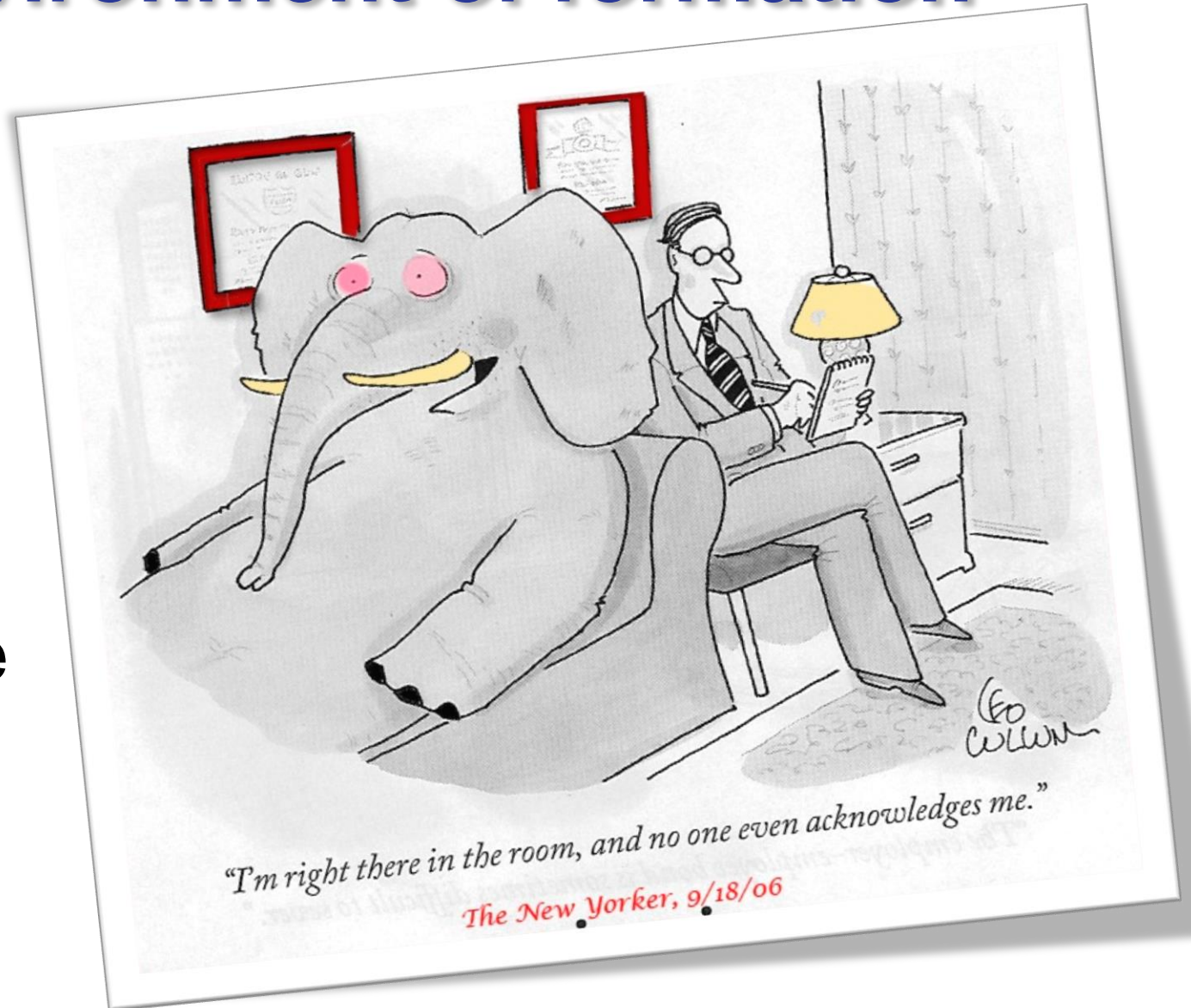
- Age of BH host rock is 1.685Ga (Page et al, 2005)
- Before 2.4Ga the earth's atmosphere/hydrosphere was reduced
- Snowball earth ~2.4-2.2Ga
- 2.4-1.8Ga oxidation
- Did most large SEDEX deposits form after 1.8Ga (due to changes in ocean chemistry?)
- Changes first occurred in restricted basins



Pb+Zn vs age of SEDEX deposits
Horizontal bars = uncertain age
(from Leach et al, 2005)

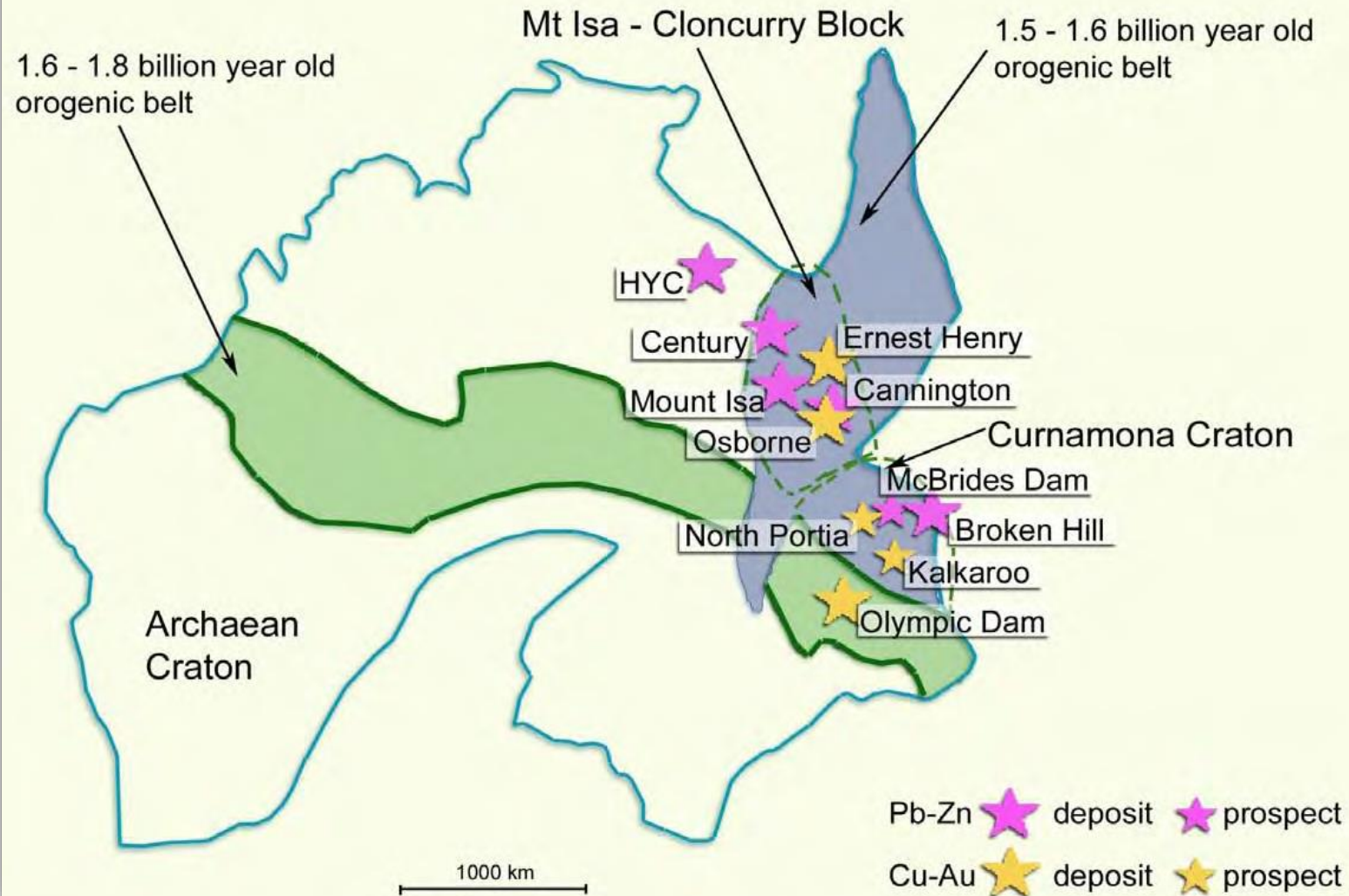
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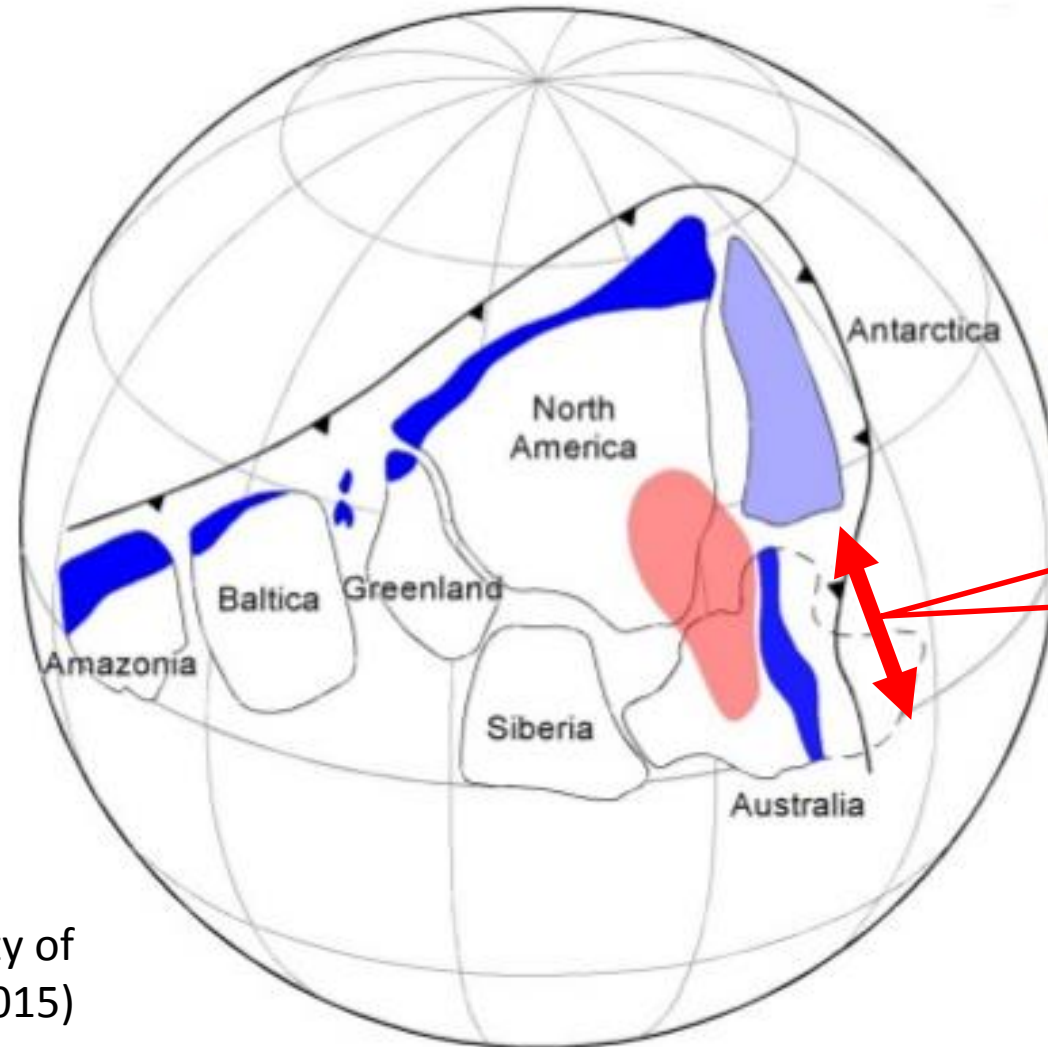
Located in 'cluster' of massive Pb-Zn-Ag deposits

SOURCES: David Giles (UofA), Havilah Resources NL



Location – lower latitude, continental margin

Early
Paleoproterozoic
global
reconstruction



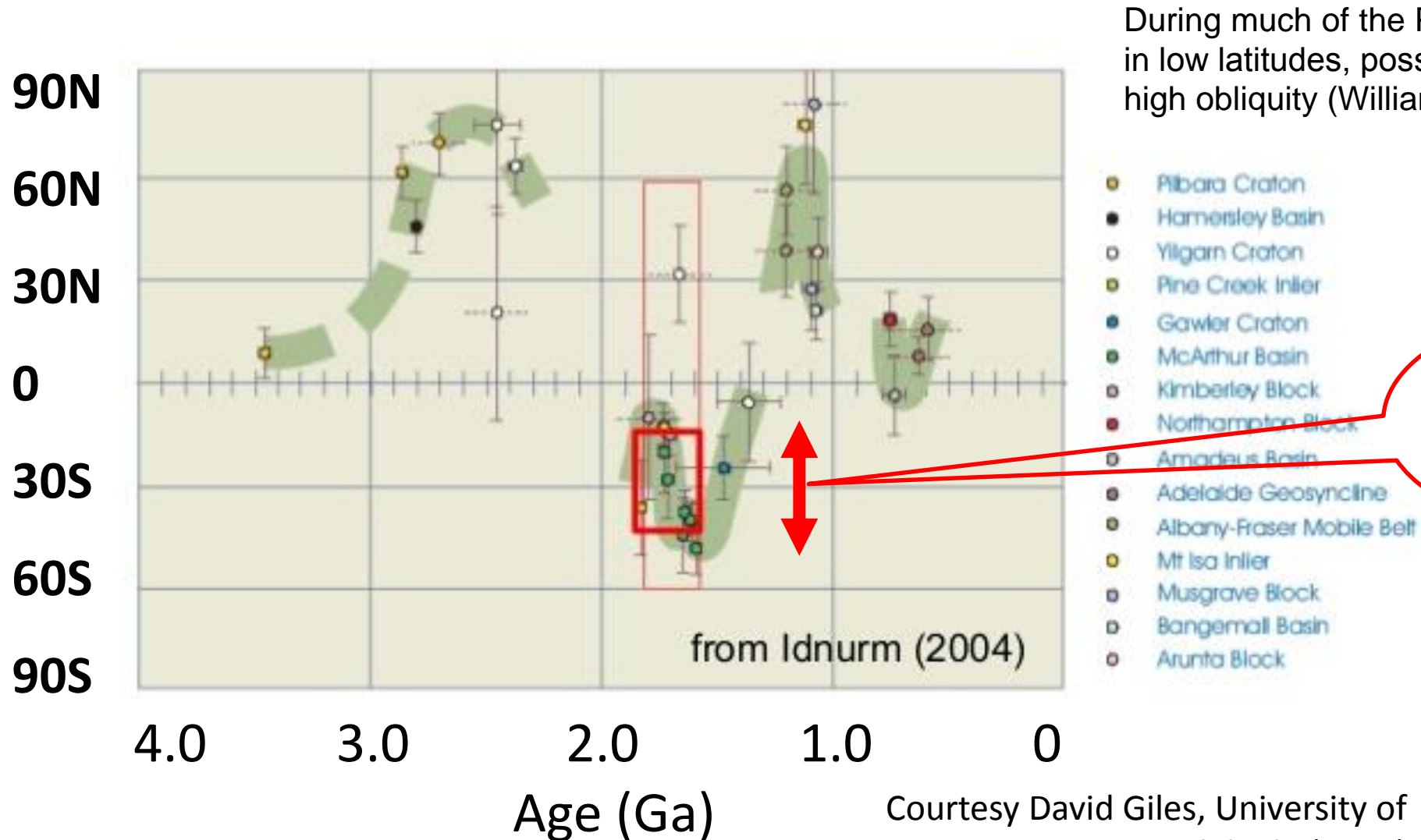
Widespread but
lower latitudes
(0-25°?)

Lower than Australia is
at present (12-42°)

Courtesy David Giles, University of
Adelaide (2015)

or.....

Location – broad latitude means season change

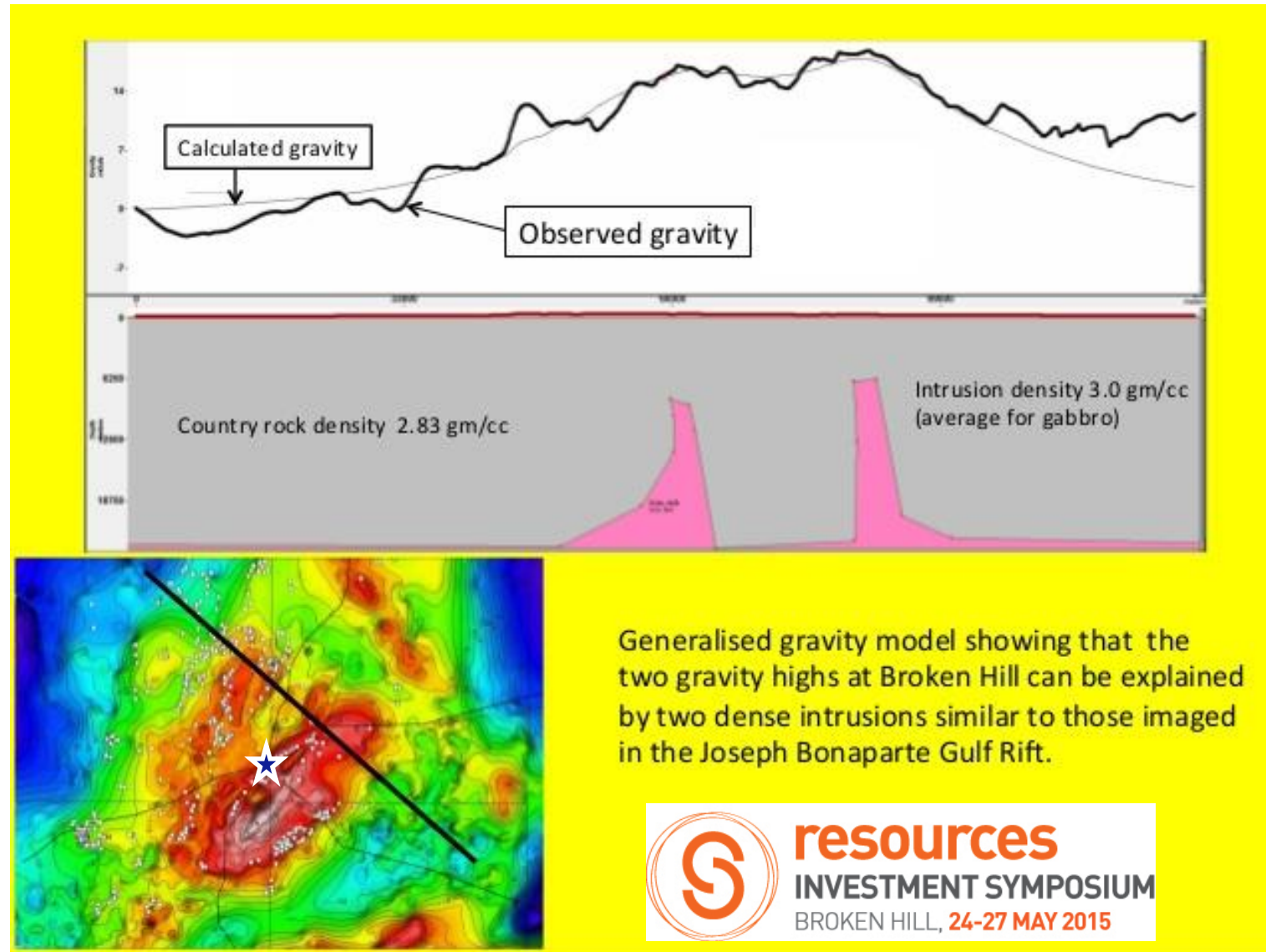


**Widespread
latitudes (5-50°)**

Broader than Australia
is at present (12-42°)

Courtesy David Giles, University of
Adelaide (2015)

Tectonics – early rift structure? (Peter Gunn)



BH Ore body - Environment of formation

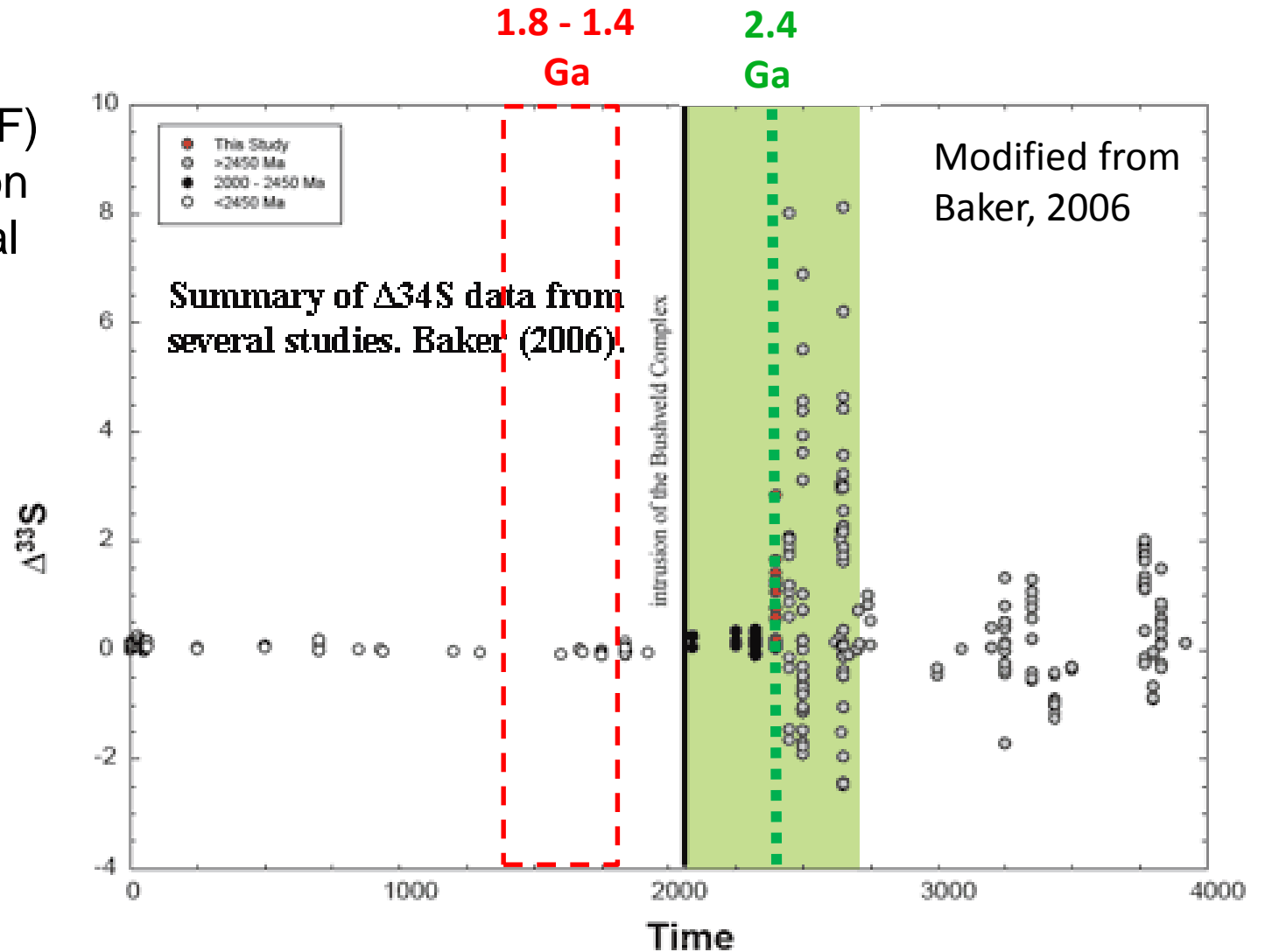
- Age
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Atmosphere – sulphur isotopes signal O₂ at 2.4Ga

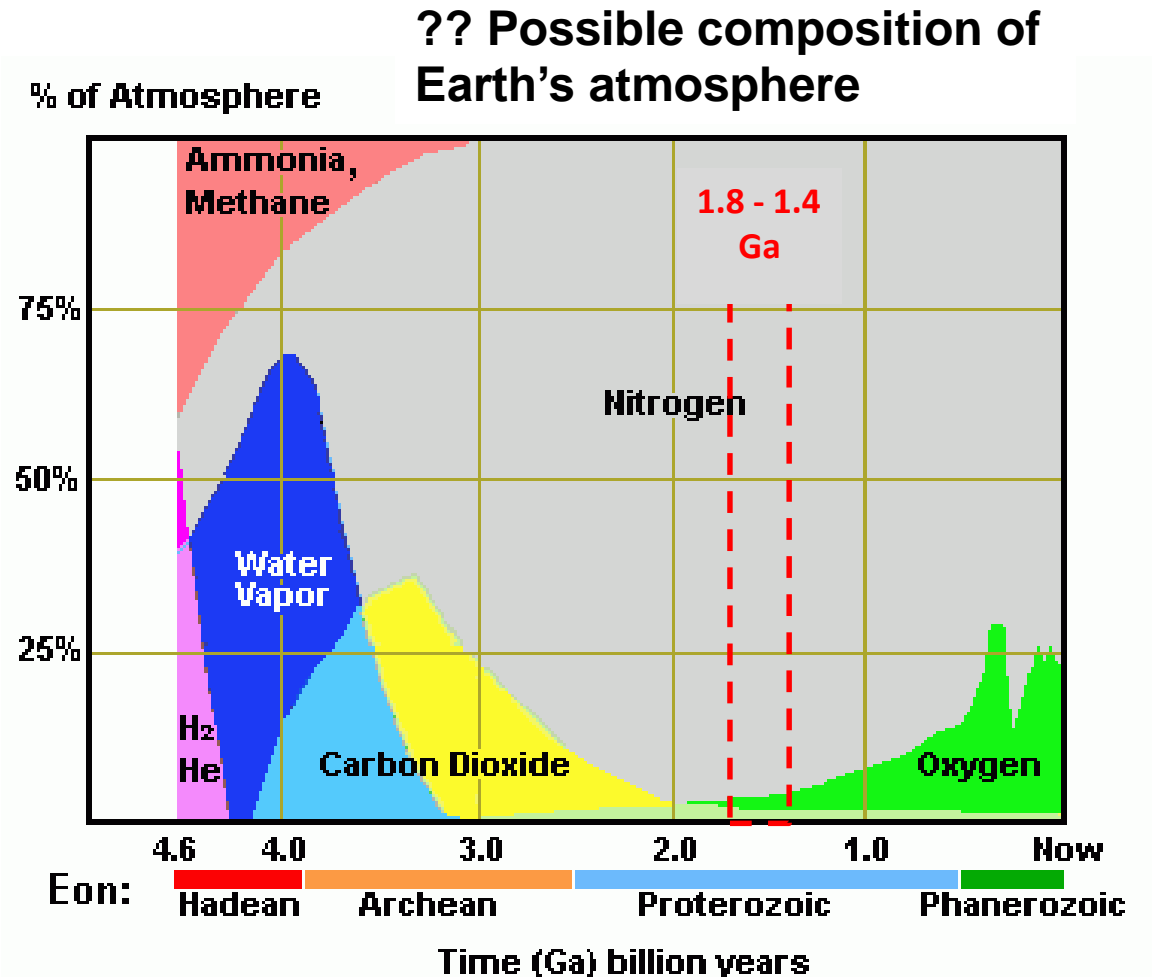
- Mass-independent fractionation (MIF) reactions are caused by UV radiation
- They are high energy photochemical reactions
- UV light must penetrate the atmosphere and react with atmospheric sulphur in an O₂ free atmosphere

When there is atmospheric oxygen, sulphur is oxidised to sulphate & rain carries sulphate to sea (acid rain)



Atmosphere 'composition' has changed

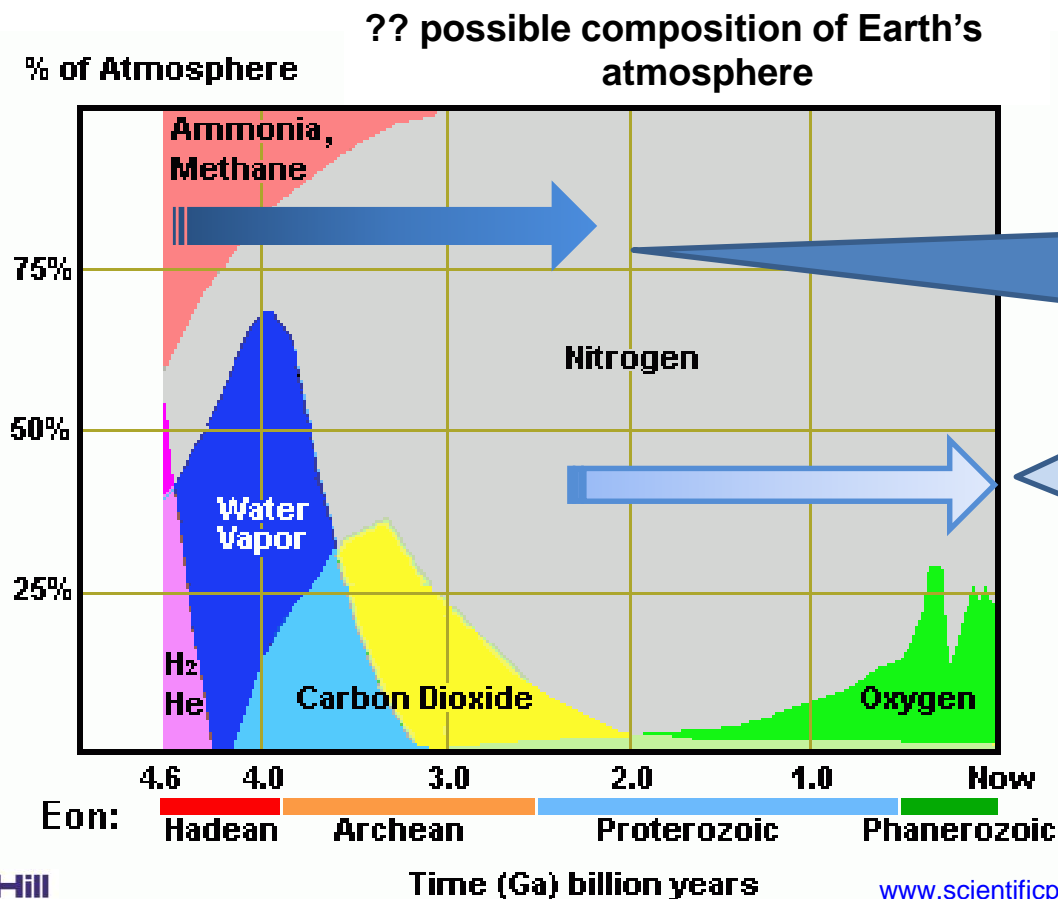
- early Earth atmosphere was denser than present.
- because water, CO₂, methane, ammonia and sulphur contents were much higher.
- because of Earth's denser air only relatively large meteors could reach ground - many would burn up.



www.scientificpsychic.com/etc/timeline/atmosphere-composition.html

Lessons from Venus

- Venus has a dense atmosphere (96% CO₂)
- As a result very few meteorites impact the surface (these burn up during entry)
- 'Vaporised' meteorites are added to the Venus atmosphere and elements are widely distributed
- Early Earth's atmosphere was much denser than present



Because of early Earth's **denser air** only relatively large meteors could reach the ground surface. Most would burn up in the denser atmosphere and contribute to widespread element distribution.

Most impact structures are younger than 2.5Ga. Relatively **thin air** results in less meteorite burn-up, less elemental/metal contribution to the atmosphere.

Did meteorites introduce appreciable metals from space?

- ~200-300 tons of extraterrestrial material enter the Earth's atmosphere each day.
- Over 'life of earth' this is ~ 350,000 - 500,000 billion tons.
- Micrometeorite "impacts" occur millions of times daily.
- Annual influx weight of micrometeorites estimates between >14mtpa to 10,000tpa.

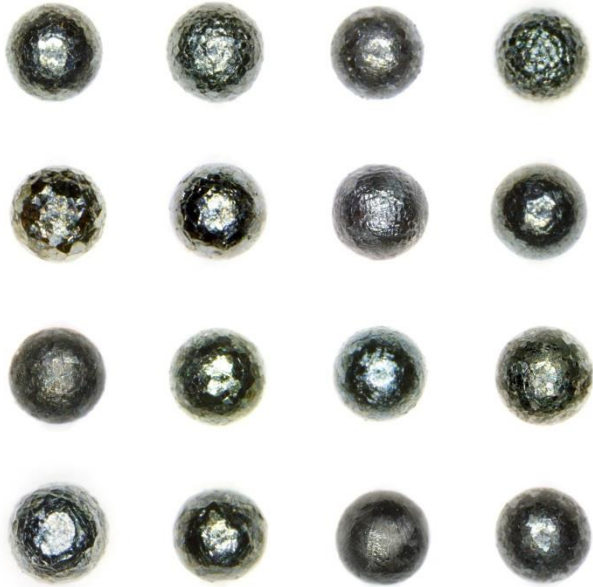


Image courtesy: Jon Larsen, 2011



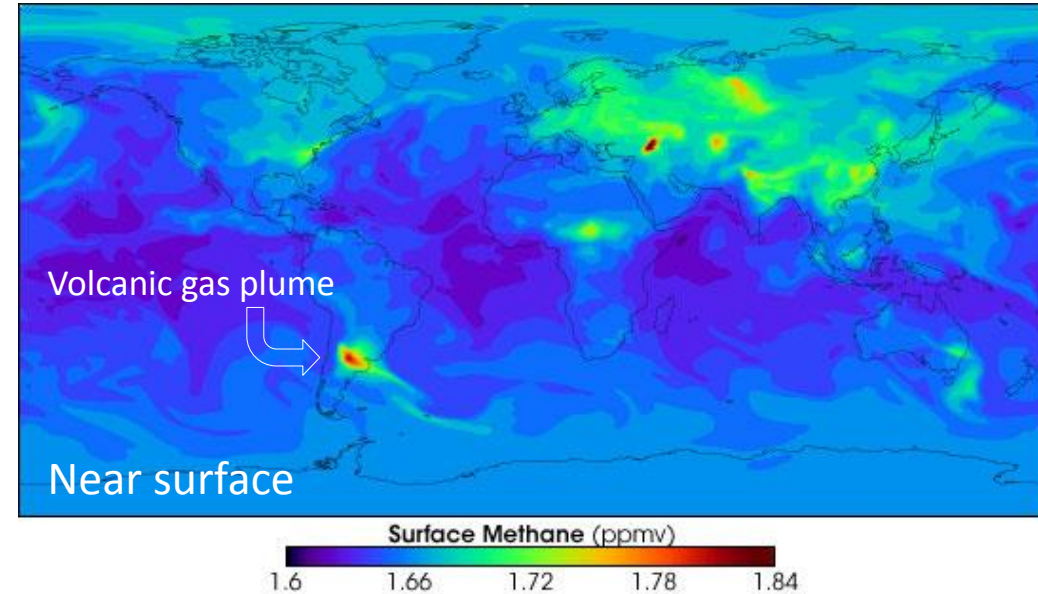
In a denser (higher CO₂) pre-Paleoproterozoic atmosphere many micrometeorites would burn to meteorite smoke and cosmic dust

Ryan Thompson, 2012

http://geologicnow.com/8_Thompson.php#

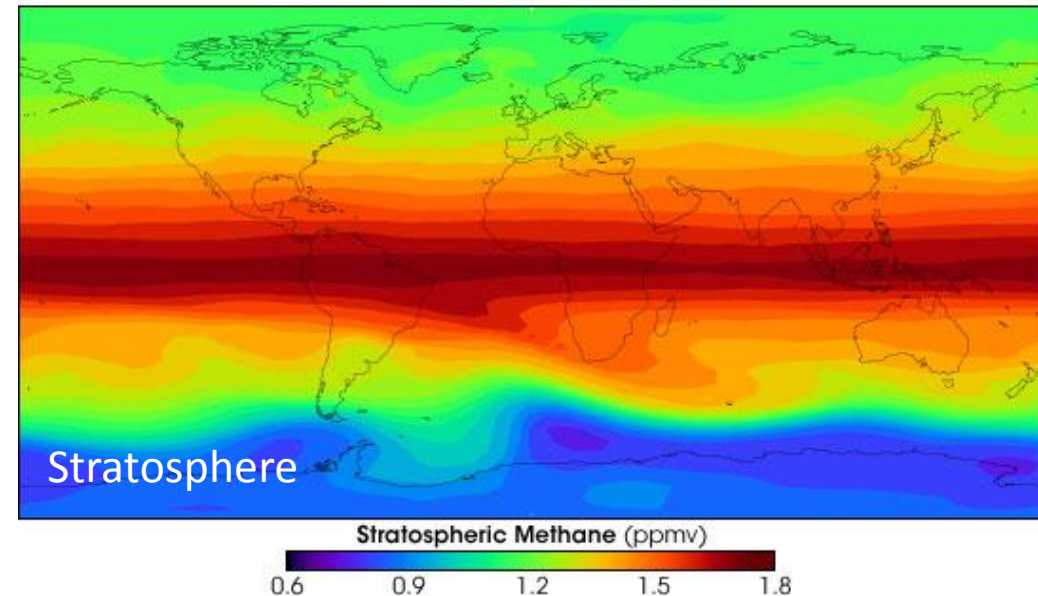
Atmospheric gas distribution is not uniform (e.g. methane)

Distribution of methane
near surface (top)



stratosphere (bottom)

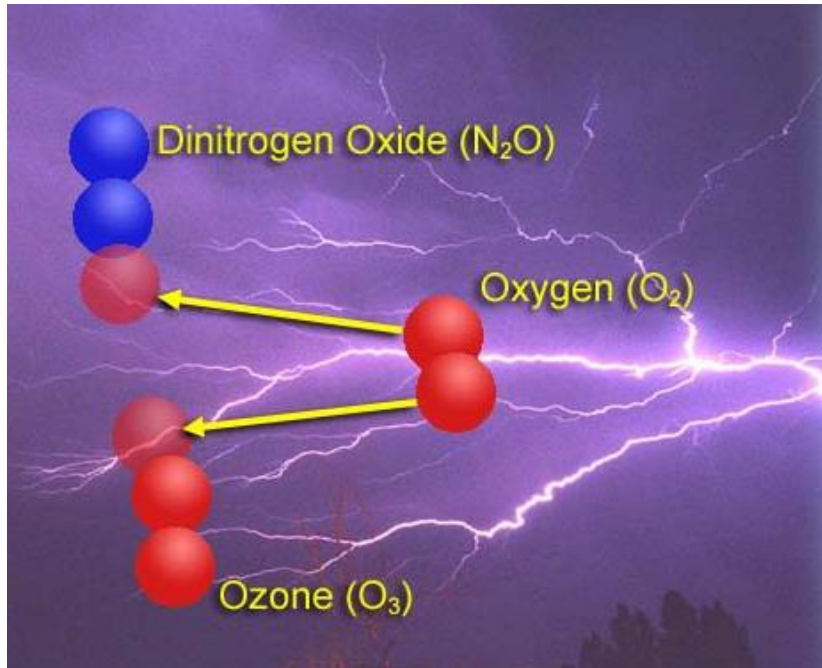
Methane is created near
ground level and is carried into
the stratosphere by rising air in
lower latitudes.



Source; NASA

Paleoproterozoic Earth – lightning was important!

- Lightning produces ozone – first (pre-life) contribution of oxygen
- Main source of fixing nitrogen in early atmosphere
- Main screen for damaging UV light



A typical lightning flash measures about 300 million volts and 30,000 amps

Today 50-100 lightning strikes occur every second (5-10 million per day)

In the Archean & Paleoproterozoic lightning strikes were much more frequent

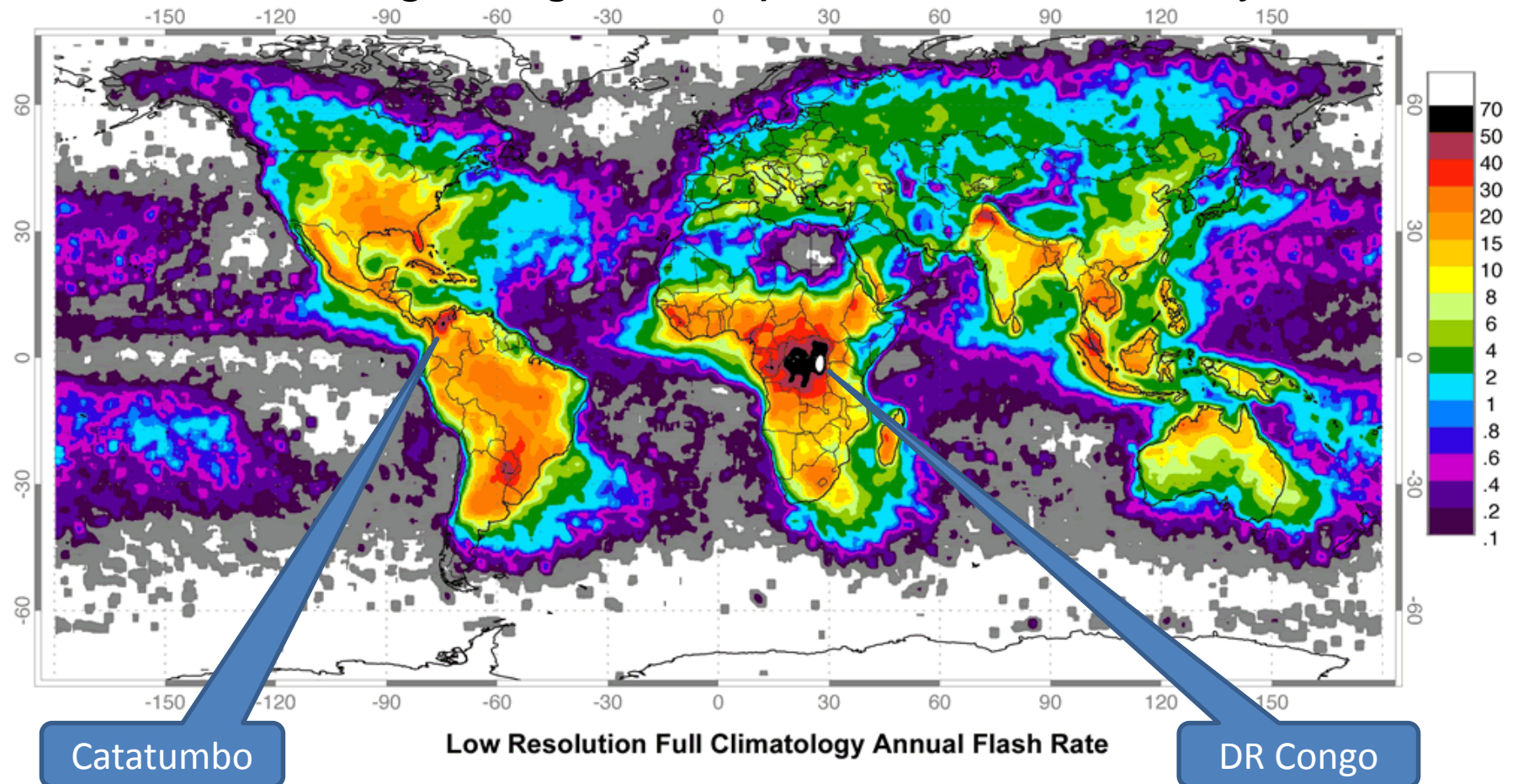
Lightning flash discharges coalesce and get stronger, creating electromagnetic waves circling around Earth, to create a beating pulse between the ground and the lower ionosphere at about 85km (Schumann Resonance).

Lightning strikes are not uniform and most are on land

Number of lightning strikes per kilometre² each year

- Few strikes occur near poles
- Most strikes are over land

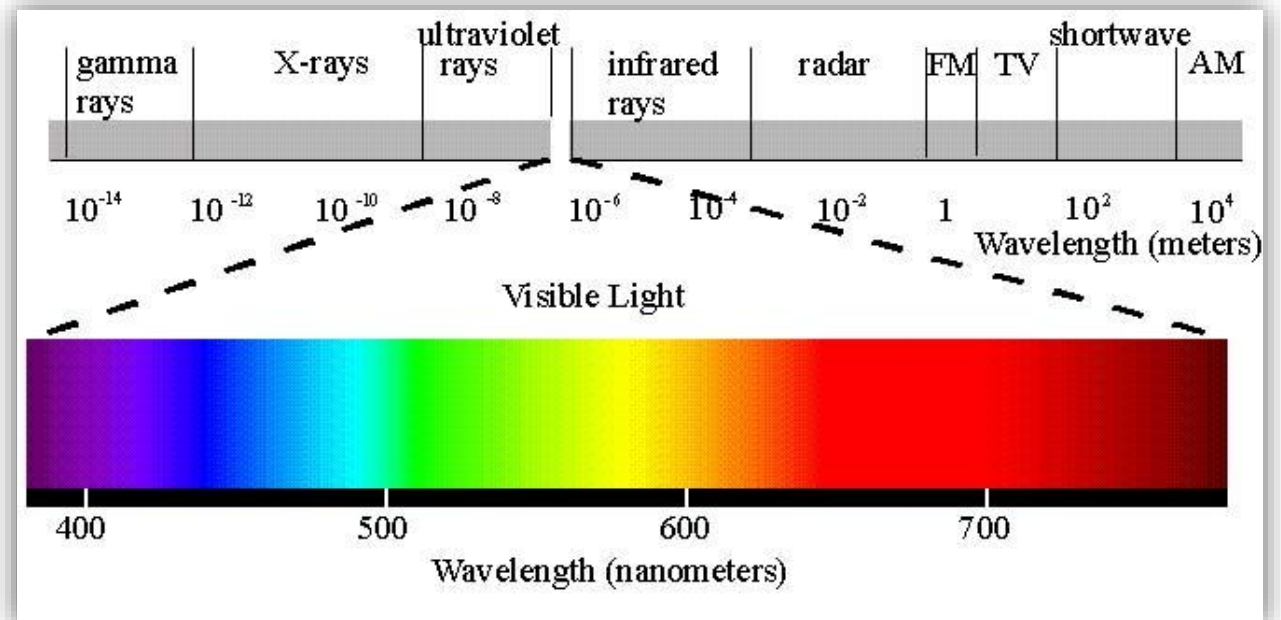
Lightning on Paleoproterozoic earth would also have had more impact over land or shallow water near coasts.



Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments.

Lightning produces ozone....

- Ozone filters UV light & without the ozone layer to absorb UV light much life as we know it would die.
 - Micronised and nano-scale zinc provides strong protection against damage from UV light (eg sun screens)
 - Gamma radiation is electromagnetic radiation of an extremely high frequency (high-energy photons) and is biologically hazardous.
 - Because of lead's density and large number of electrons it is well suited to blocking gamma & X-rays
-
- Gamma rays, X-rays & UV light kill most microbes.
 - Did Zn (+Pb) provide sunscreen 'slip slop slap' protection for some ancient microbes?
 - Did some early microbes evolve to use metals as 'protection' from radiation in a low ozone atmosphere?



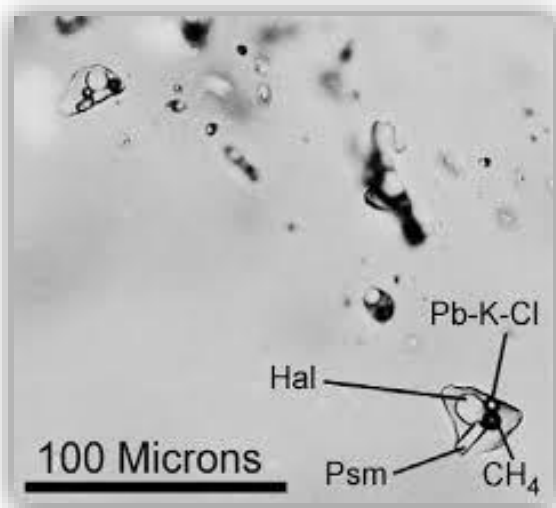
BH Ore body - Environment of formation

- Age
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Clues from inclusions

- High salinity fluid inclusions from Broken Hill (and Cannington) ore were analysed by PIXE (proton-induced X-ray emission) and LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry).
- High Pb (>1%) and Zn (>1000 ppm) and Pb/Zn ratios much higher than most crustal brines.
- Laser Raman studies showed occurrence of methane.
- PIXE showed that Pb is in a Pb-K-Cl solid & Zn is in the liquid phase.
- The inclusions have very low sulphur contents.



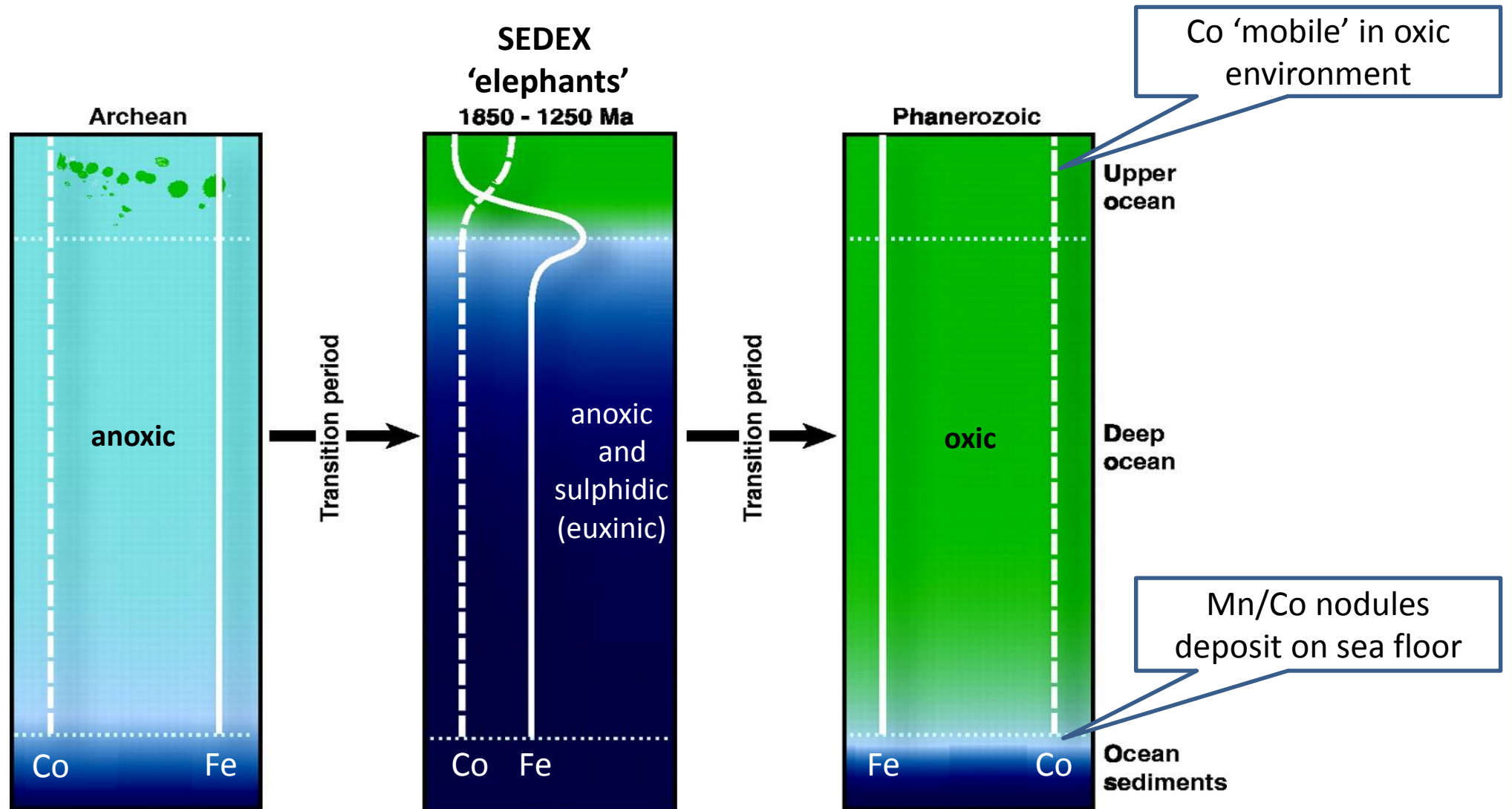
Williams et al (2005); Lead and zinc-rich fluid inclusions in Broken Hill-type deposits: Fractionates from sulphide-rich melts or consequences of exotic fluid infiltration?

http://link.springer.com/chapter/10.1007/3-540-27946-6_219#page-1

Early oceans had more water!

- Since earth formed **oceans have lost about 25%** of their original mass.
- Water in the oceans was split into hydrogen, deuterium (D or $2H$, aka heavy hydrogen) by methanogenesis. Both are low-density gases which rose into the atmosphere and eventually dissipated into space.
- The atmosphere became richer in oxygen which reacts with both H and D to produce water which falls as precipitation.
- At present the vast bulk of the water on Earth is held in a closed system that prevents the planet from drying.

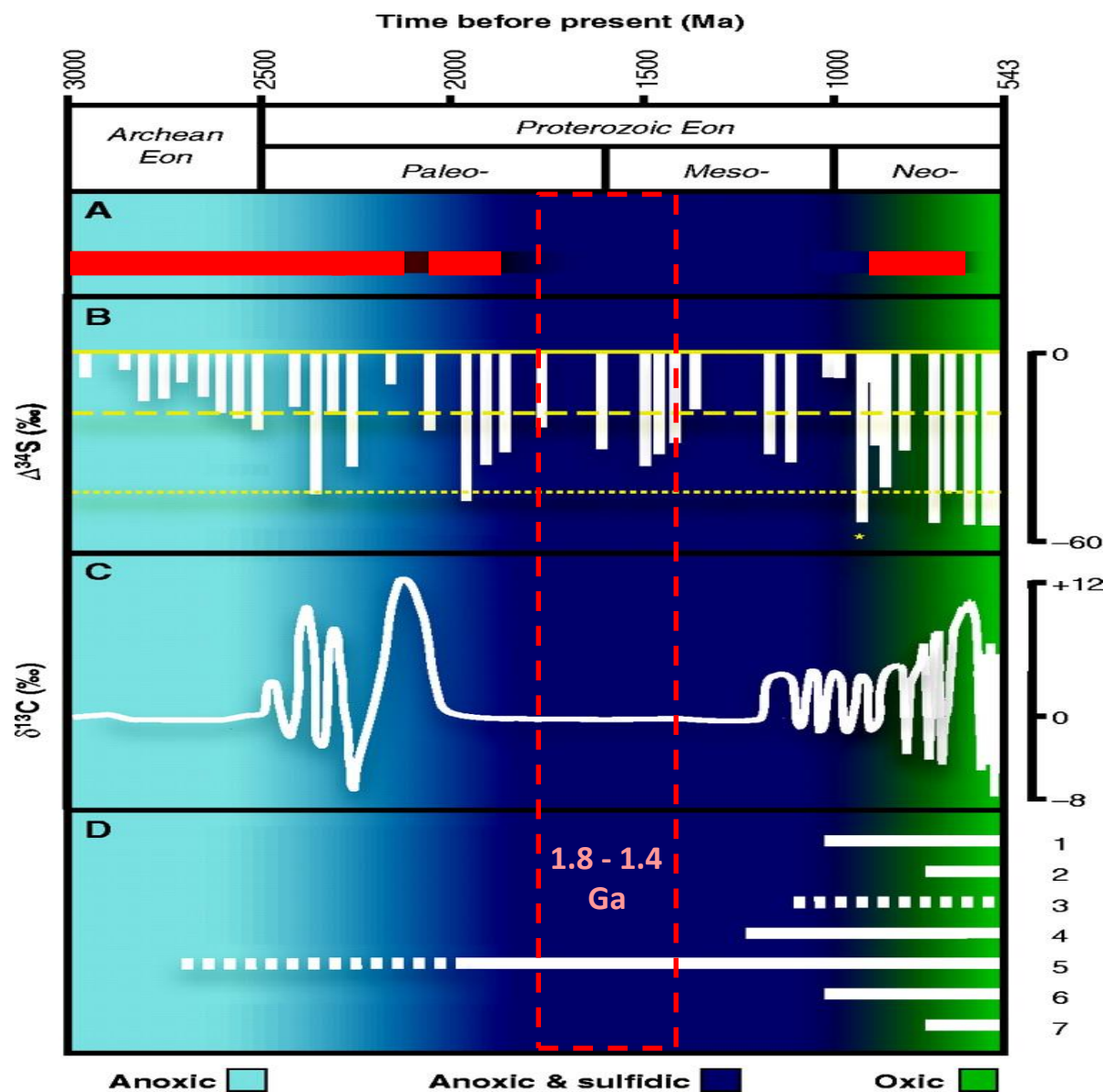
Changing water chemistry over time



Modified after A D Anbar, A H Knoll, Science 2002;297:1137-1142

Don Canfield (1998)

http://ebme.marine.rutgers.edu/HistoryEarthSystems/HistEarthSystems_Fall2008/Week5b/Canfield_Nature_1998.pdf



Banded iron formation

difference in $\delta^{34}\text{S}$
Between coeval marine sulphides
and sulfates

Range of values of $\delta^{13}\text{C}_{\text{carb}}$

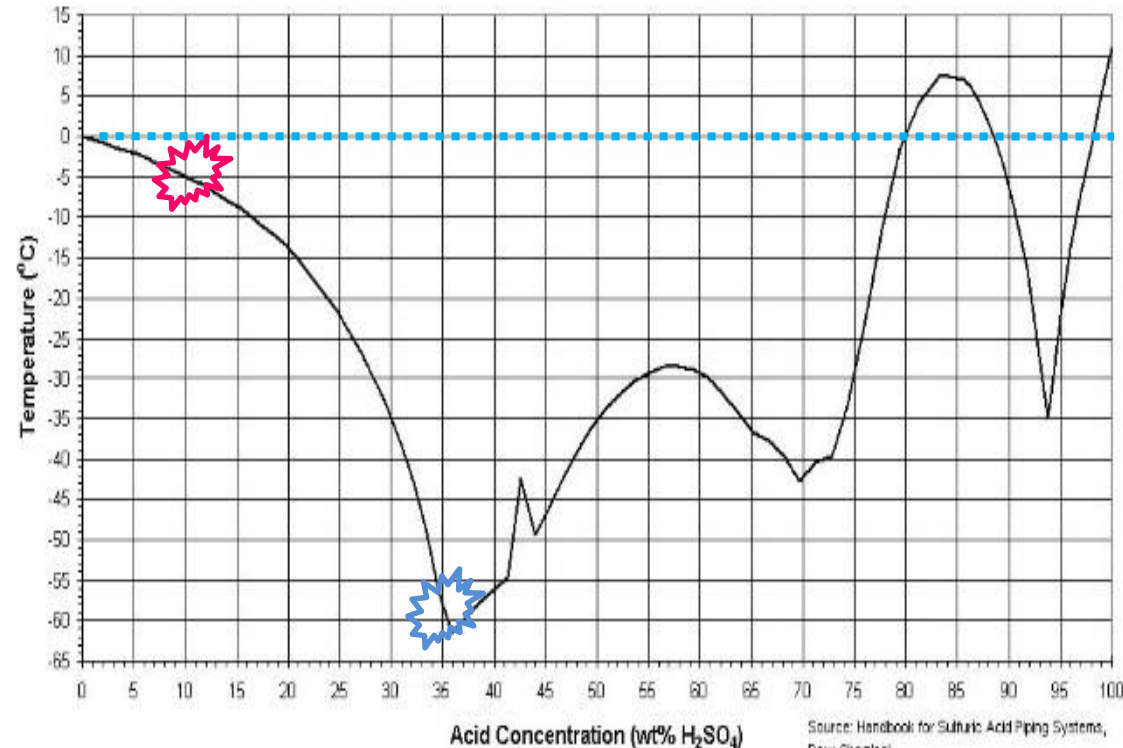
Eukaryotic evolution
(Note: significant algae, cellulose etc
only in last 1000 Ma)

Anoxic-oxic transitions can increase metal solubility

- **Anoxic-oxic transitions may markedly increase the solubility of some metals in seawater.**
- **Suboxic conditions lead to the reductive dissolution of Fe–Mn oxyhydroxides, increasing the concentration of Fe and Mn in water by orders of magnitude.** Concentration of some elements (e.g. Pb, Zn, As, Mo, REE) are controlled by absorptive scavenging and co-deposition with these oxyhydroxides; and as a consequence of reductive dissolution of oxyhydroxides, they increase significantly in concentration.
- **Oxic to anoxic oceanic shifts can trigger massive changes in the cycling of Fe–Mn oxyhydroxides sequestered in sub-seafloor sediments** and trigger a benthic flux of Fe, Mn and associated trace elements from the sediments into the anoxic water.
- **Increases in metal deposition can be made by encroachment of metal-enriched, oxygen-depleted oceanic waters into oxic environments.** After a redox front, perhaps moving into shallow(?) water, metals can be re-oxidized and precipitated at the redox interface between the anoxic water mass and local oxic shallow water.

Higher H_2SO_4 means less ice

Freezing points of sulphuric acid



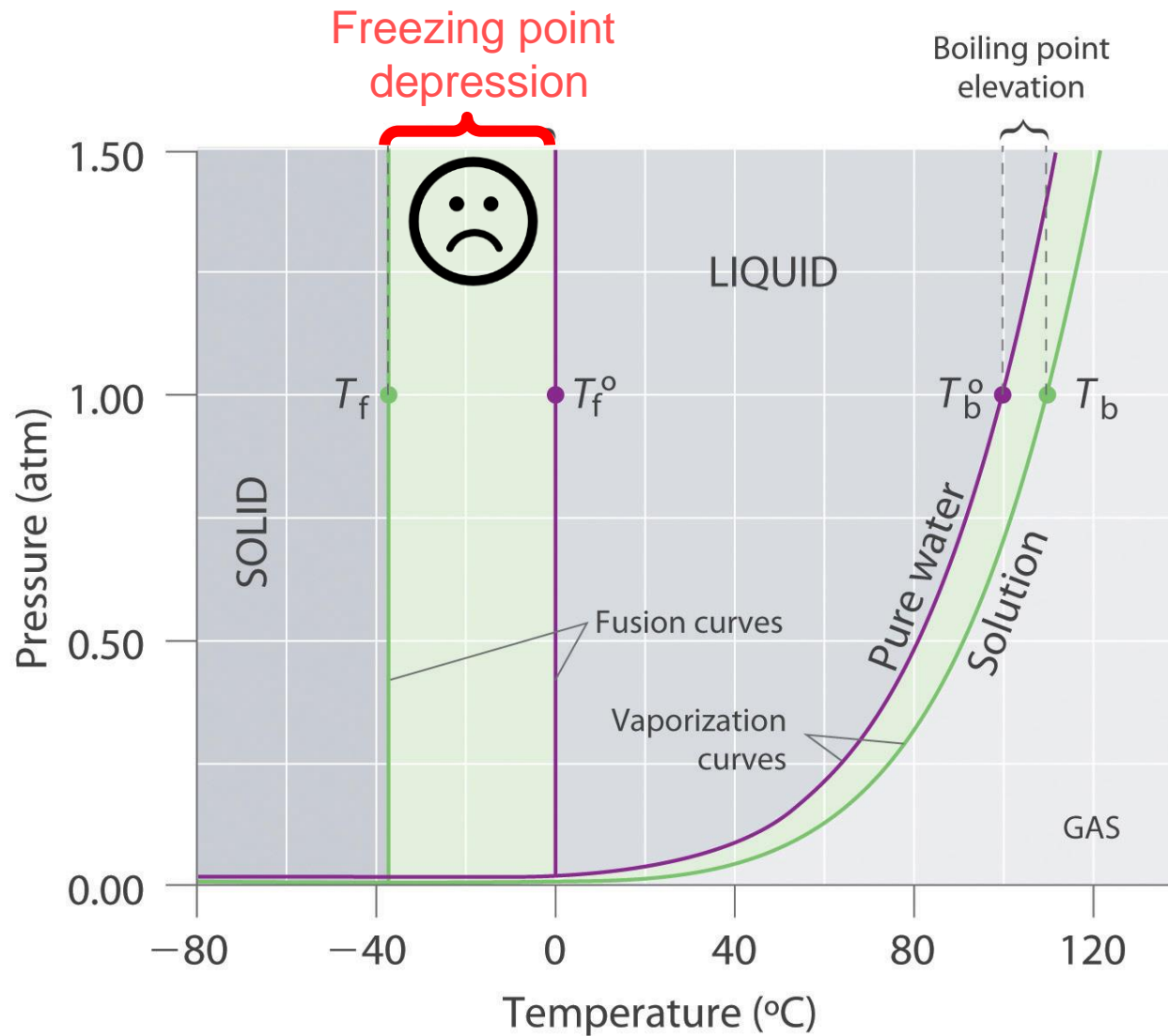
Sulphuric acid in solution with water causes significant freezing point depression down to;

-5°C at 10% H_2SO_4

-59°C at 36% H_2SO_4

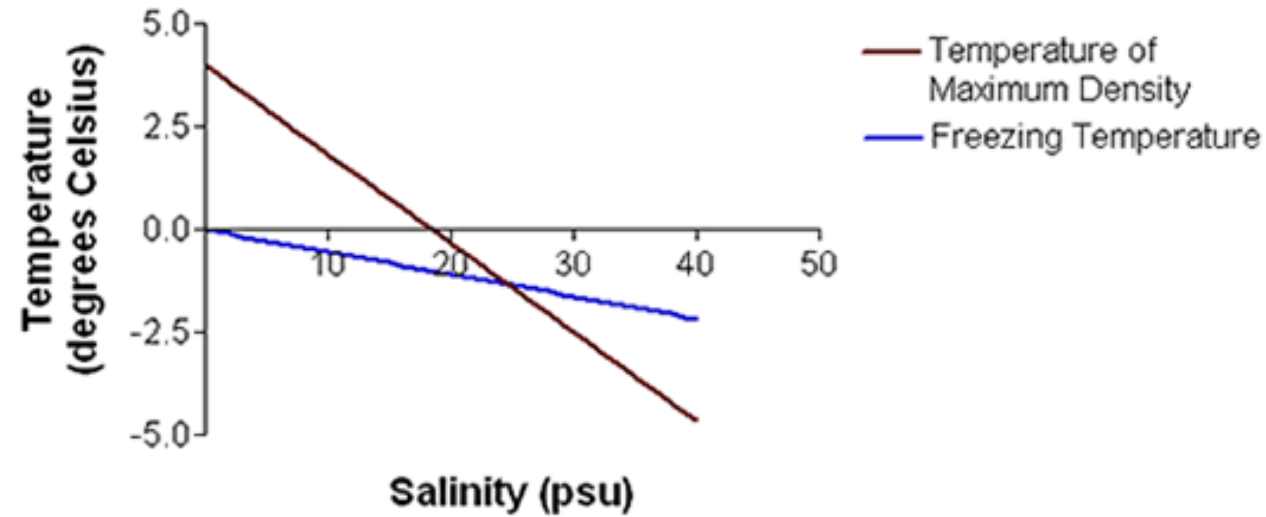
Increasing acidity lowers temperature of ice/snow formation

Higher solute content means less ice



Changes to the freezing point & boiling point of a solution depend on the number of solute particles rather than the type of particles (**colligative properties**)

Higher salinity means less ice



Sea ice required lower temperatures to form in salty Paleoproterozoic waters. Salt in ocean water causes water density to increase as it nears freezing point and cold ocean water tends to sink. As a result, salty sea ice forms slowly, compared to freshwater ice, because salt water sinks away from the cold surface before it cools enough to freeze.

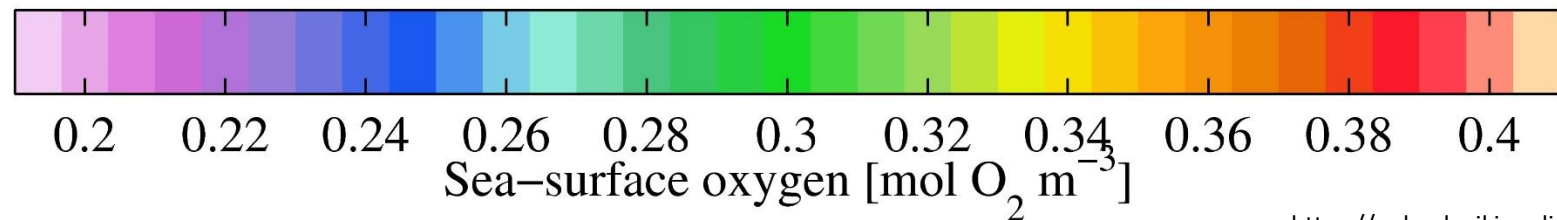
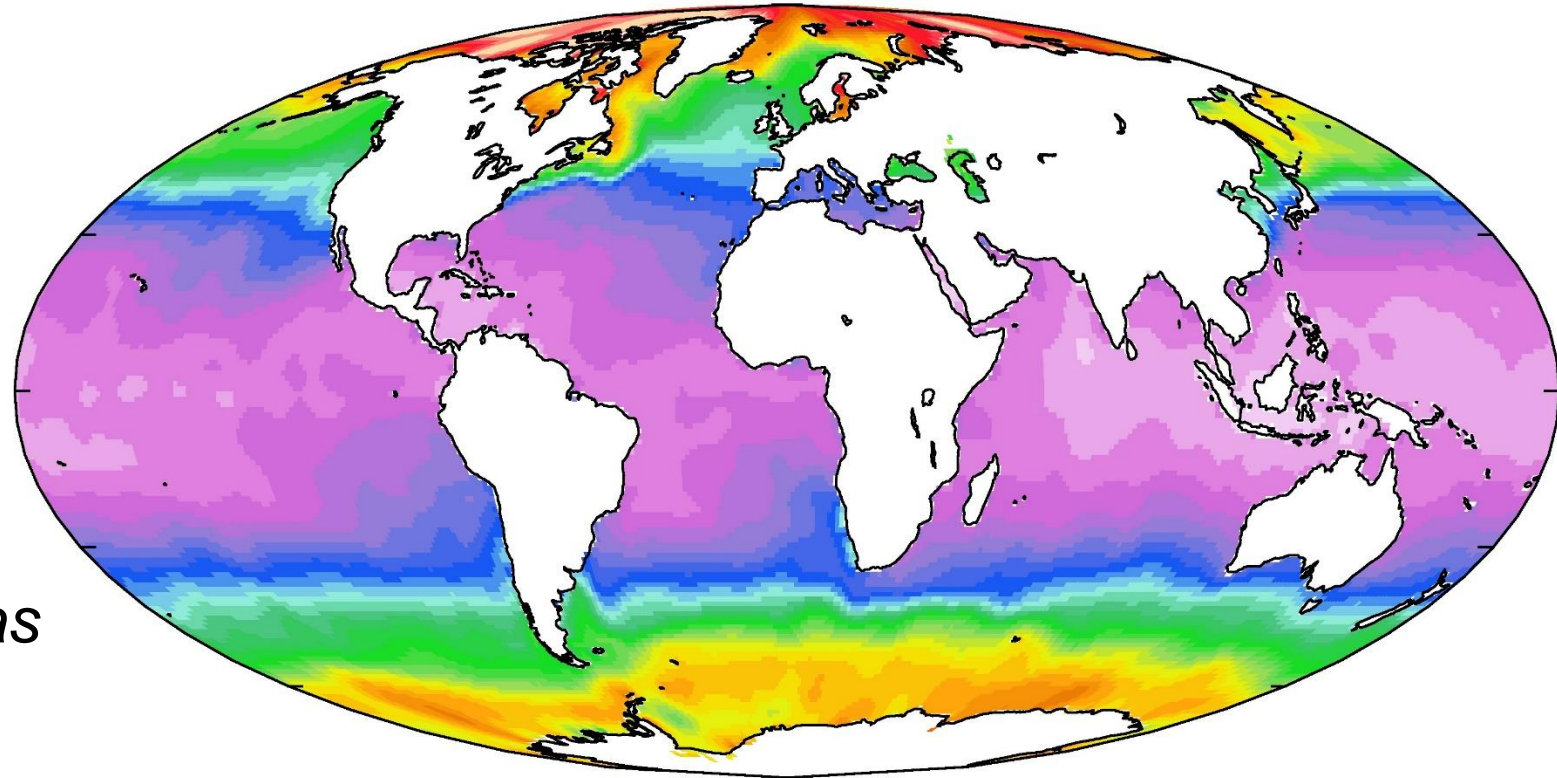
Why saline? Brinicles under sea ice increase salinity as well as dissolved metal contents

- 'Sea stalactites' form when sinking brine is so cold it causes the seawater to freeze around it and when the brine sinks from the frozen ice it falls to the seabed because it is more dense than seawater.
- **In brinicles the salt concentration of trapped brine increases by ~10% every 1°C of cooling.... As well as every other chemical compound found in the seawater.**



Colder water contains more oxygen

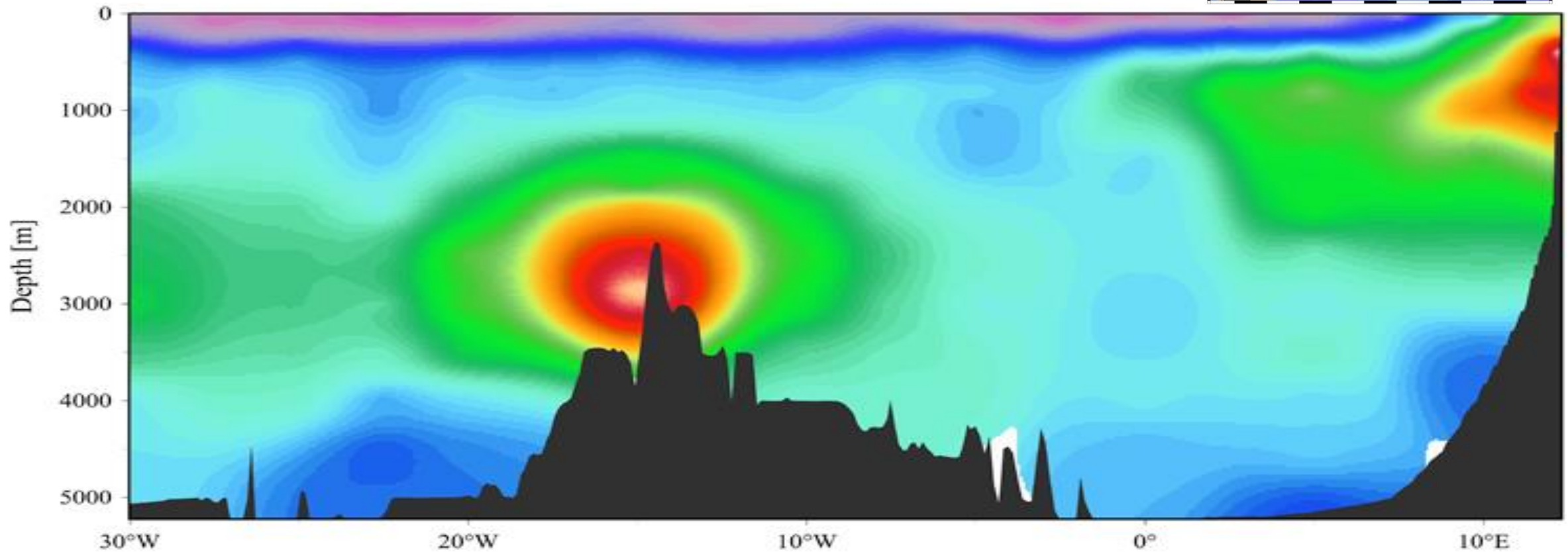
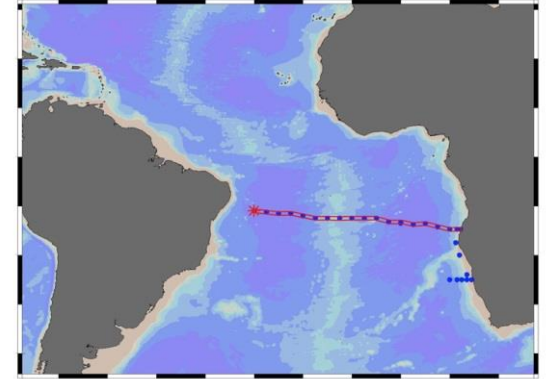
About twice the oxygen in polar seas compared with equatorial waters



Fe content in oceans can vary...

A plume of iron and other micronutrients more than 1,000 km long above hydrothermal vents in the Atlantic Ocean. Elevated Fe concentrations persist for >1,000 km

<http://nanopatentsandinnovations.blogspot.com.au/search?updated-min=2013-01-01T00:00:00-05:00&updated-max=2014-01-01T00:00:00-05:00&max-results=50>



BH Ore body - Environment when it formed?

- Age
- Location
- Atmosphere
- Hydrosphere
- Environment, climate
- What about cobalt?



Earth's climate during the Achaean & Paleoproterozoic remains highly uncertain. Relevant geologic evidence is sparse and occasionally contradictory

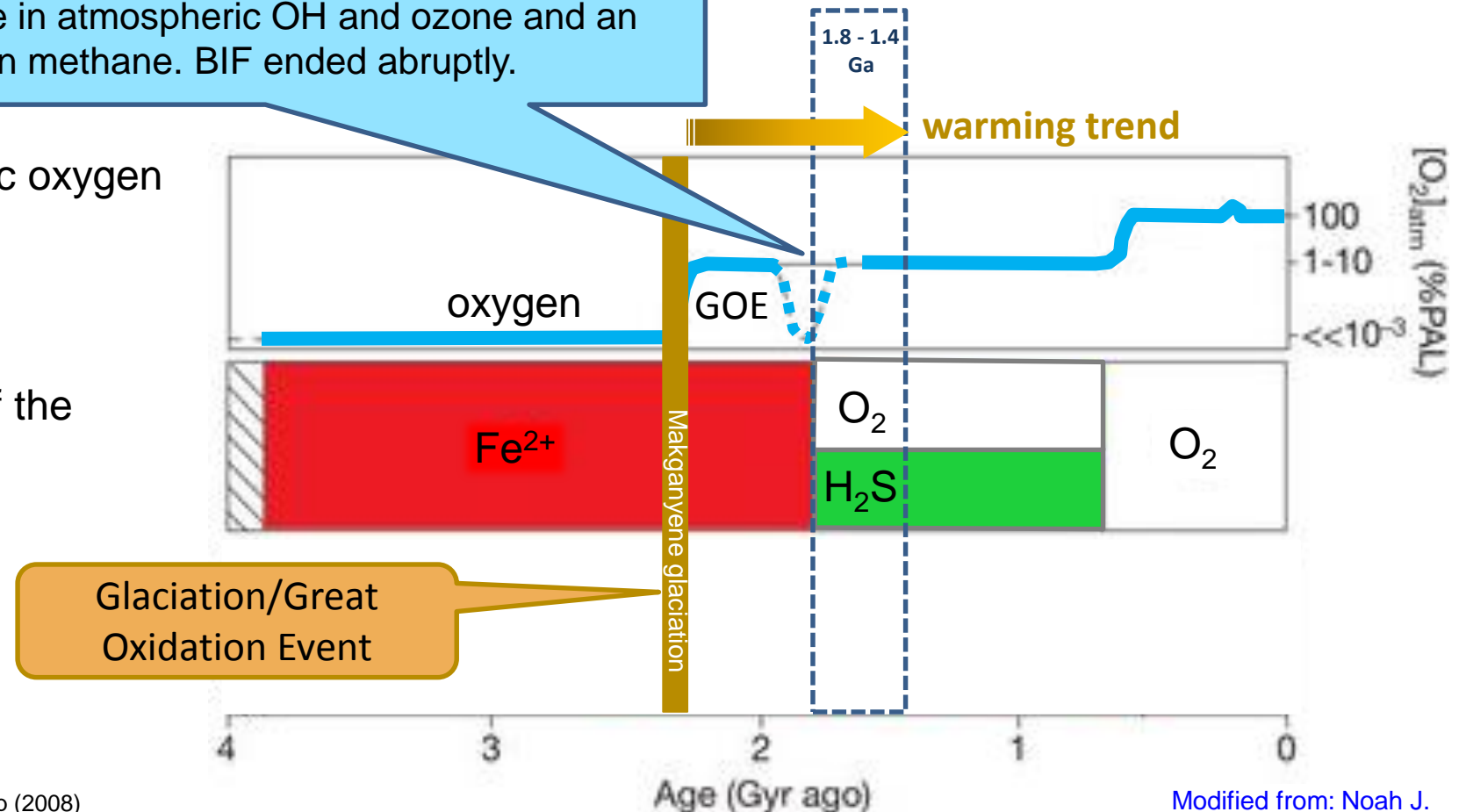
- Solar luminosity was 20–25% lower than today.
- ~2.3 Ga, the climate became extremely cold (Huronian glaciation). Evidence for ice exists on at least three continents (North America, Africa and Australia). Coincides with the Great Oxidation Event (GOE). BH formed as the earth warmed and ice retreated
- As O₂ rose it would have shortened the photochemical lifetime of CH₄ causing its concentration to drop. Dramatic, local changes in oxygen and methane may have occurred

Broken Hill ore body & Paleoproterozoic SEDEX deposits formed following abrupt changes to ocean chemistry

Iron-rich oceans changed to sulphidic (euxinic) resulting in a dramatic collapse in atmospheric OH and ozone and an increase in methane. BIF ended abruptly.

Estimates of atmospheric oxygen compared with present atmospheric level (PAL).

Chemical composition of the deep ocean.



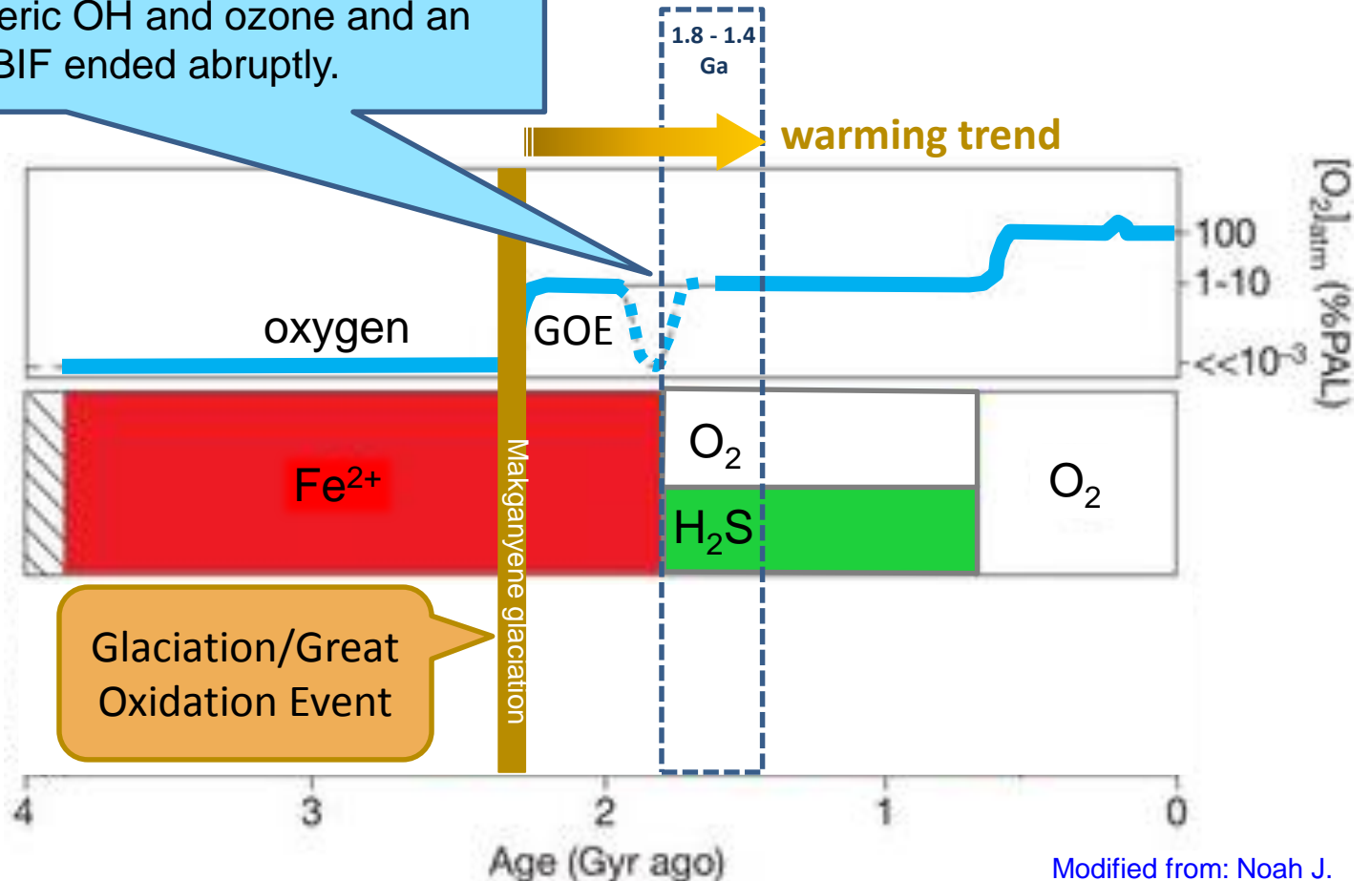
Discussion in Meyer & Kump (2008)
<http://eesc.columbia.edu/courses/w4937/Readings/Meyer.Kump.2008.pdf>

Modified from: Noah J. Planavsky et al
Nature 477, 448–451 (2011)

Possible cause of acidification (H₂S increase)

Iron-rich oceans changed to sulphidic (euxinic) resulting in a dramatic collapse in atmospheric OH and ozone and an increase in methane. BIF ended abruptly.

- Earth warms & ice recedes after the Makganyene glaciation (~2.3Ga)
- Blooms of blue green algae in shallow water produce O₂
- Atmospheric O₂ consumed/balanced/reduced by weathering processes as ice recedes
- Sulphates, weathered rock & nutrients added to deep oceans
- As O₂ is used up by weathering, microbe 'blooms' adapt in anoxic deep oceans and produce energy via sulphides from sulphates



Modified from: Noah J. Planavsky et al
Nature 477, 448–451 (2011)

Consequences of acidification (H_2S increase)

Input of H_2S (microbial?) between 1,000 and 2,000 times the present ocean value ($\sim 0.01\text{ppmv}$, below human detection by smell) ...
to **100ppmv** (about where our olfactory nerve becomes paralysed)

- OH radical **(water) in atmosphere falls by several orders of magnitude** (reaction with H_2S)
- consequence of OH depletion is an abrupt **increase in methane** to $\sim 100\text{ppmv}$
- because H_2S reacts rapidly with singlet O in the stratosphere, the O abundance falls abruptly i.e. **ozone levels are destroyed**

Deep hypersaline anoxic basins (DHABS)

- very salty, sulphidic water fills depressions (10s – 100s metres) at ocean deeps (usually >3km water depth)
- include most sulphidic water on Earth with thriving microbe communities
- no light, high pressure (350x), salty (can be 10x seawater), no oxygen (anoxic)
- anaerobic bacteria use nitrate and sulphate for respiration, carbon comes from CO₂ and CH₄ (methane)

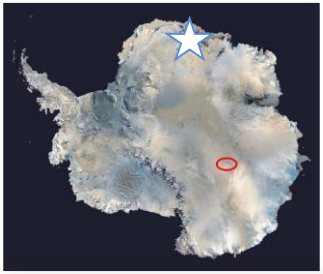
| Concentration (Millimolar) | Discovery Basin | Urania Basin | Normal seawater |
|--|-----------------|--------------|------------------------------------|
| Salt ions | | | |
| Sodium (Na ⁺) | 68 | 3503 | 528 |
| Magnesium (Mg ²⁺) | 4995 | 316 | 60 |
| Chloride (Cl ⁻) | 9491 | 3729 | 616 |
| Sulfate (SO ₄ ²⁻) | 96 | 107 | 32 |
| Toxic compounds | | | |
| Hydrogen sulfide (HS ⁻) | 0.7 | 16 | 2.6 x 10 ⁻⁶ (0.0000026) |
| Methane (CH ₄) | 0.03 | 5.6 | 1.5 x 10 ⁻⁶ (0.0000015) |



Sulphide mud from Urania Basin floor

Lake Untersee, ice covered lake in N Antarctic. A modern analogue?

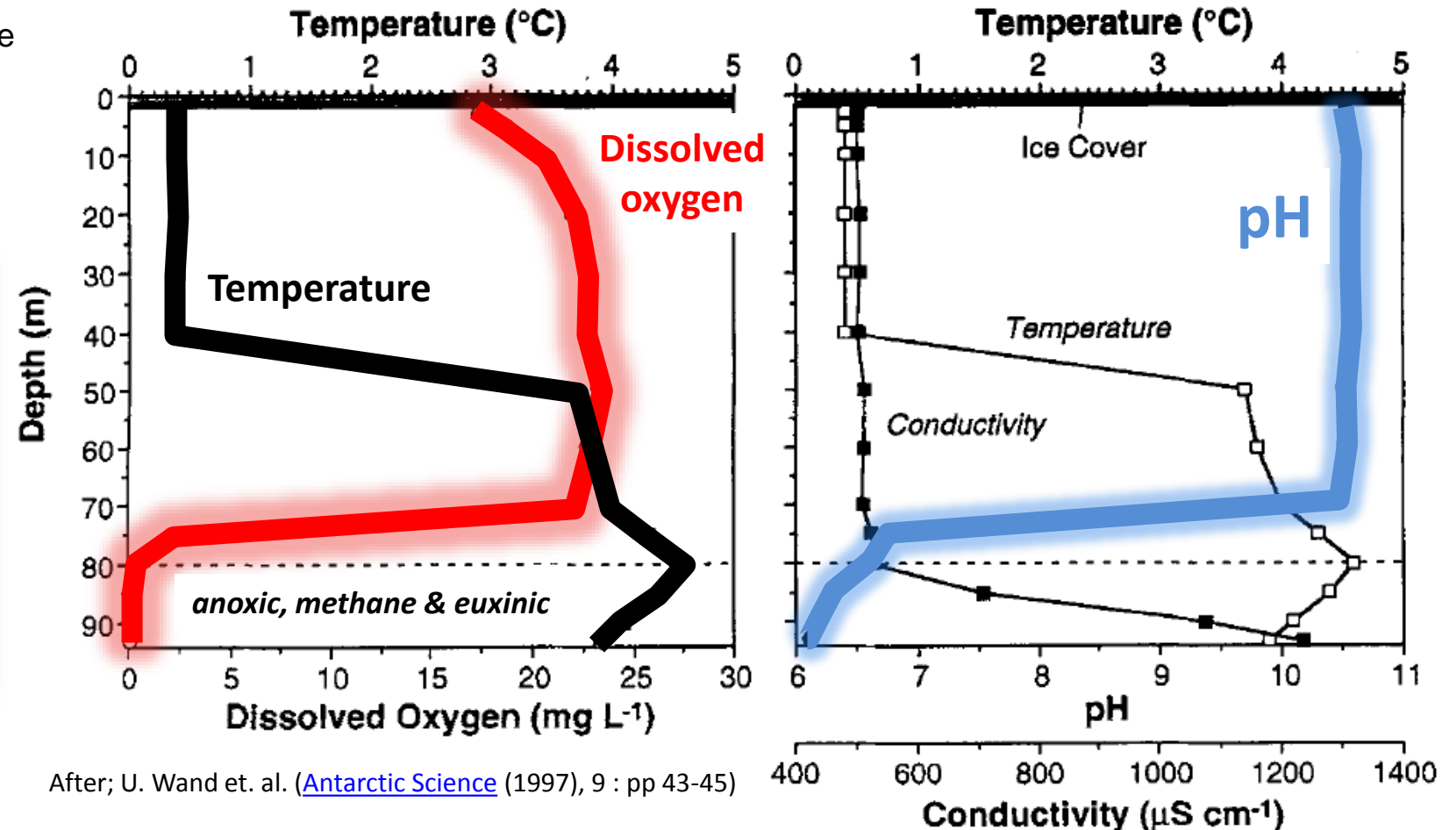
Lake dimensions 6.5 x 2.5km, max depth 169m, permanent ice cover (2-6m) for 100,000yrs, saline, sulphidic & methane enriched bottom waters, chemocline at 80m.



Average surface temperature
-10.6°C



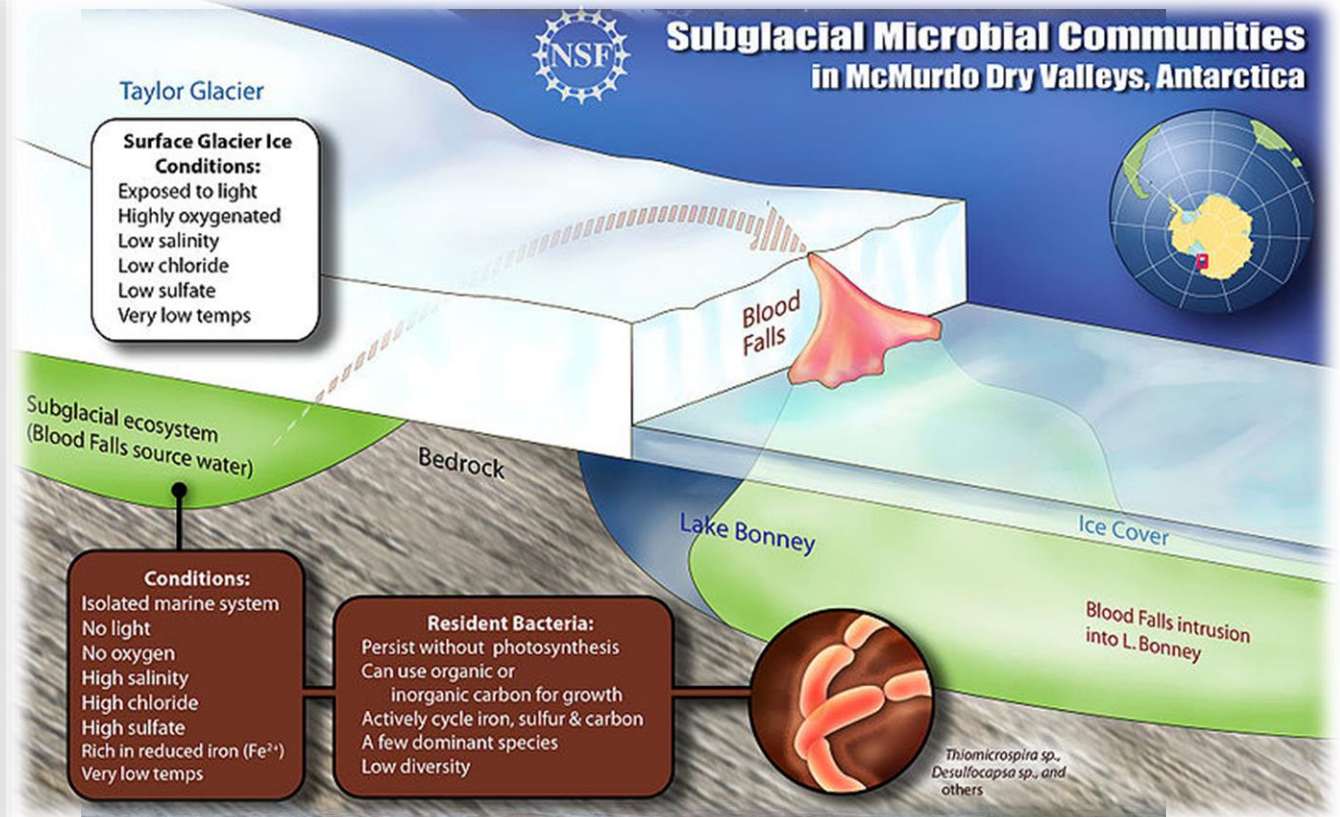
Microbial mats of anaerobic bacterial stromatolites on lake floor



After; U. Wand et. al. ([Antarctic Science](#) (1997), 9 : pp 43-45)

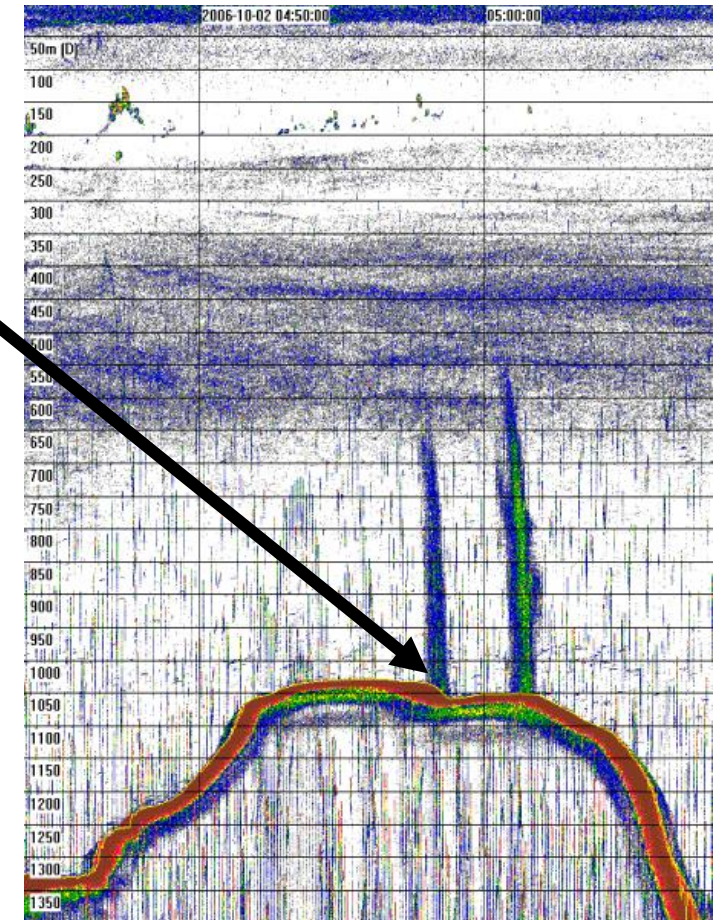
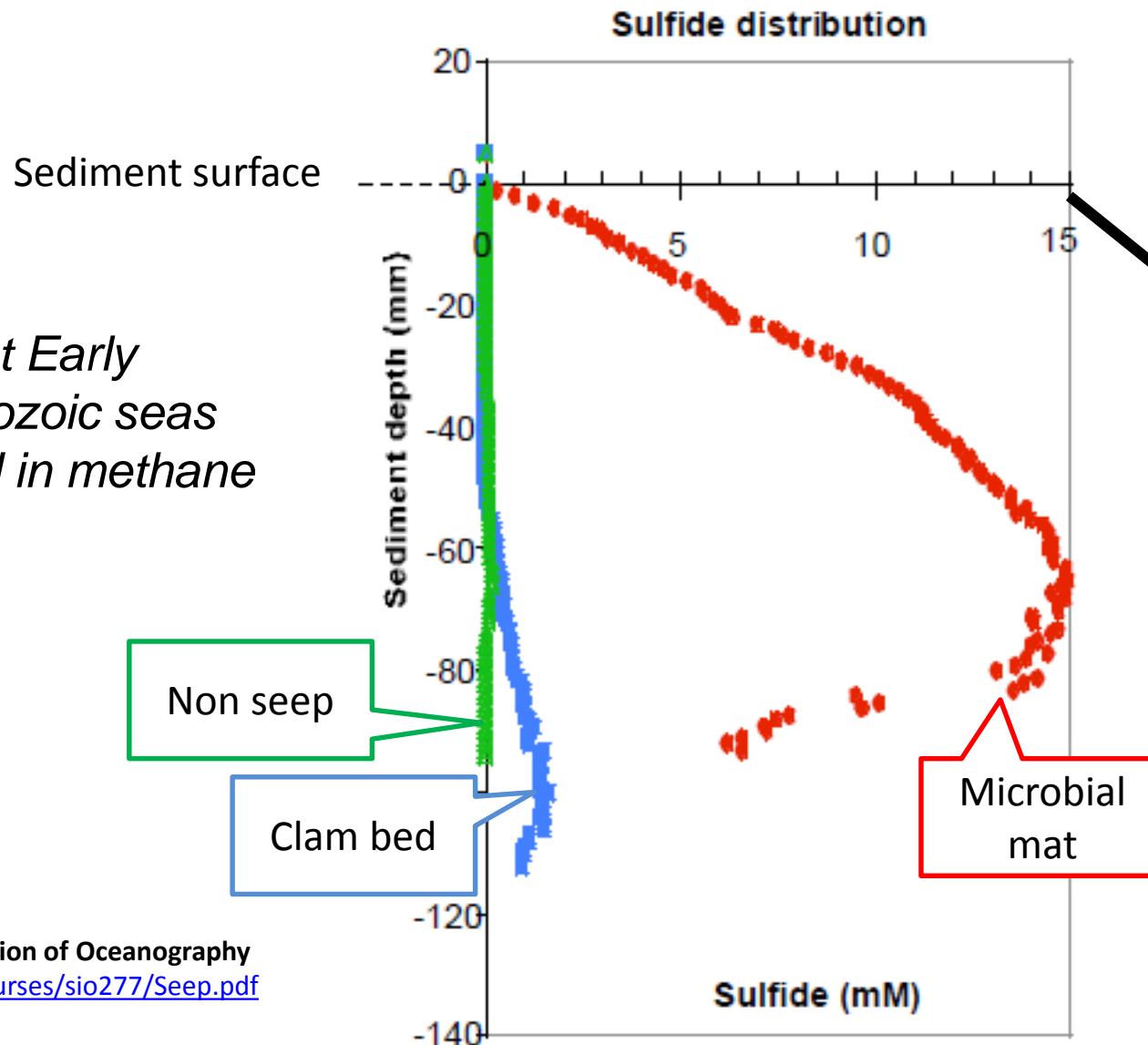
'Blood Glacier' leakage from a hypersaline rift lake

Water underneath the ice and soil of the Taylor Valley (Antarctica, Dry Valleys) extends at least 12km inland, is 2my old and is hypersaline. Red iron hydroxides form as the ferrous, sulphate rich water becomes oxygenated. Most of the 17 bacterial assemblages identified respire Fe(III) or SO_4^{2-} .



Microbial mats at methane seeps produce sulphide in sediment

Note that Early Palaeoproterozoic seas were enriched in methane



Methane – sonar images of methane rising from deep sea floor

Source: Scripps Institution of Oceanography
<http://iod.ucsd.edu/courses/sio277/Seep.pdf>

BH Ore body - Environment of formation

- Age
- Location
- Atmosphere
- Hydrosphere
- Environment, climate
- What about cobalt?



Anything that is unrelated
to elephants is irrelephant.

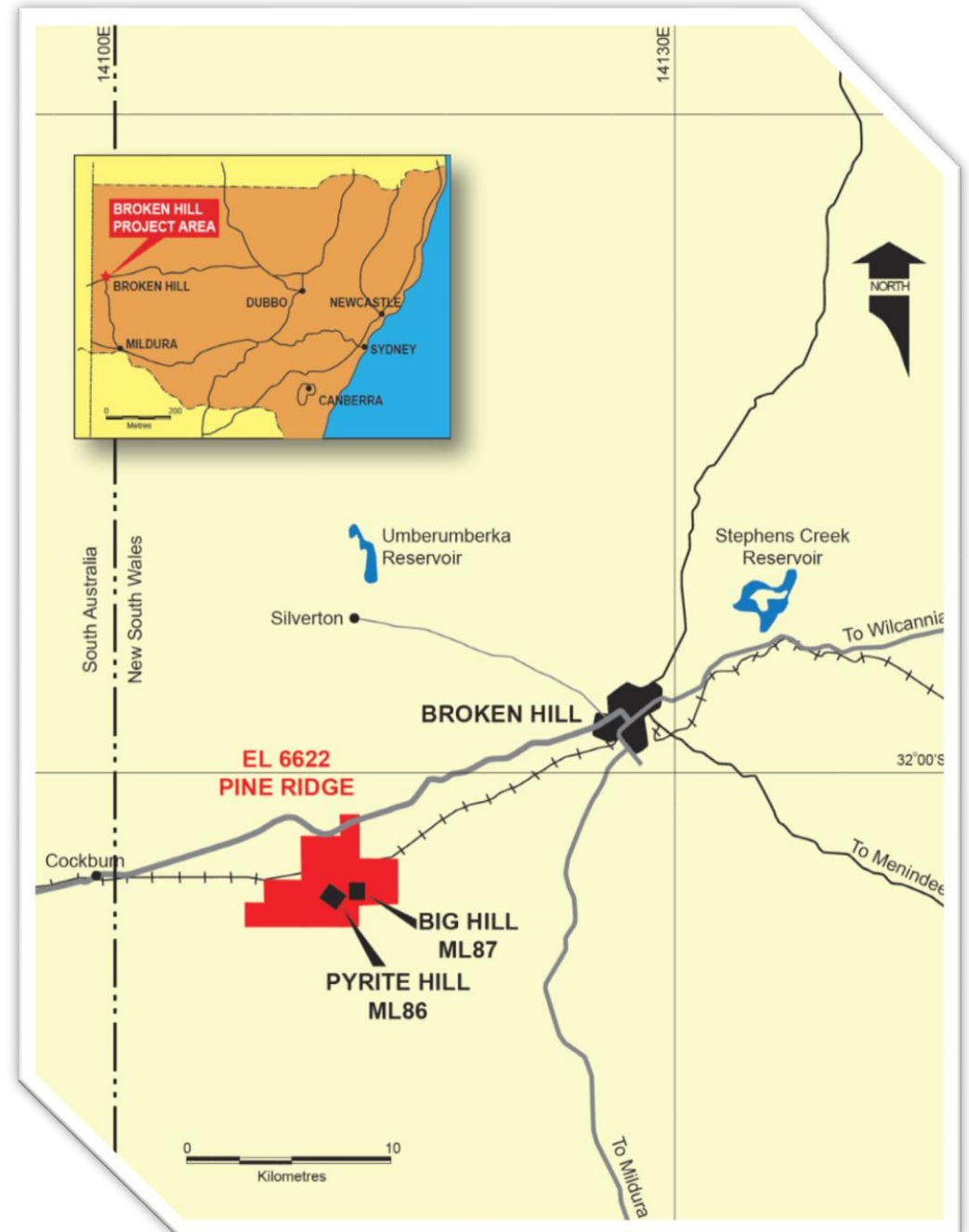
Location of Broken Hill Prospecting's Thackaringa Cobalt-Pyrite Project

Extensive Paleoproterozoic stratabound pyrite horizons

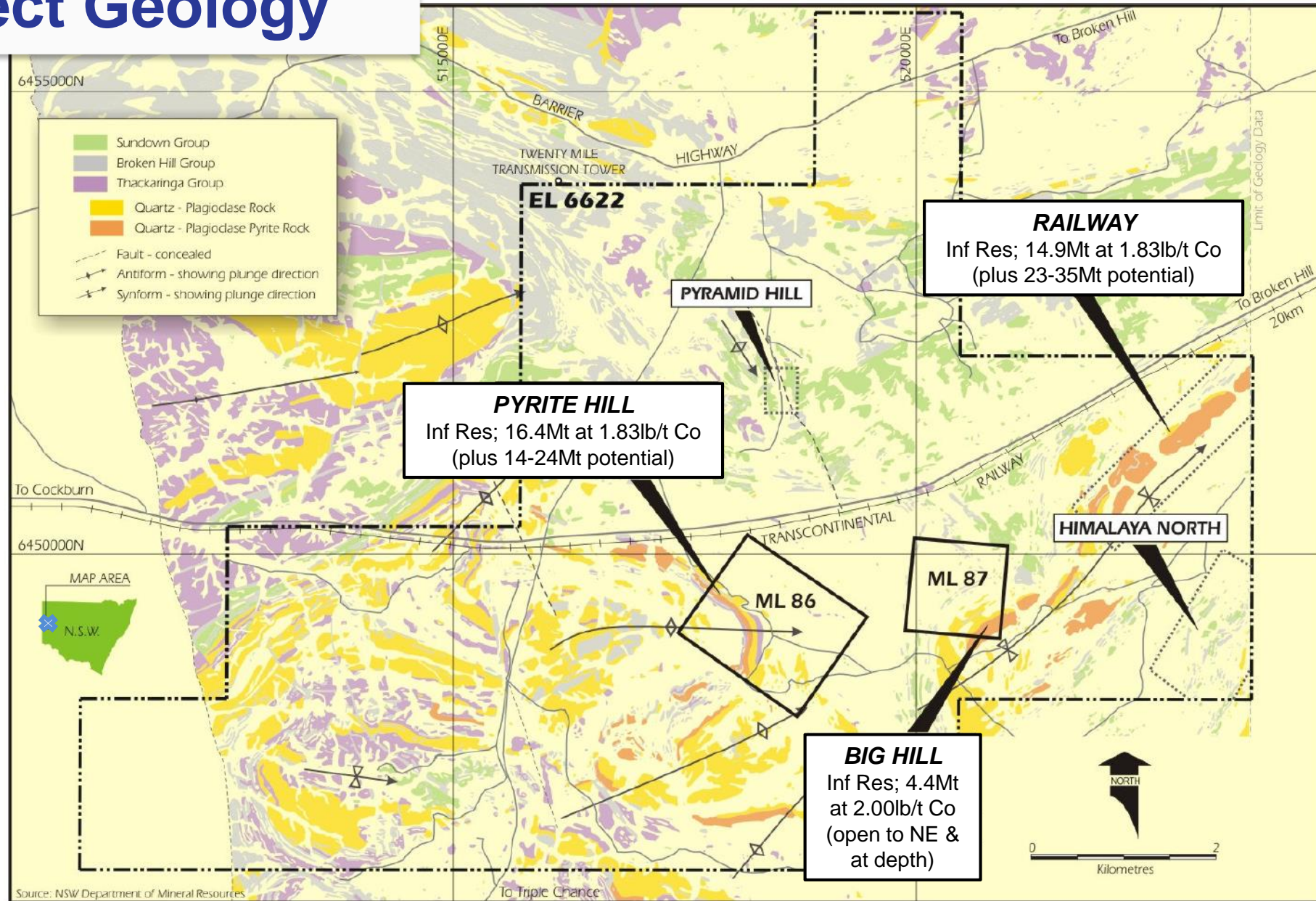
Only 25km SW of Broken Hill - but very different

Inferred Resources total 35.7Mt of 0.084% cobalt
(30kt contained cobalt), plus

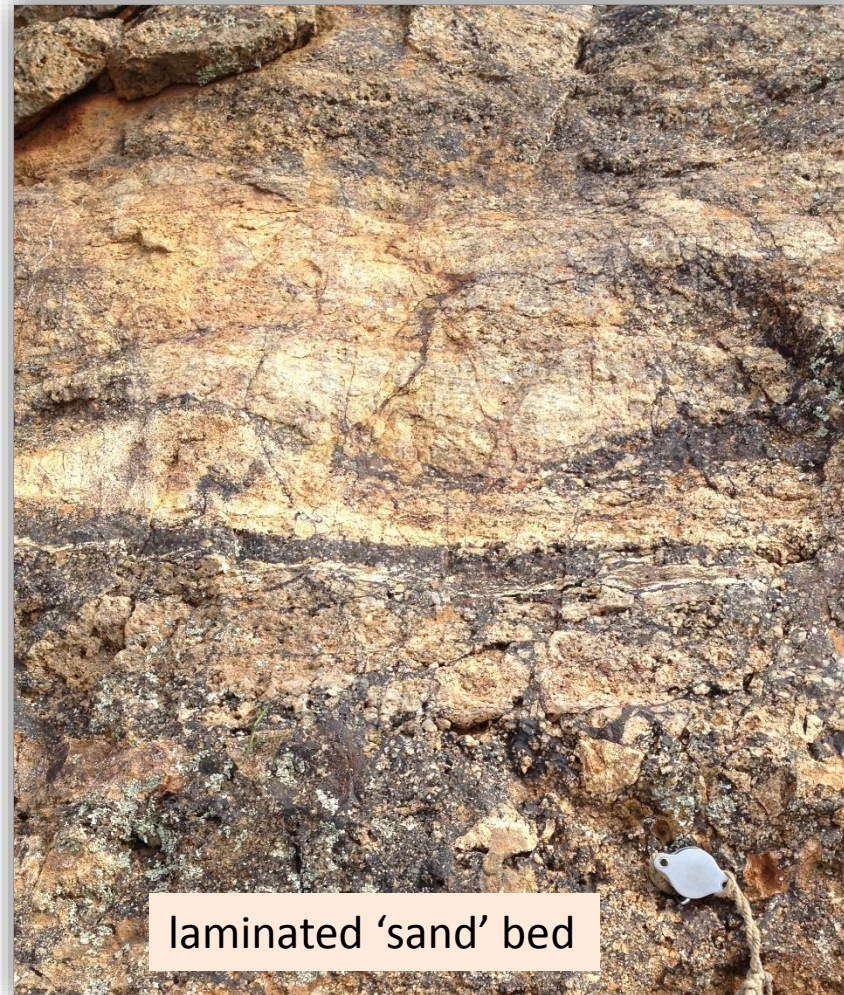
Potential 37-59Mt of 0.0775%-0.084% Co
(28.7kt - 45.7kt contained cobalt)



Project Geology



Thackaringa hostrock is paragneiss



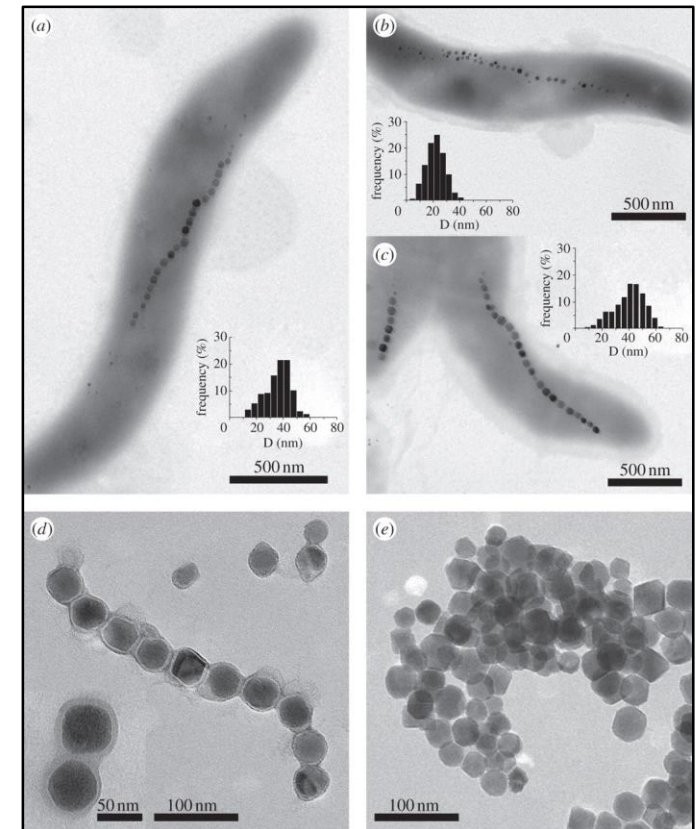
Albite-quartz gneiss host rock

- Well defined, thin, regular and continuous layering, sometimes massive and recrystallised
- Average grainsize approx 1mm
- >200m thick at Pyrite Hill & Big Hill
- Graded bedding, cross bedding
- Scour and fill structures, nodules and pebbly horizons
- Stratabound, continuity and conformable
- Zones of cobaltiferous pyrite, massive (to 10m thick) and disseminated (to 50m thick)
- Origin?
 - Evaporative salt lake, sabkha
 - Volcano-sedimentary (Plimer, 1976)?
 - Na rhyolite
 - analcime-rich glassy tuffs (Coombs, 1965)
 - Intrusive, metasomatic (Vernon, 1961), metamorphic?
 - “aplite”, Na schist
 - Others? Sediment basin?
 - **Pringle’s Rumen model** (refer previous talk)

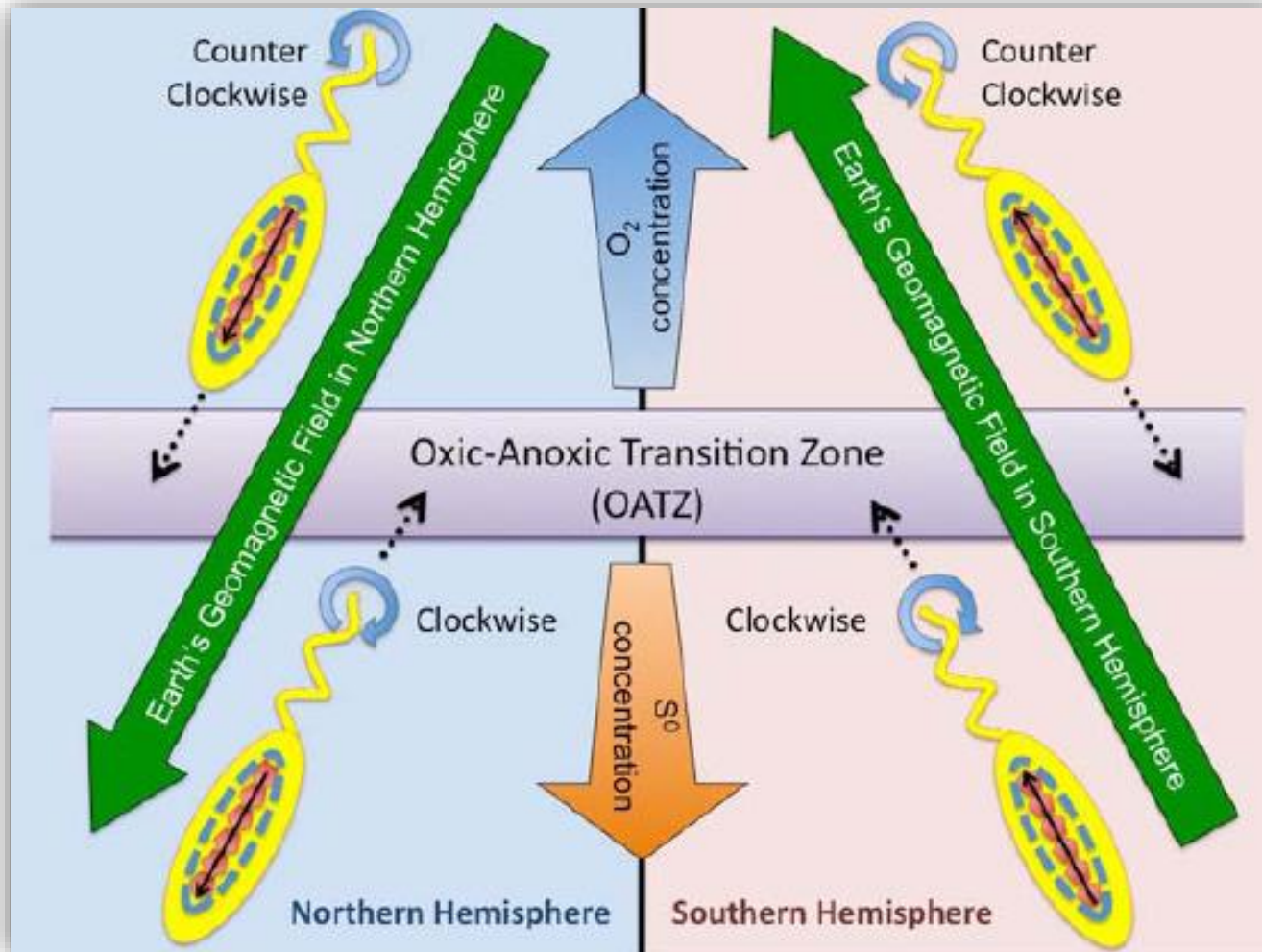
| average of 10 albite quartz gneiss drill samples (Plimer, 1976) | |
|--|--------------|
| SiO ₂ | 68.35 |
| TiO ₂ | 0.67 |
| Al ₂ O ₃ | 18.11 |
| Fe ₂ O ₃ * | 1.22 |
| MnO | 0.01 |
| MgO ** | 1.08 |
| CaO | 0.35 |
| Na₂O | 7.96 |
| K ₂ O | 0.81 |
| P ₂ O ₅ | 0.08 |
| H ₂ O | 0.83 |
| * total iron as Fe ₂ O ₃ (trace pyrite?) | |
| ** Mg occurs in albite and trace biotite | |

Extreme environment & toxic bugs

- Deep Hypersaline Anoxic basins are arguably the most extreme environment on earth (saline, deep water, low/no oxygen, no light, methane, sulphidic)
- studies report brine-lake sediments have the highest concentration of extracellular DNA reported in a natural environment.
- The chemocline separates seawater from brine, the oxic-anoxic transition zone (usually tens of metres thick) separates oxygenated and oxygen-free water:
 - Bacteria species/communities vary between brine basins.
 - Two types of magnetostatic bacteria based on magnetism; magnetite (Fe_3O_4) and **greigite** (Fe_3S_4). The latter dominate in anoxic sulphidic environments.
 - Both use the earth's magnetic field to move towards/within the oxic-anoxic transition zone.
 - Cobalt incorporation into Fe_3S_4 makes it a stronger magnet.



Magnetotactic bacteria use the earth's magnetic field to move

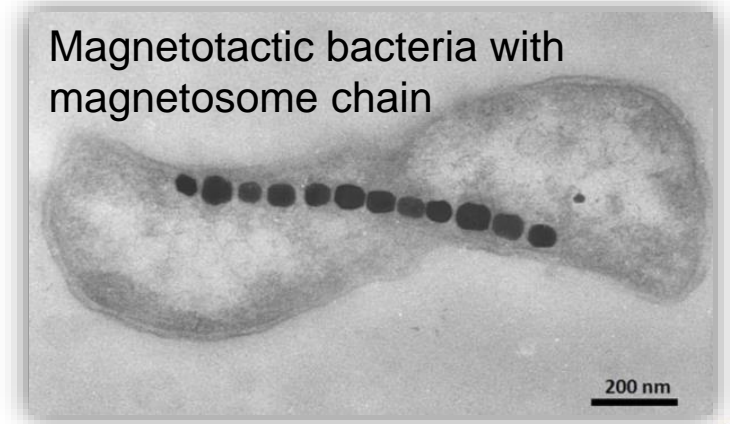


In both N and S hemispheres, cells at higher than optimal oxygen concentration in the oxidized state swim forward by rotating their flagella counter clockwise.

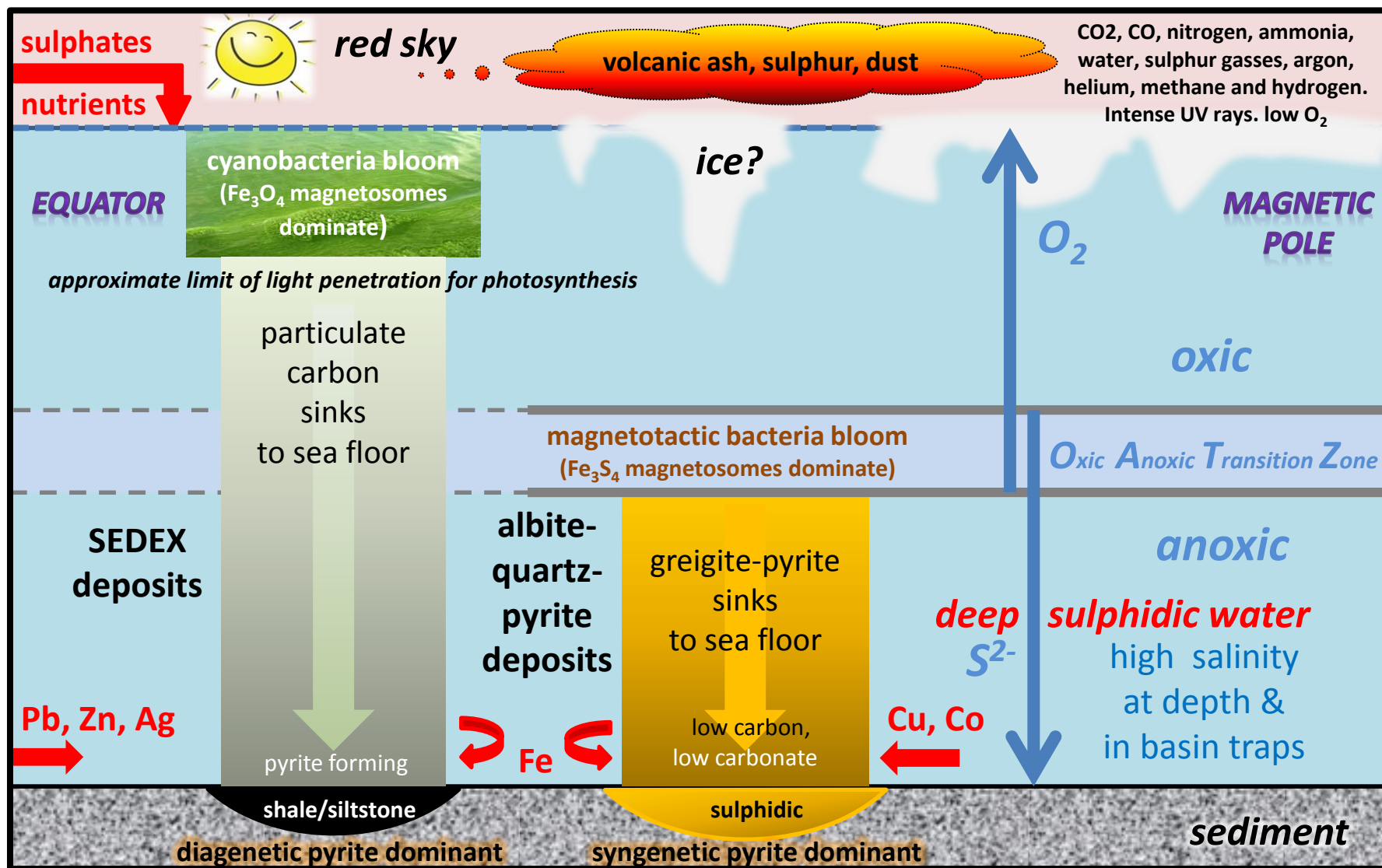
Cells at lower than optimal oxygen concentration in the reduced state rotate their flagella clockwise and swim backward without turning around.

Movement can be fast! (100x cell length per second)

Magnetotactic bacteria with magnetosome chain



Magnetotactic bacteria are found in greatest numbers in the OATZ. They use the earth's magnetic field for optimal positioning with respect to S²⁻ and O₂.



Models for 'end-member' Paleoproterozoic sedimentary basin-hosted base metal deposits.
 SEDEX (eg Mt Isa Pb/Zn/Ag, Broken Hill) → Quartz - pyrite deposits (eg Mt Isa Cu, Thackaringa)

Summary

- BH likely formed in a stratified, saline briny water rift basin during a dramatic worldwide change in deep ocean chemistry (Fe^{2+} to hydrogen sulphide) accompanied by an abrupt increase in methane and a collapse of atmospheric ozone.
- The Thackaringa Co-Pyrite deposit formed in a restricted saline anoxic & euxinic basin via microbial activity. BH ore formed not long after Thackaringa (~15my). Both were probably similar in size but very different in make-up (Fe, S, base metals).
- BH may have had been in a similar setting to Thackaringa but with much higher 'availability' of base metals. Did colonies of sulphur fermenting bacteria concentrate metals (smoker plumes?) from circulating saline and sulphidic water?



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Final comments;

I hope that the message I leave is that in mineral exploration we need to; step out of the herd, 'view the scene' and think outside of the box.

Not only are geology, structure, rock geochemistry & geophysics important but we must pay attention to the environment where, and when, the mineral deposit formed.

Understanding the environment is the key to understanding the process.

Thank you