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new frontiers new south wales

Mapping, magnetics and microscopes: Understanding the setting of VAMS mineralisation in the Ordovician Girilambone Group, western NSW

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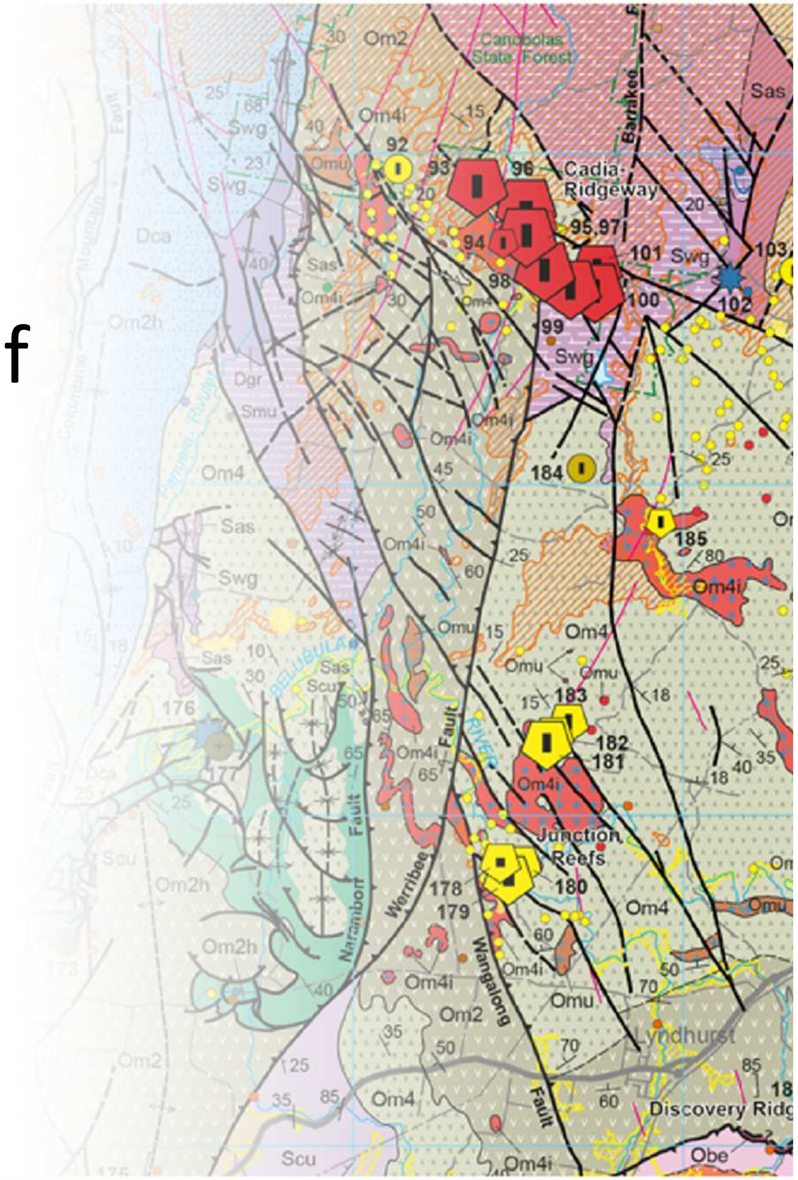
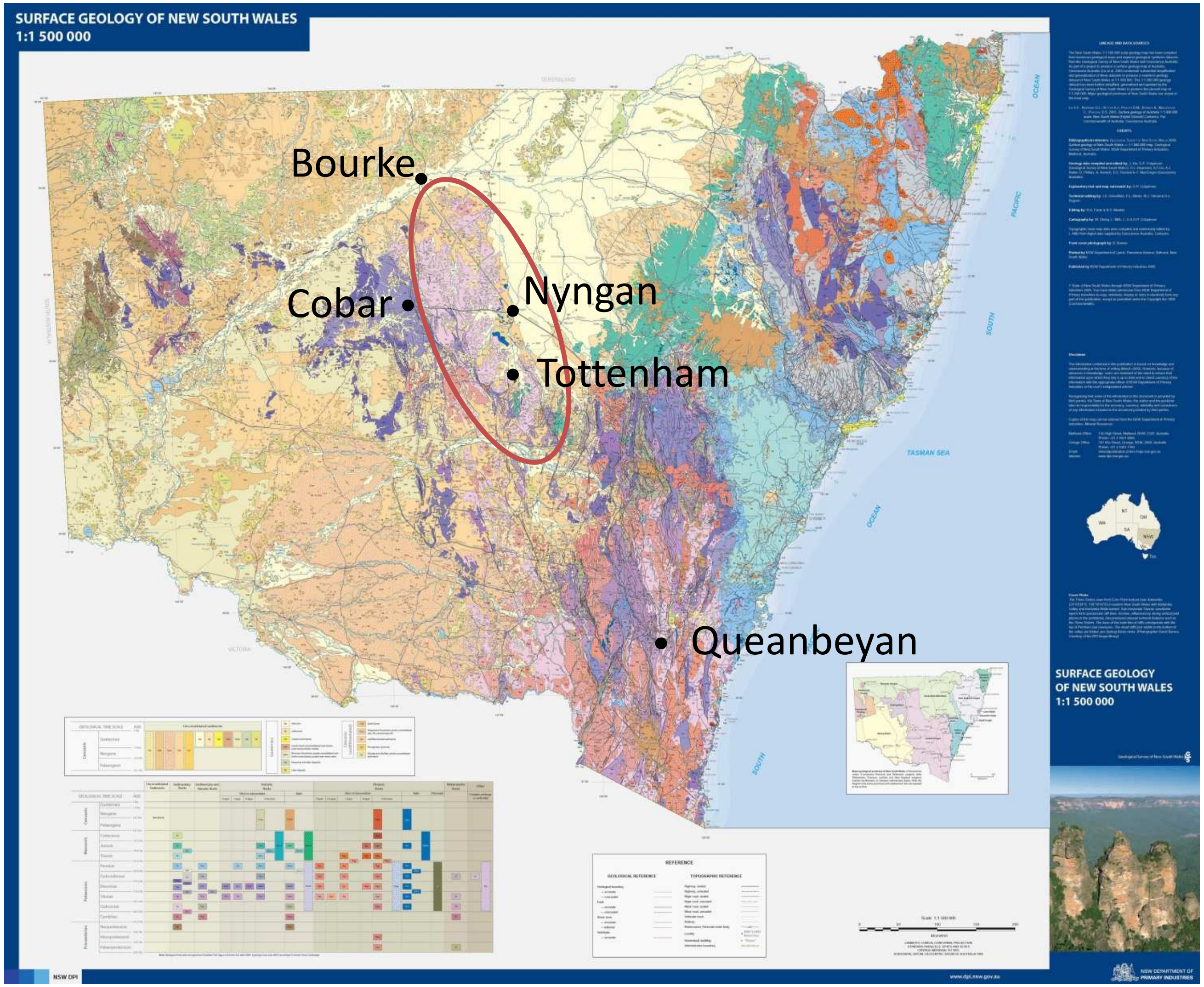


Overview

- Location
- Why and what
- Geological overview
- Outcomes
- Genetic model
- Exploration guide
- Summary

Location


WELCOME TO
TOTTENHAM
CENTRE OF N.S.W
DISTRICT POPULATION 600
ELEVATION 240m


SURFACE GEOLOGY OF NEW SOUTH WALES
1:1 500 000
Bourke
Cobar
Nyngan
Tottenham
Queanbeyan
TASMAN SEA
SURFACE GEOLOGY
OF NEW SOUTH WALES
1:1 500 000

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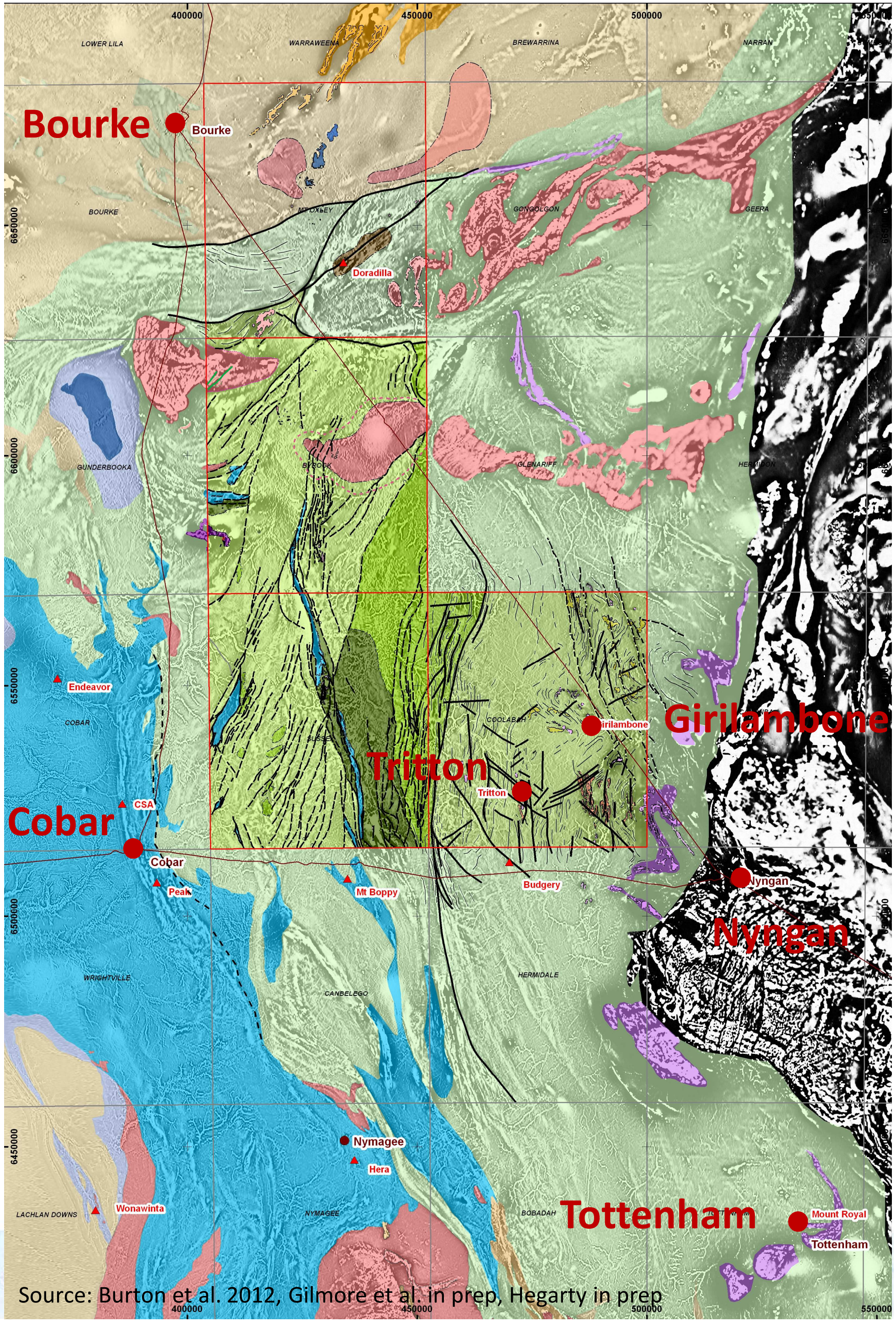
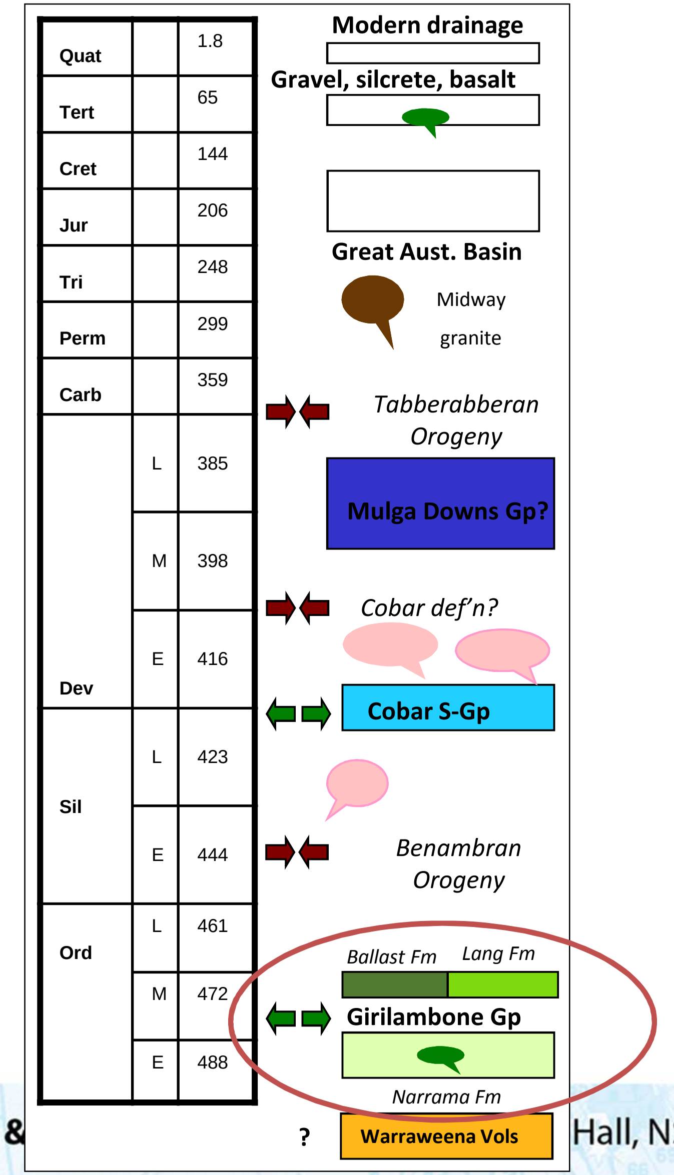
Why and what

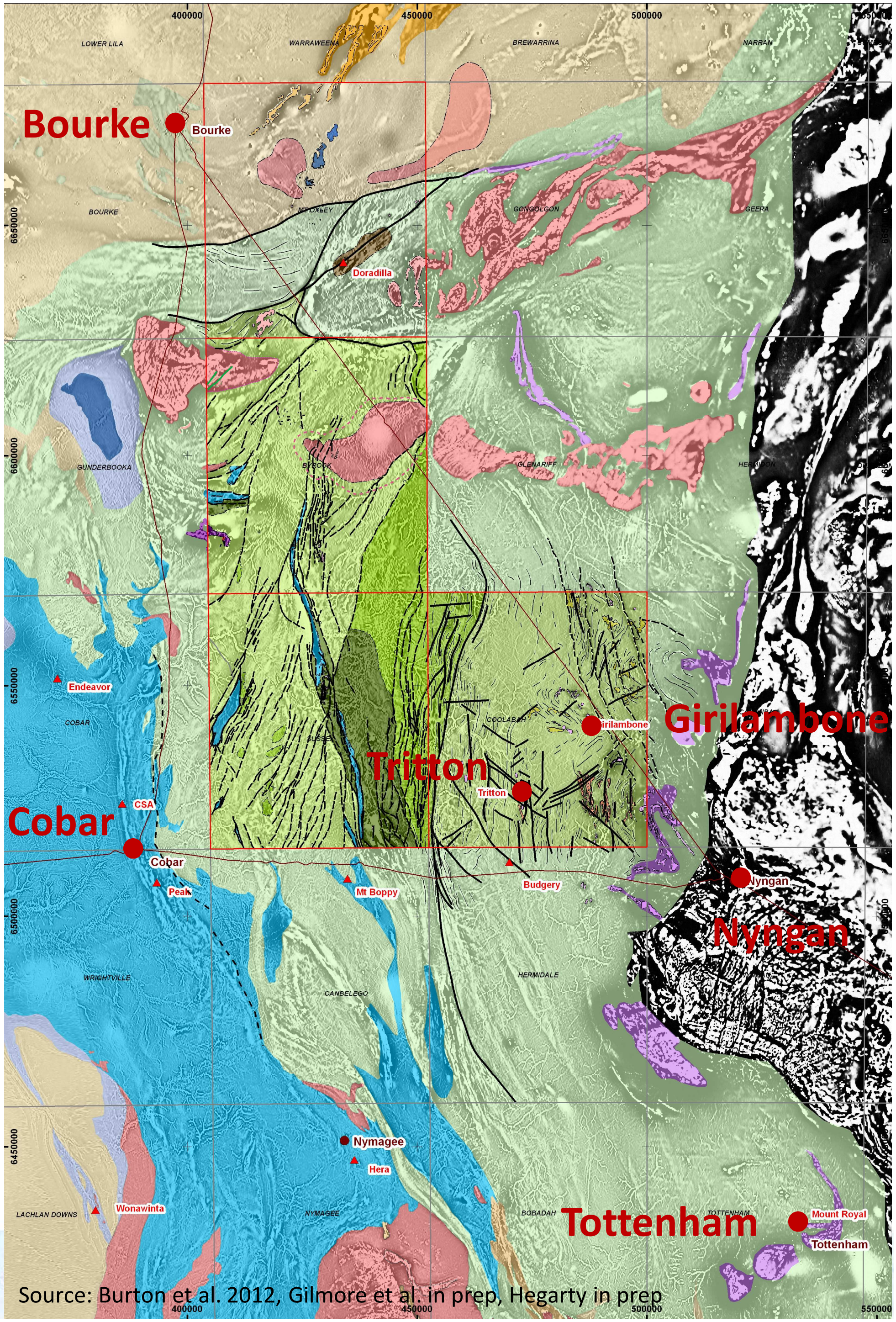
- Poor mapping resolution
  - Continue 100k mapping
- Cu-rich deposits (e.g. Tritton) poorly constrained
  - Syngenetic or orogenic?
- Multi-discipline
  - Mapping
  - Potential field modelling
  - Mineral systems study
  - Research project
    - M. Econ. Geology (CODES)
- Collaboration
  - Industry
  - Geoscience Australia



Source: Burton et al. 2012, Gilmore et al. in prep, Hegarty in prep

Geological overview

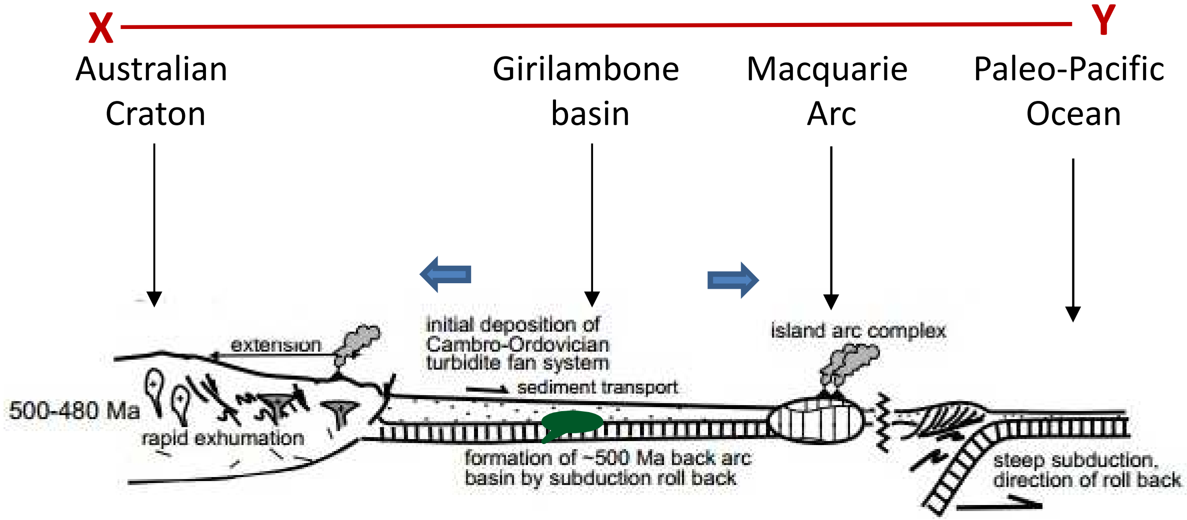




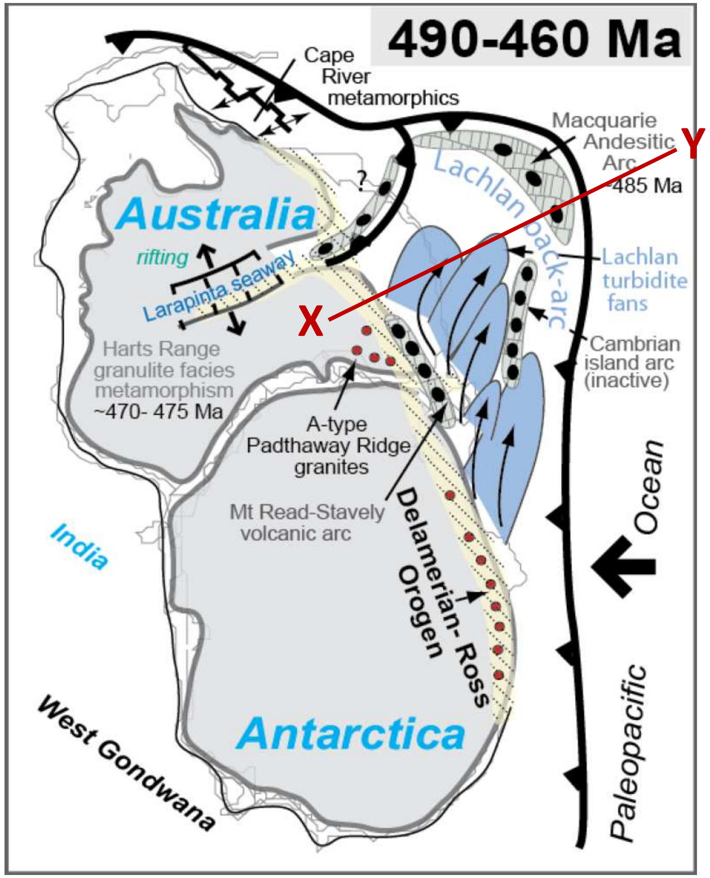
Source: Burton et al. 2012, Gilmore et al. in prep, Hegarty in prep

Geological overview

- Early Ordovician
  - Widespread extension
  - Back arc setting
- Turbidite deposition
- MORB-affinity mafic rocks



Source: Foster and Gray 2000



Source: Foster and Goscombe (2013), Geosciences 3 (3), Geoscience Australia – Shaping A Nation.

Mapping – turbidites

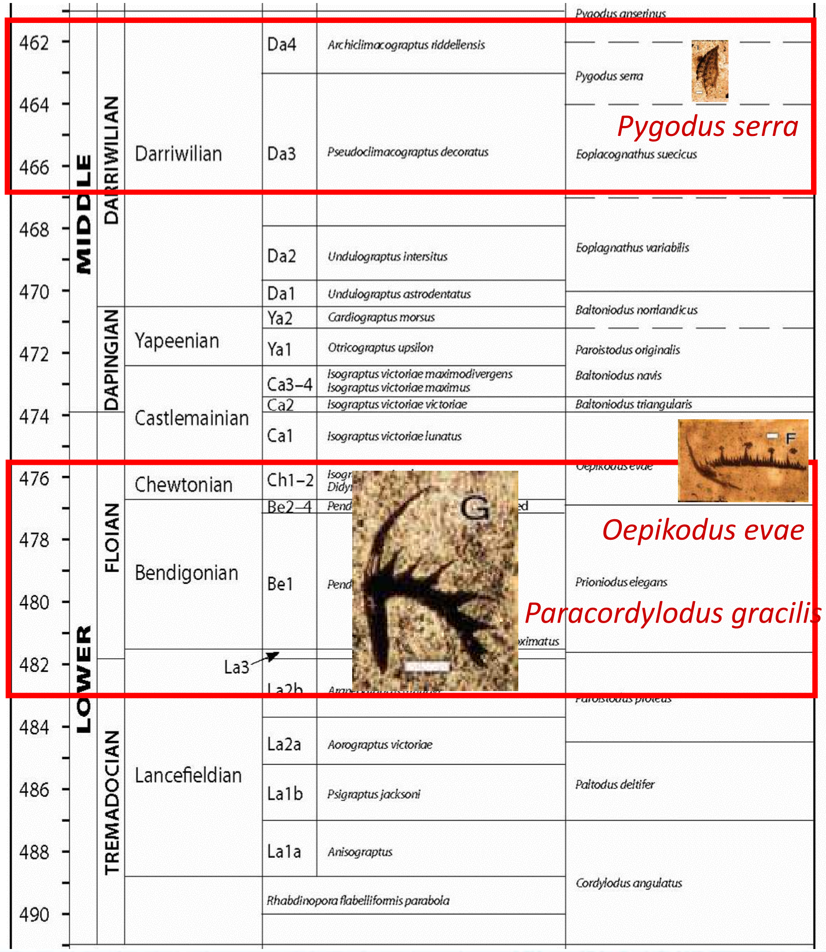
- Poor surface exposure …
- Interbedded sandstone, siltstone and claystone
  - Minor chert horizons
- Thicker quartz-rich sand horizons
  - Same provenance as turbidites[1]
  - Channel(s) across fan?
  - Metamorphosed to quartzite

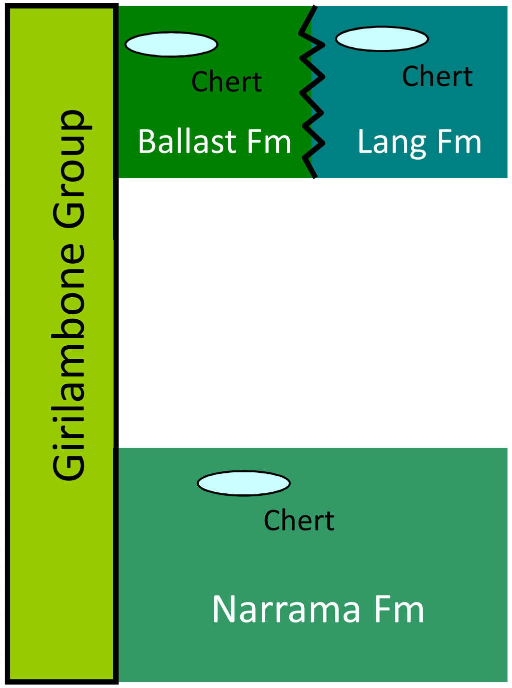
- Metamorphosed – lower greenschist
- Deformed – asymmetric folding

1 -Fraser et al. 2014

Mapping – biostratigraphy

- Conodonts in chert and siliceous siltstone





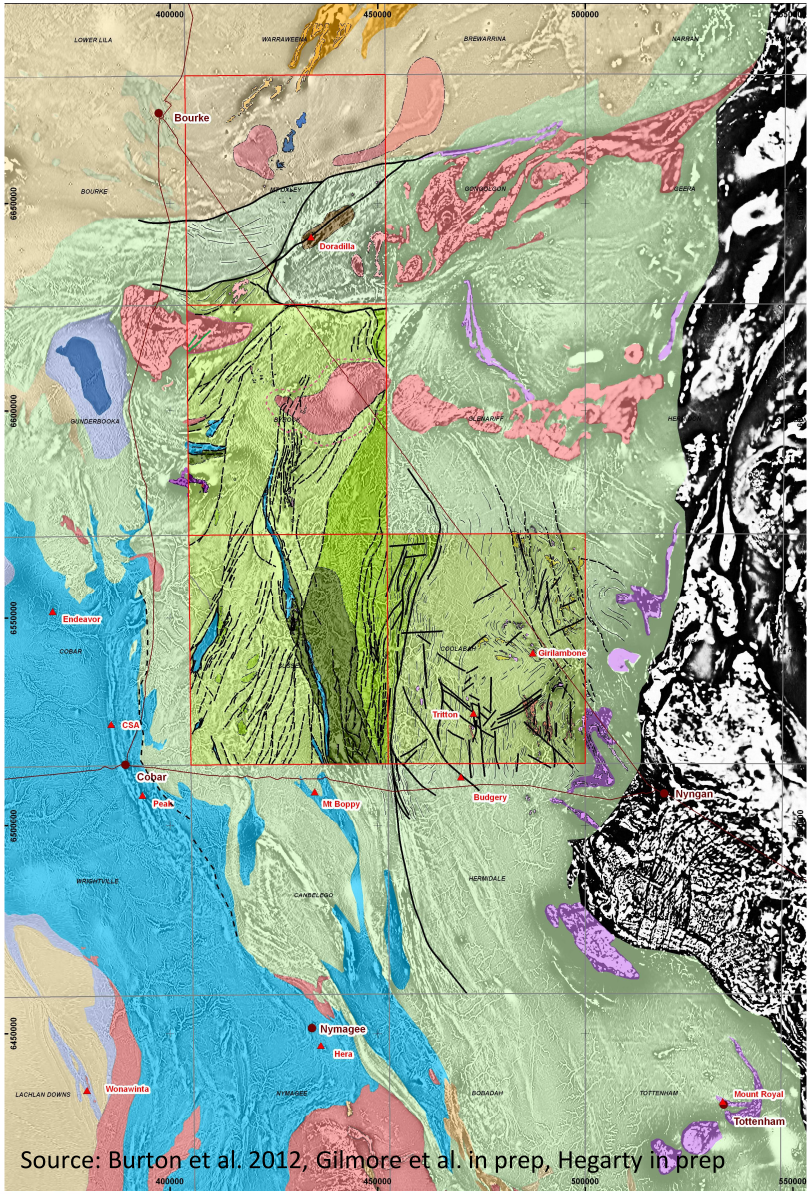
Schematic only!

Thanks to Dr Ian Percival

Mapping – mafic rocks

- Basalts and mafic schists[1, 2]
  - Ocean island basalts
  - Mid-ocean ridge basalt
- Ultramafic rocks[3,4]
  - ‘Alpine style’ harzburgite
  - ‘Alaskan style’ complexes

Pillow basalts, Mount Dijou

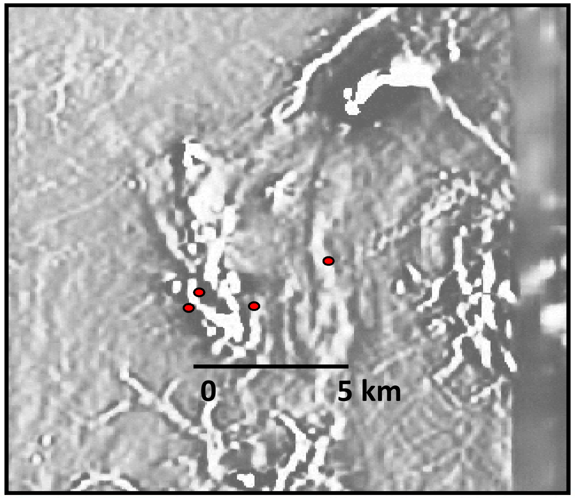


Source: Burton et al. 2012, Gilmore et al. in prep, Hegarty in prep

1 – Burton 2011, Burton 2014, Barron et al. 2007, Bruce 2013

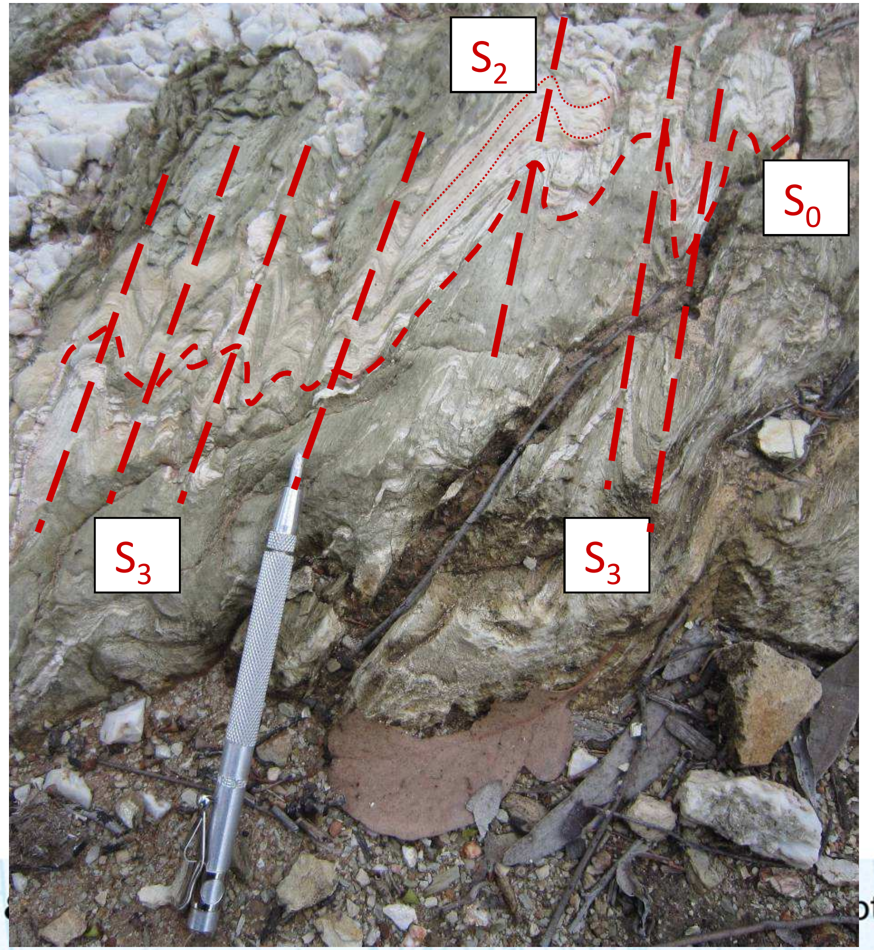
Mapping – silica-iron rocks

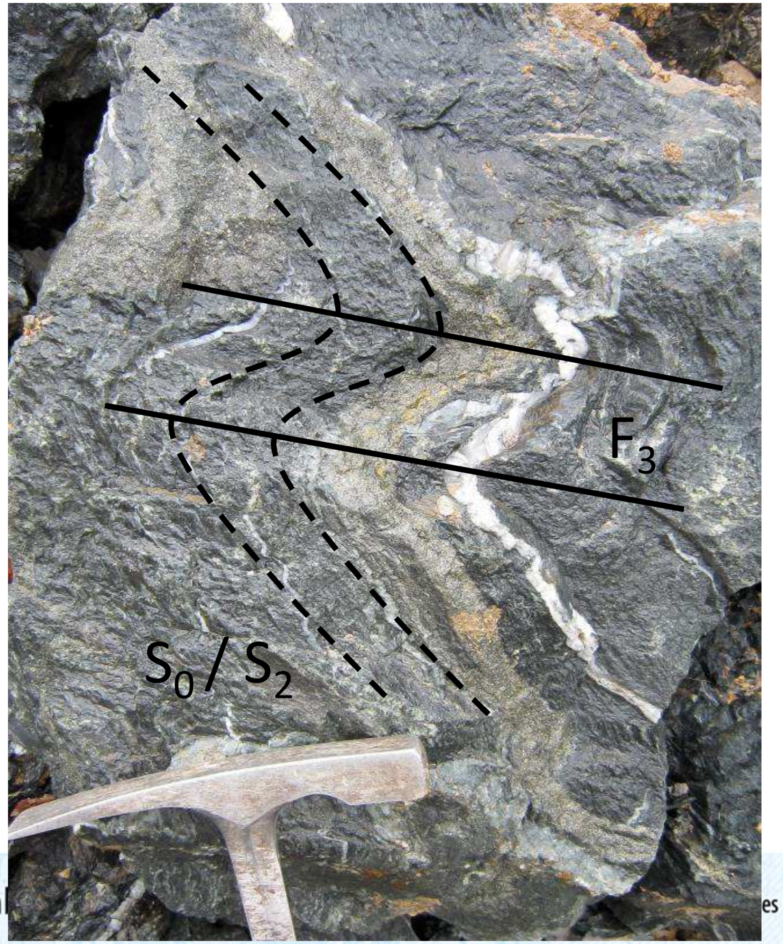
- More extensive than previously mapped
  - The ‘pink quartzite’ of Smith and Hopwood in the 1970s
- 3 things about them …
  - Magnetic
  - Same deformation fabrics & geometry as surrounding turbidites
  - Look identical to those over ore zones



Mapping – structure

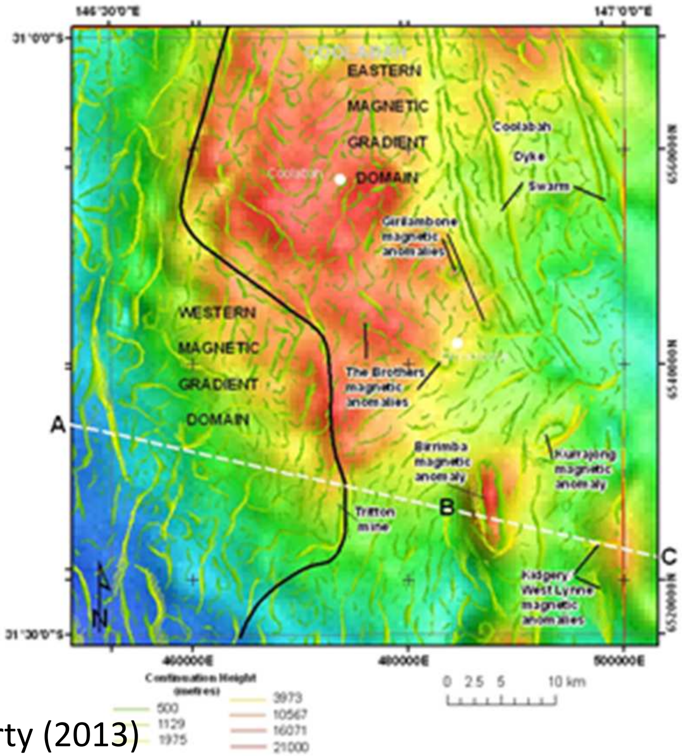
- Main deformation event was the Benambran Orogeny ~440 Ma
  - Ar-Ar evidence (Fergusson et al. 2005)

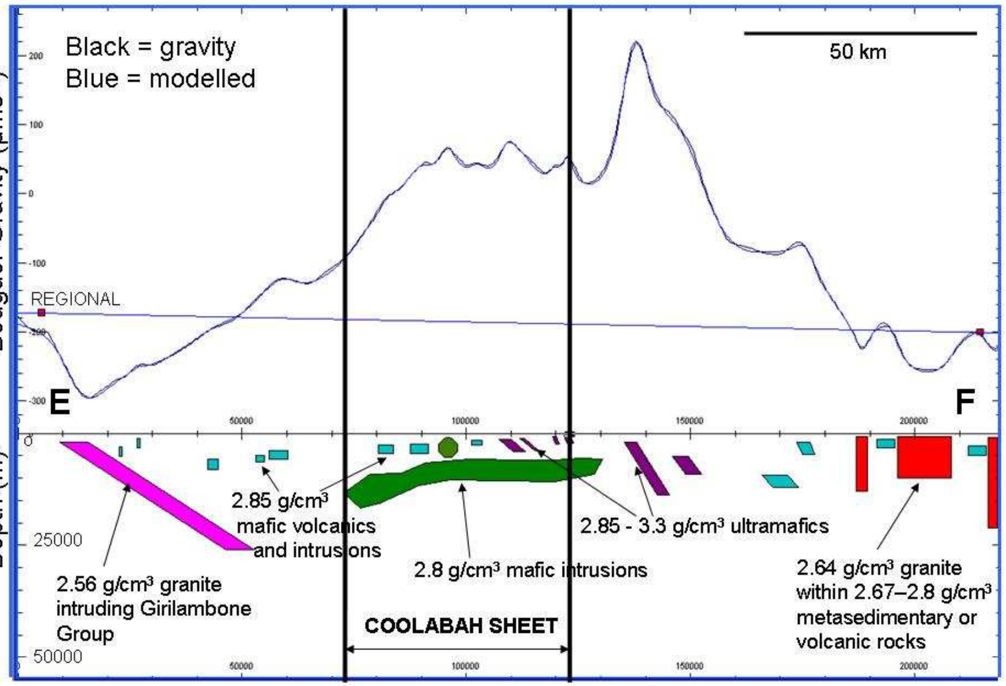




Mapping – potential field models

- Magnetic and gravity models (Hegarty 2013)
  - Known mafic rocks on margins of gravity highs
  - High density basement – a large mafic intrusion at 5km?



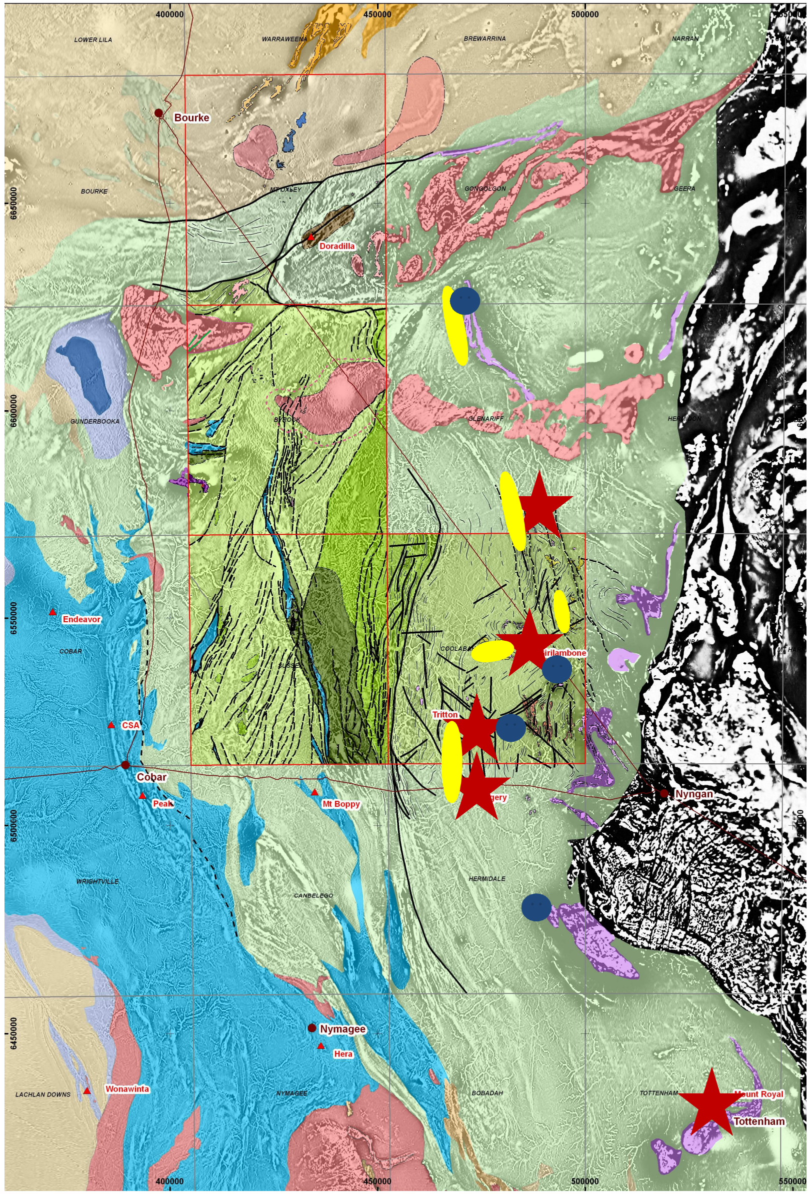


Hegarty (2013)

Mapping – summary

- Two packages of turbidites
  - Early Ordovician (Narrama Fm)
    - Mafic and ultramafic rocks
    - Coarser grained
    - Hosts mineralisation
    - Hosts silica-iron rocks
      - Magnetic
    - Chert and quartzite markers
  - Middle Ordovician (Ballast, Lang)
    - Finer grained

- Consistent structure regionally
  - F3 fold axis



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Mineralisation

- Range of interps!
  - Syngenetic VAMS
    - 1970s, 2010s
  - Orogenic
    - 1990s, 2000s
- Tritton resources
  - 50 Mt @ 2% Cu[1]
  - >755 000t Cu
    - Mined and identified resources[2]
- 'Very large' deposit on global VAMS scale[3]

1 - Jones 2012, 2 - Straits 2012, 3 – Galley et al. 2007

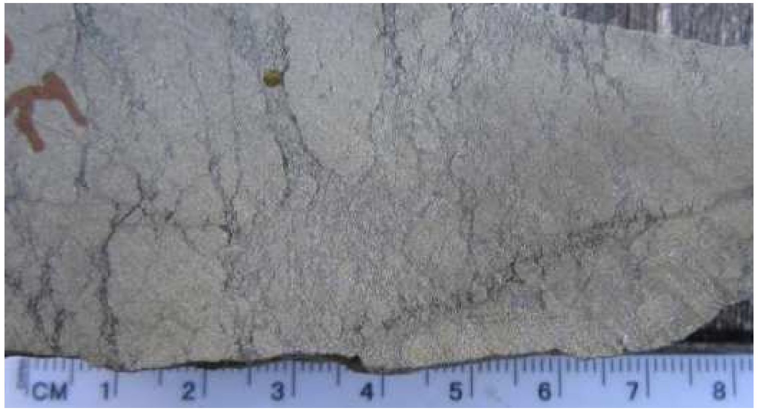
BLE 3. Examples of large-tonnage volcanogenic massive sulphide deposits of the World (Canadian deposits in

NAME	COUNTRY	Orogen	Mtonnes Ore (Geol.)	CU %	PB %	ZN %	AU (g/t)	AG (g/t)	Orebody Age (est. Ma)
SUPERGIANT									
Rio Tinto (Stockwork)	Spain	Hercynian	1200.00	0.15		0.15		7.00	320
Rio Tinto (Massive)	Spain	Hercynian	335.00	0.39	0.12	0.34	0.36	22.00	320
Kholodnina	Russia	Baikal-Vitim	300.00	0.04	0.79	5.2			750
Windy Craggy (Cu,Co)	Canada	N.Cordilleran	297.40	1.38		0.25	0.22	3.83	220
Neves Corvo Group	Portugal	Hercynian	270.00	1.59	0.15	1.41		9.87	320
Gai East	Russia	Uralides (Hercynian)	269.00	1.2		0.7	1.10	7.70	395
Aljustrel Group (total)	Portugal	Hercynian	250.00	1.2	1.2	3.2	1.00	38.00	320
Brunswick #12	Canada	Appalachian	229.80	0.46	3.01	7.66	0.46	91.00	465
Gai	Russia	Uralides (Hercynian)	205.00	1.4	0.06	0.5	1.10	7.90	395
La Zarza	Spain	Hercynian	164.00	1.2	1.1	2.5	1.80	47.00	320
Ducktown	USA	Grenvillean? (Ocoee)	163.34	1		0.9	0.30	3.00	1000
GIANT									
Kidd Creek	Canada	Abitibi (Kenoran)	147.88	2.31	0.22	6.18	0.01	87.00	2714
Horne - No. 5 Zone	Canada	Abitibi (Kenoran)	144.00	1		0.9	1.40		2698
Ozernoe	Russia	Baikal-Vitim	130.00	0.01	1.2	6.2			500
Ridder-Sokol	Kazakhstan	Altaides (Hercynian)	125.00	0.3	2	4	2.50	10.00	400
Zyryanov	Kazakhstan	Altaides (Hercynian)	125.00	0.4	2.7	4.5	0.13	20.00	395
Gacun	China	Yidun, Indosinian (Tethyan)	124.00	0.72	4.62	6.66	0.46	157.00	200
Masa Valverde	Spain	Hercynian	120.00	0.5	0.6	1.3	0.80	38.00	320
Sibai	Russia	Uralides (Hercynian)	115.00	1	0.04	1.56	0.60	16.00	392
Tharsis	Spain	Hercynian	110.00	0.5	0.6	2.7	0.70	22.00	320
Yubileinoe	Russia	Uralides (Hercynian)	107.00	1.9	0.1	1.2	2.50	16.00	392
Uchaly	Russia	Uralides (Hercynian)	106.00	1.1		3.8	1.10	15.50	392
Madneuli	Georgia	Caucasian (Tethyan)	102.60	1.29		1.8	0.73	4.31	70
VERY LARGE									
Mount Lyell	Australia	Tasman	98.57	1.17	0.01	0.04	0.39	7.20	495
Rouez	France	Caledonian	90.74	0.6		1.5	1.50	21.00	600
Aznalcollar	Spain	Hercynian	90.00	0.51	0.85	1.8	0.48	37.00	320
LaRonde (incl.LaRonde-II)	Canada	Abitibi (Kenoran)	88.00	0.3		1.7	5.07	40.90	2710
Skorpion	Namibia	Gariep	85.00		0.71	8.05			752
Podolsk	Russia	Uralides (Hercynian)	84.10	2.01	0.13	1.3	1.49	27.60	392
Murgul	Turkey	Pontides (Tethyan)	83.14	0.76	0.05	0.03	0.05	3.70	175
Ruttan	Canada	Trans-Hudson	82.80	1.37	0.08	1.63	0.49	13.11	1900
Tambo Grande 3	Peru	S.Cordilleran	82.00	1	0.3	1.4	0.80	25.00	104
San Nicolas	Mexico	C.Cordilleran	79.90	1.34		2.27	0.53	30.00	136
Pyhasalmi	Finland	Svecokarelian	75.70	0.9	0.06	1.9	0.20	14.00	1921
Sotiel	Spain	Hercynian	75.20	0.56	1.34	3.16	0.21	24.00	320
Los Frailes	Spain	Hercynian	70.00	0.34	2.25	3.92		62.00	320
Heath Steele	Canada	Appalachian	69.90	0.58	0.89	2.89	0.54	47.00	465
Ulaan	Mongolia	Kazakh-Mongol(Hercyn.)	68.00		1.2	2	0.21	53.00	380
Caribou	Canada	Appalachian	64.69	0.51	1.6	4.29	1.89	51.00	465
Crandon	USA	Trans-Hudson	63.50	1		6.5			1870
Flin Flon	Canada	Trans-Hudson	62.93	2.2		4.1	2.85	43.20	1875
Zincgruvan(+Knalla)	Sweden	Svecokarelian	60.00		3.2	10.4		69.00	1890
Tishin	Kazakhstan	Altaides (Hercynian)	60.00	0.5	0.9	5.3	0.90	15.00	395
Geco	Canada	West.Superior (Kenoran)	58.40	1.86	0.15	3.45		50.06	2720
Tambo Grande 1	Peru	S.Cordilleran	56.20	1.6	0.3	1	0.50	26.00	104
Deerni (Cu-Co)	China	Indosinian (Tethyan)	54.00	1.23		1.57	0.42	4.73	260
Horne-H&G Orebodies	Canada	Abitibi (Kenoran)	53.70	2.2			6.10	13.00	2700
Mount Morgan	Australia	Tasman	50.00	0.7	0.05	0.1	4.70	0.60	385
Outokumpu(Cu,Zn,Co)	Finland	Svecokarelian	50.00	3.3	0.006	1.07	0.07	9.00	1970
Artem'yev	Kazakhstan	Altaides (Hercynian)	50.00	1.4	1.6	2.2	1.20	143.00	375
Lousal	Portugal	Hercynian	50.00	0.7	0.8	1.4	0.70	21.00	300
LARGE									
Britannia	Canada	N.Cordilleran	49.31	1.08	0.033	0.28	0.34	4.03	150
Novo-Leninogorsk	Kazakhstan	Altaides (Hercynian)	48.00	0.16	1.43	4.04	1.54	32.80	395
Prieska	South Africa	Namaqua	47.00	1.7		3.8	0.00		1300
Anyox-Hidden Creek	Canada	N.Cordilleran	45.96	1.37			0.17	9.52	195
Hanaoka Mine (total)	Japan	Japan arcs(Tethyan)	43.50	1.2	1.5	4.7	0.40	68.00	15
Aguas Tenidas	Spain	Hercynian	41.00	1.3	0.91	3.1	0.50	37.00	320
Hongtoushan	China	Sino-Korean Platform	40.00	1.75		2.4	0.77	32.40	3000
Maleev	Kazakhstan	Altaides (Hercynian)	40.00	2.3	1.3	7.5	0.75	75.00	390
Orlovskoye	Kazakhstan	Altaides (Hercynian)	40.00	2.4	0.5	2.1	0.80	47.00	392
Ashele (#1)	China	Altayshan (Hercynides)	34.00	2.51		2.98	0.57	104.03	375
Xiaotieshan	China	Tarim-NorthQilian (Calod.)	34.00	1.26	3.39	5.33	2.28	126.20	440
Arctic (Brooks Range,Ak)	USA	N.Cordilleran	32.93	4	0.8	5.5	0.70	55.00	365
Rosebery	Australia	Tasman	32.70						
Liwu	China	Yidun, Indosinian (Tethyan)	31.00						
Belousov	Kazakhstan	Altaides (Hercynian)	30.00						

Source: Galley et al. (2007)

Mineralisation – consistent features

- Host
  - Turbiditic metasedimentary rocks
- Footwall
  - Mafic schist (ex-basalt) and sills
  - MORB-affinity [1,2]
- Hangingwall
  - Silica-iron rocks overlie ore
  - Mass flow with massive sulfide clasts at Tritton [3]

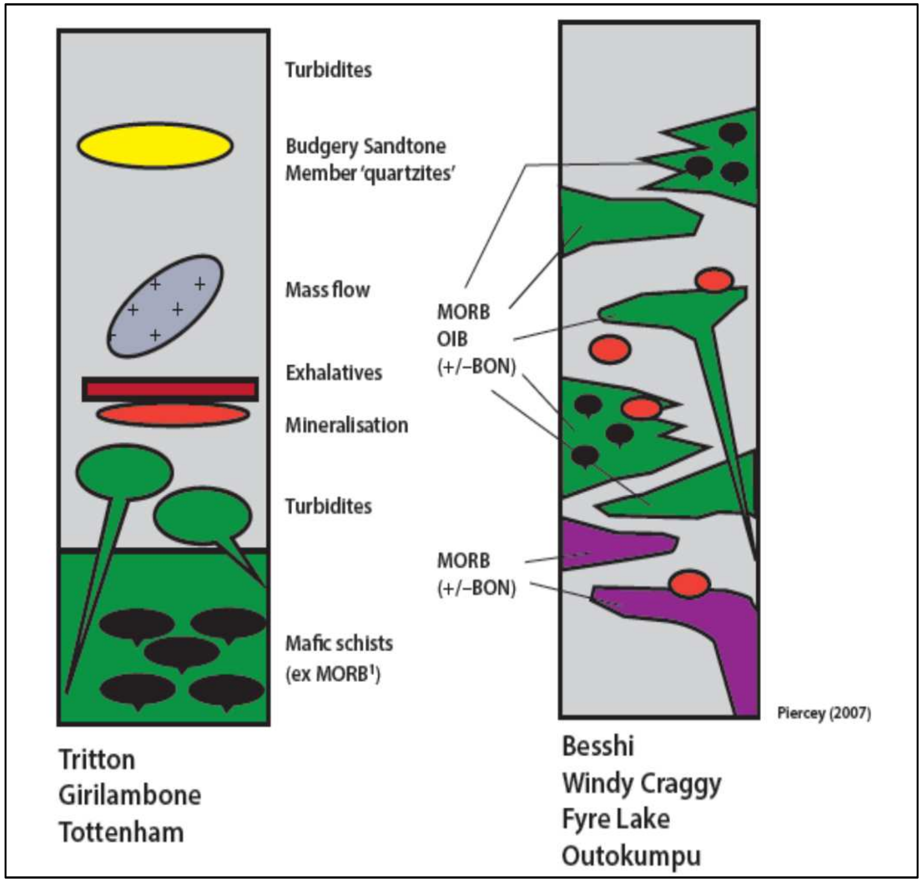


1 - Burton 2011, 2 – Burton 2014, 3 - Jones 2012

Mineralisation – consistent features

- Mineralisation[1]
  - Massive sulfide (cpy–py) zone
  - Pyrite-rich banded zone
  - Sub-economic veins in FW
  - Cu rich (elevated Au, Zn, Ag)

- Zoned alteration[1]
  - Proximal Fe- to distal Mg-chlorite in FW
  - Silicification of the ore zone
  - Carbonate-altered HW



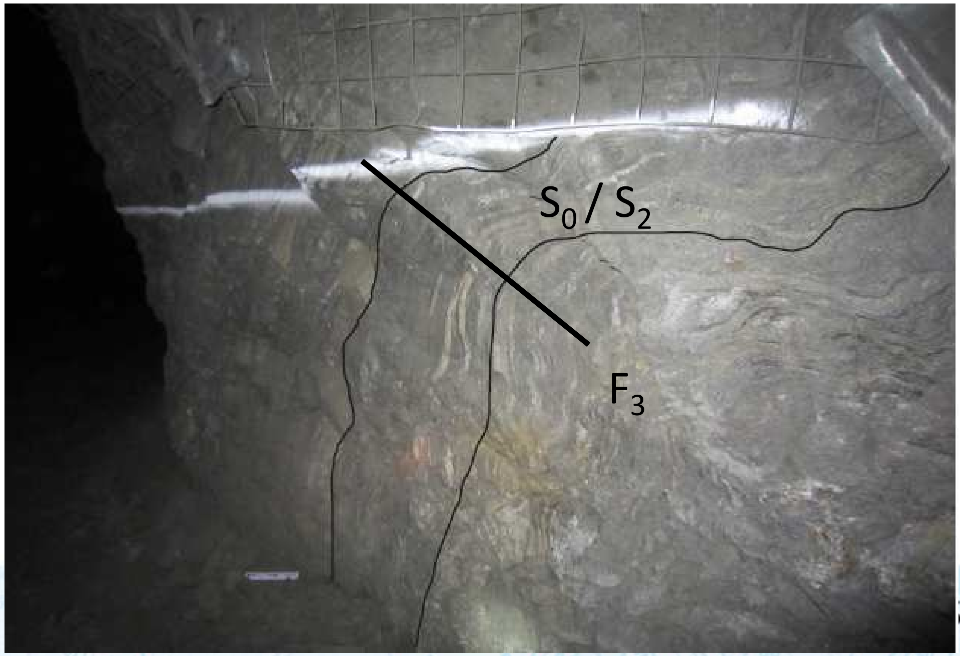
Gilmore (2014, 2015) after Piercey (2007)

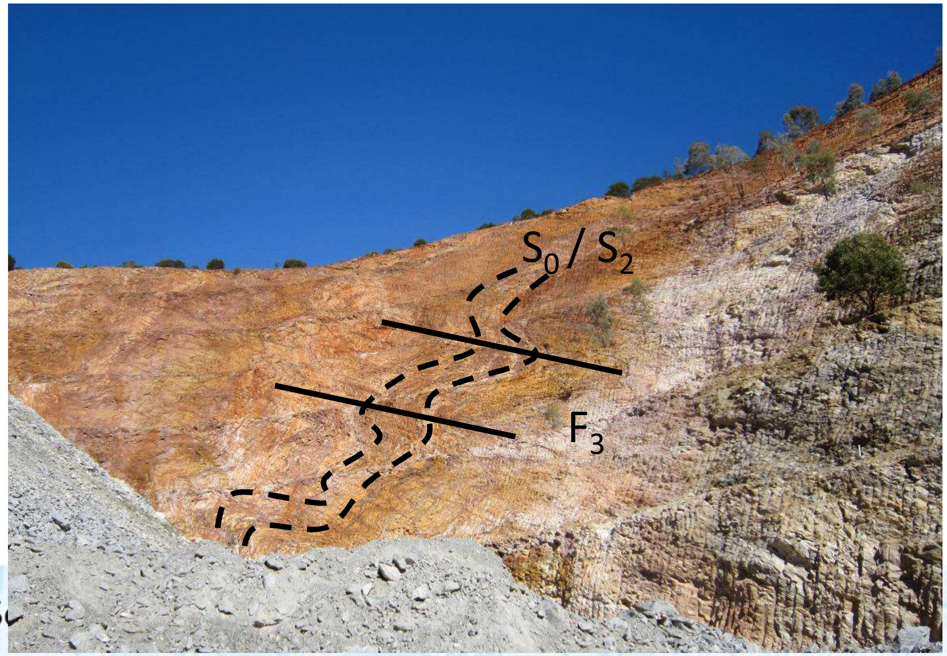
1 - Jones 2012

Mineralisation – consistent features

Deformation

- Mineralisation deformed the same as turbidites
  - i.e. mineralisation predates Benambran Orogeny
- Some remobilisation of chalcopyrite
- Late brittle faults

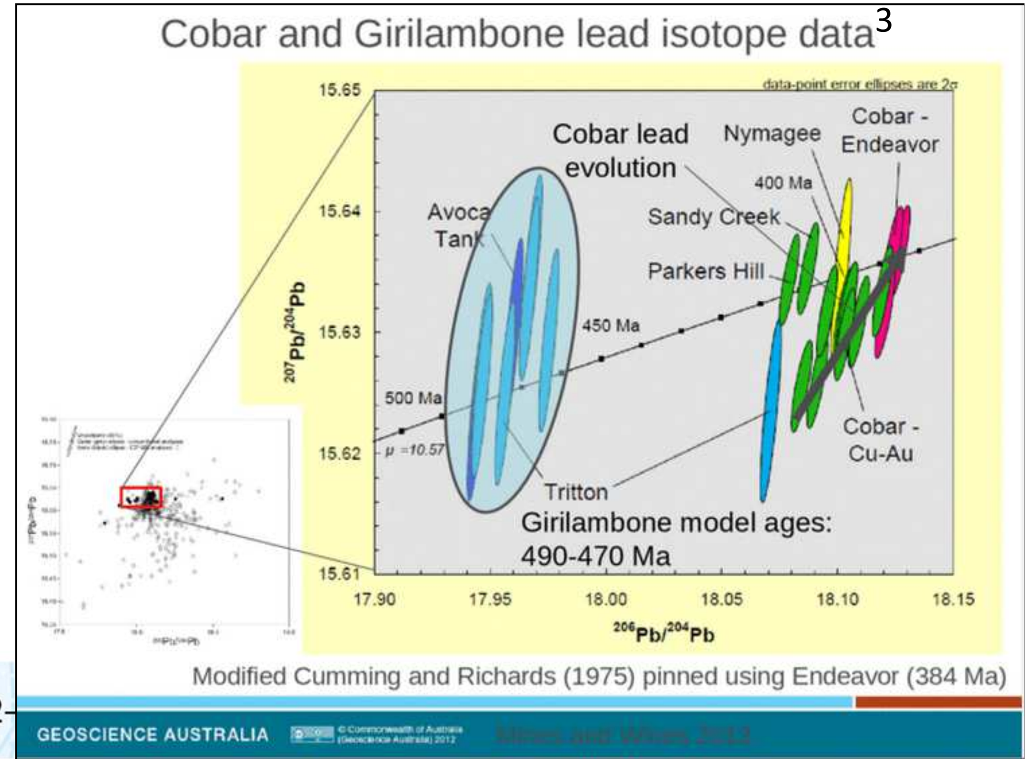




Mineralisation – age evidence?

- Hosted by Early Ordovician Narrama Formation
  - Biostratigraphy
  - Supported by detrital zircon provenance[1]

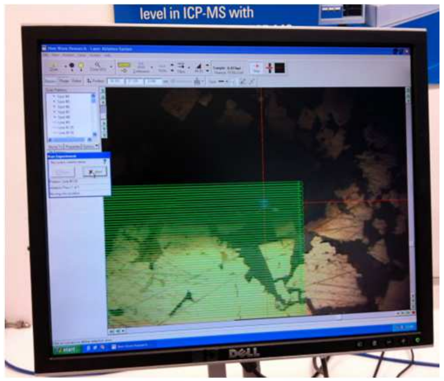
- Plus Pb isotope model ages[2,3]
  - Mostly Late Cambrian to Early Ordovician
  - Minor Devonian

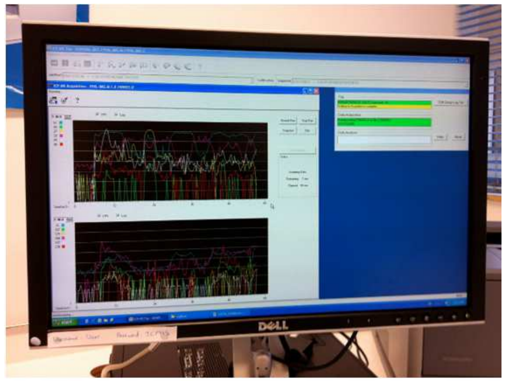


Source: 1 – Fraser et al. (2014), 2 – Downes (2008), 3 - Huston et al. (2013)

Research project

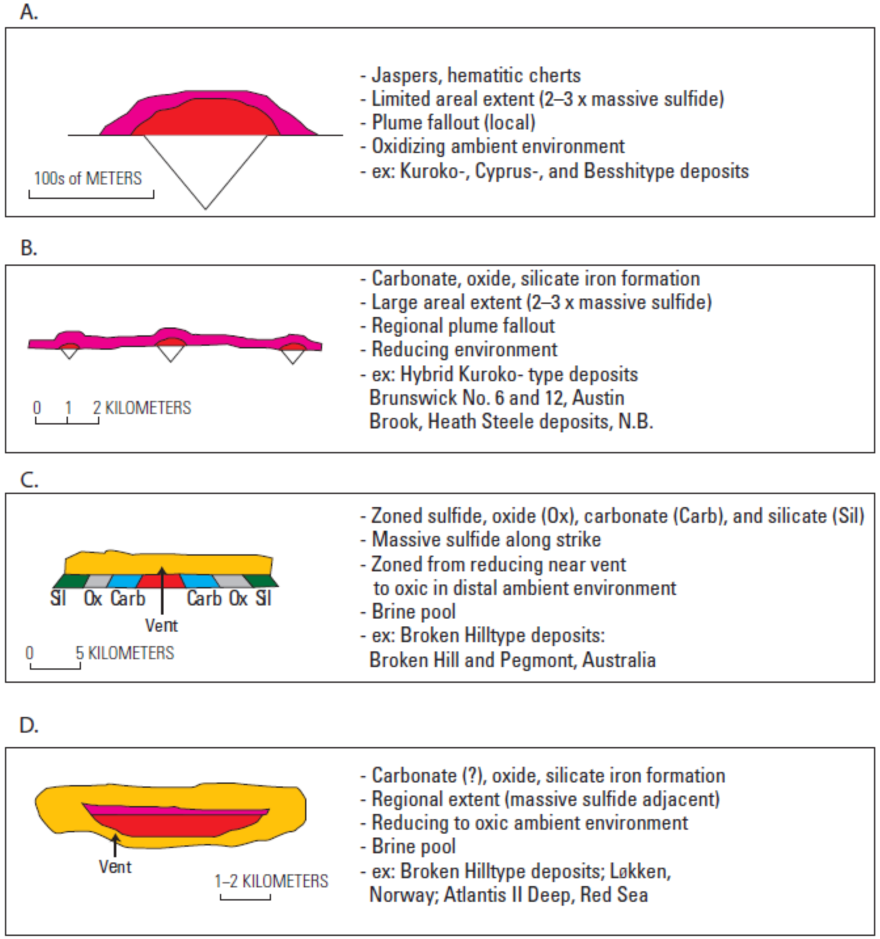
- Significance of silica-iron rocks
  - Formation? Are they exhalative?
  - Mineralised v non-mineralised
  - Exploration vector?
- Mineralisation
  - Formation?
- Tools
  - Sulfur isotopes
  - Petrophysics
  - Pyrite geochemistry
    - Laser ablation ICPMS





Silica-iron rocks

- Exhalative or exhalite
- Worldwide feature with VAMS
  - Time and space
  - Typically overlie ore levels
  - Laterally extensive
- Form from 'hydrothermal input to ongoing sedimentation'[1]
- Geochemistry of magmatism influences type
  - Felsic systems = barite
  - Mafic systems = jaspers

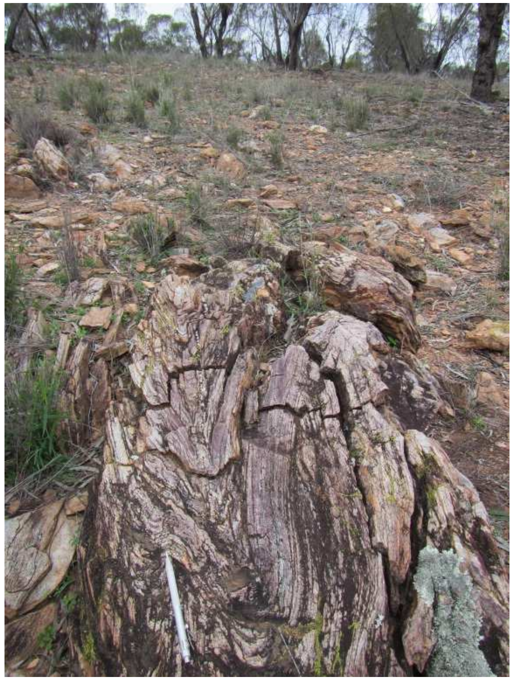


Slack (2010) USGS

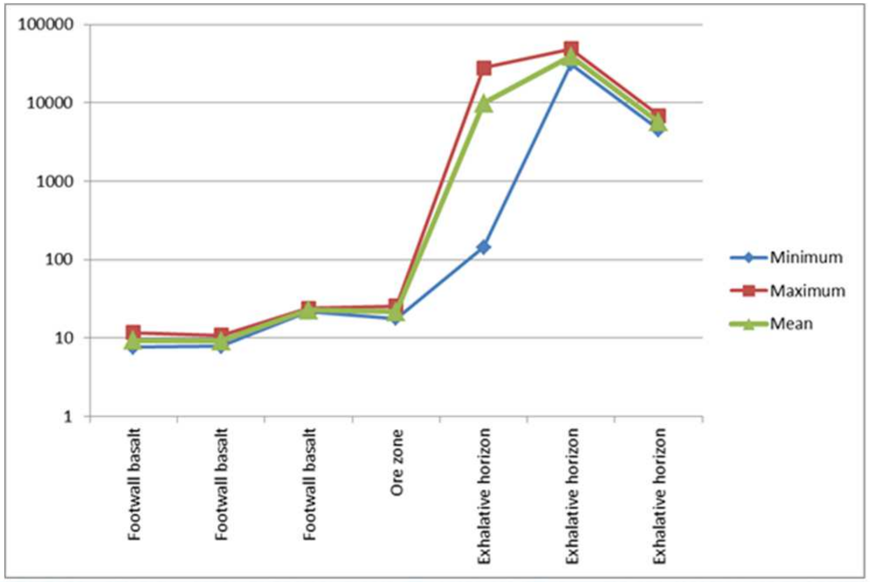
1 – Gibson et al. 2007

Silica-iron rocks

- Only in Early Ordovician Narrama Fm.
- Always near mafic or ultramafic rocks
- Layered quartz and iron oxides
- Same structure as turbidites
- 57 to 94% SiO_2
- 2 to 10% Fe_2O_3
- Variable magnetite content but still most magnetic rocks regionally
  - Average magnetic susceptibility 1452 x 10^{-5} SI
  - Maximum 52 100 x 10^{-5} SI



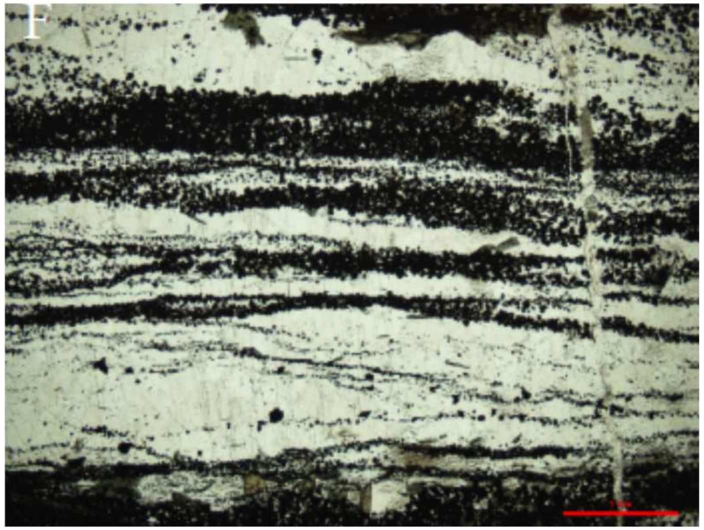
Tottenham ore zone



Silica-iron rocks

- Those associated with mineralisation are geochemically distinct
  - Positive Eu anomaly when normalised to chondrite
  - Relative enrichment in REE
  - Elevated Cu and Ag
  - Narrow range of sulfur isotopes
    - 10.2 and 12.8‰
    - Reduced seawater sulfate source
    - (other silica-iron biogenic source)

- In summary …
  - Silica-iron rocks are magnetic
  - Those associated with mineralisation can be discriminated geochemically



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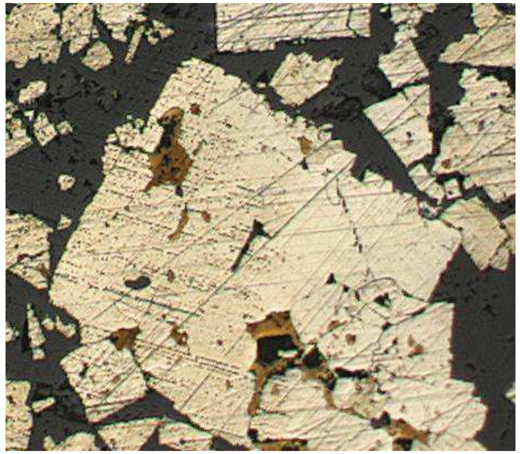
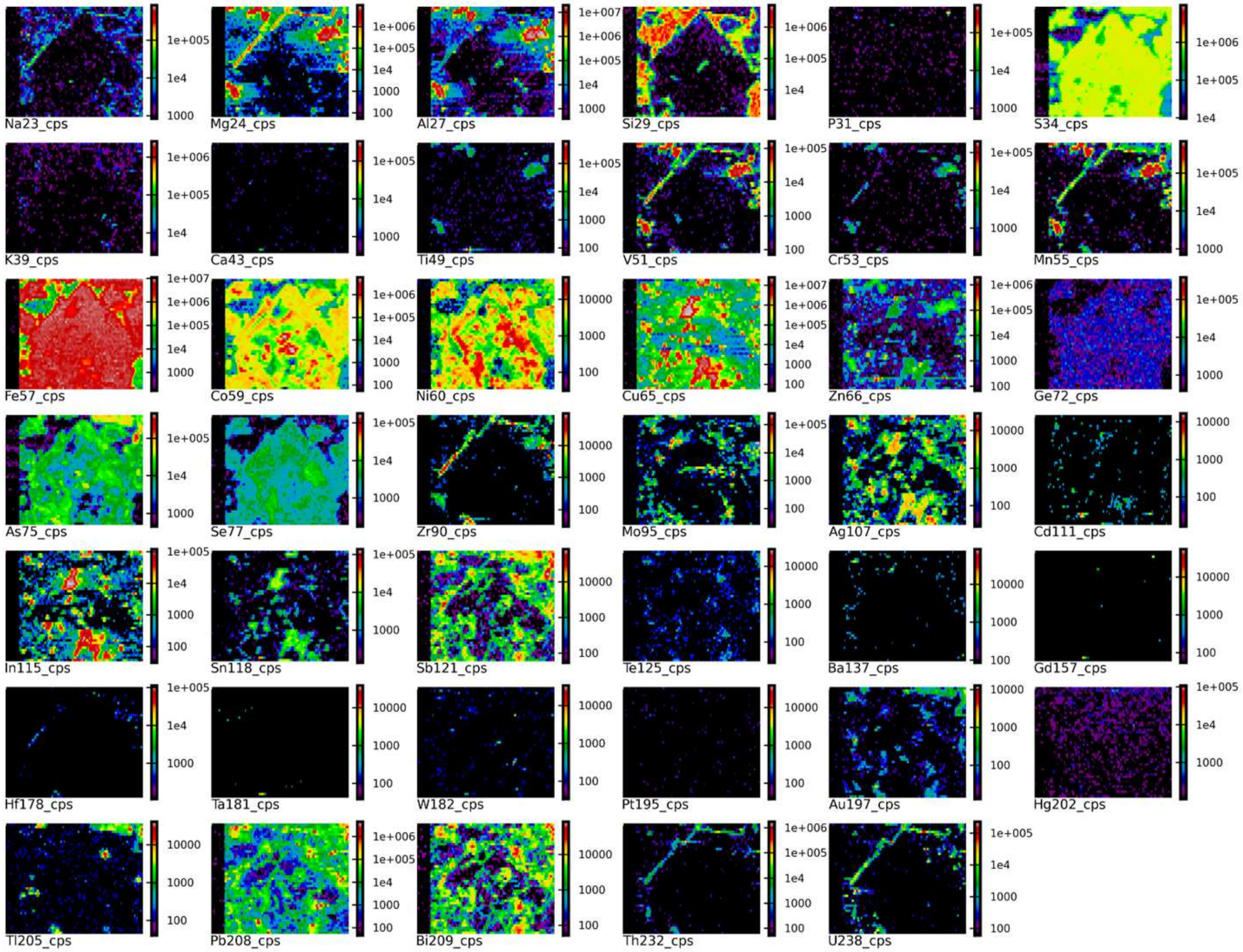
Mineralisation



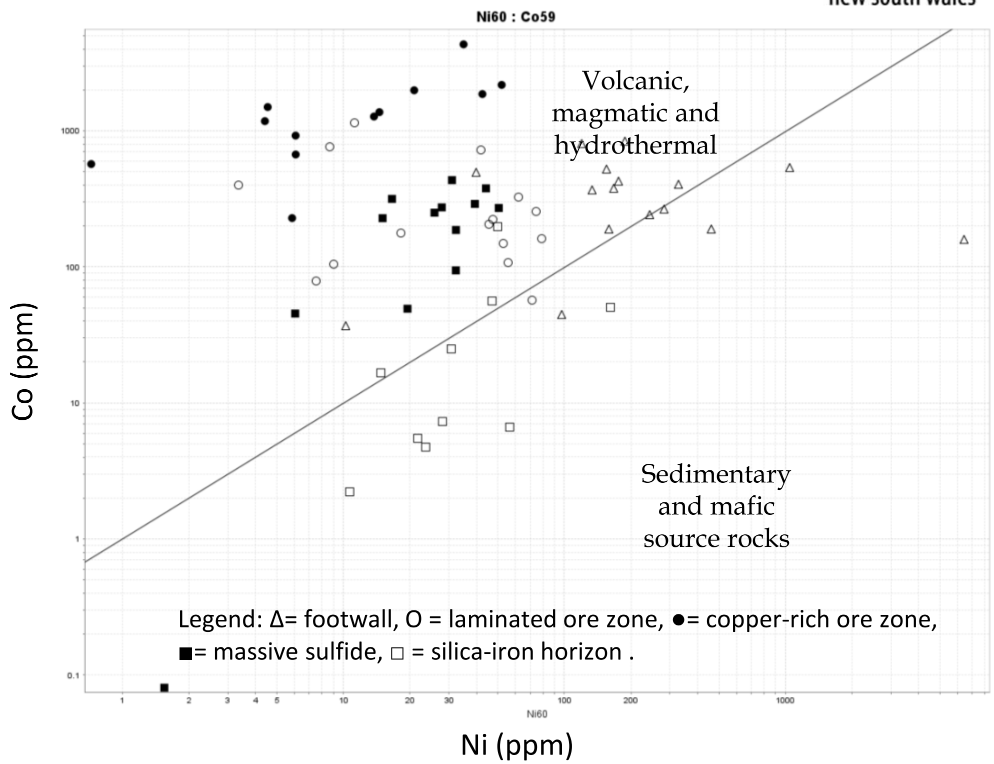
- Sample from banded pyrite ore at Tritton
- Chalcopyrite within early pyrite
- Sn (Ag-In) with Cu
  – Magmatic source
- Ni v Co ratio
  - Mafic source
- U-Th rims
  – Seawater source



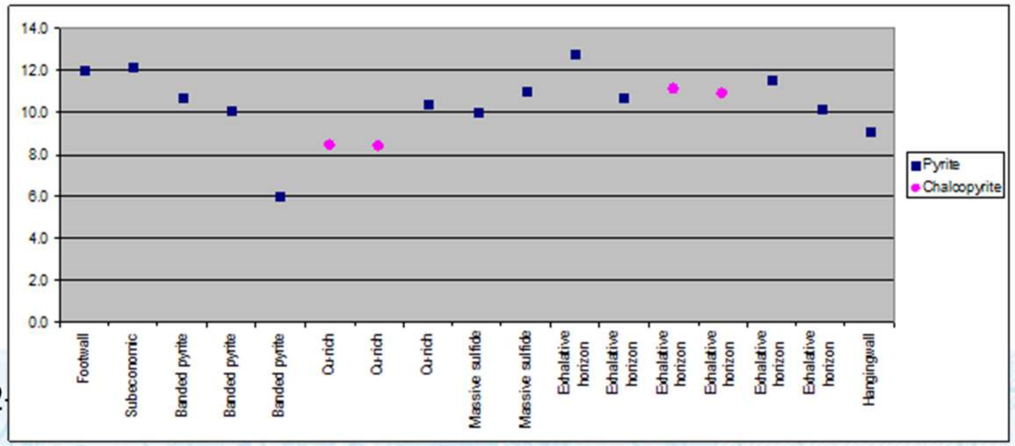
Mineralisation v silica-iron

- Pyrite geochemistry
  - As you go up sequence …
    - Lower temperature
    - Increased sediment input
- Sulfur isotopes
  - Consistent across zones
- Deformation
  - Same fabrics and geometry

- Exhalative horizons formed from same process as mineralisation

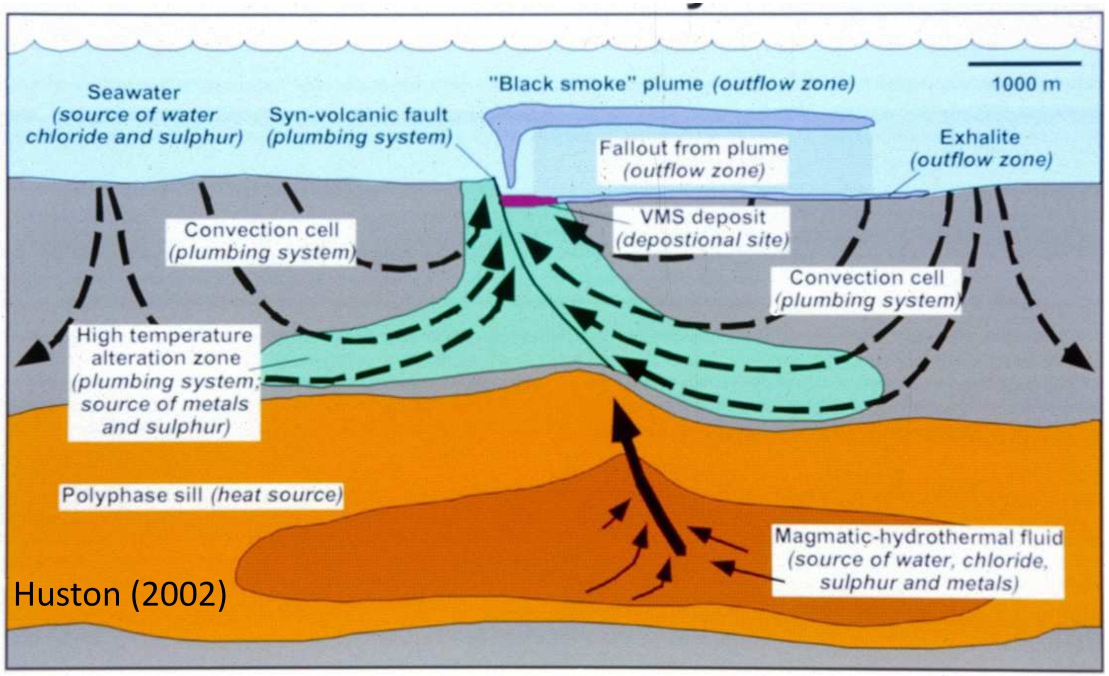


Sulfur isotopes across Tritton ore zone (‰)



Mineralisation - how did it form?

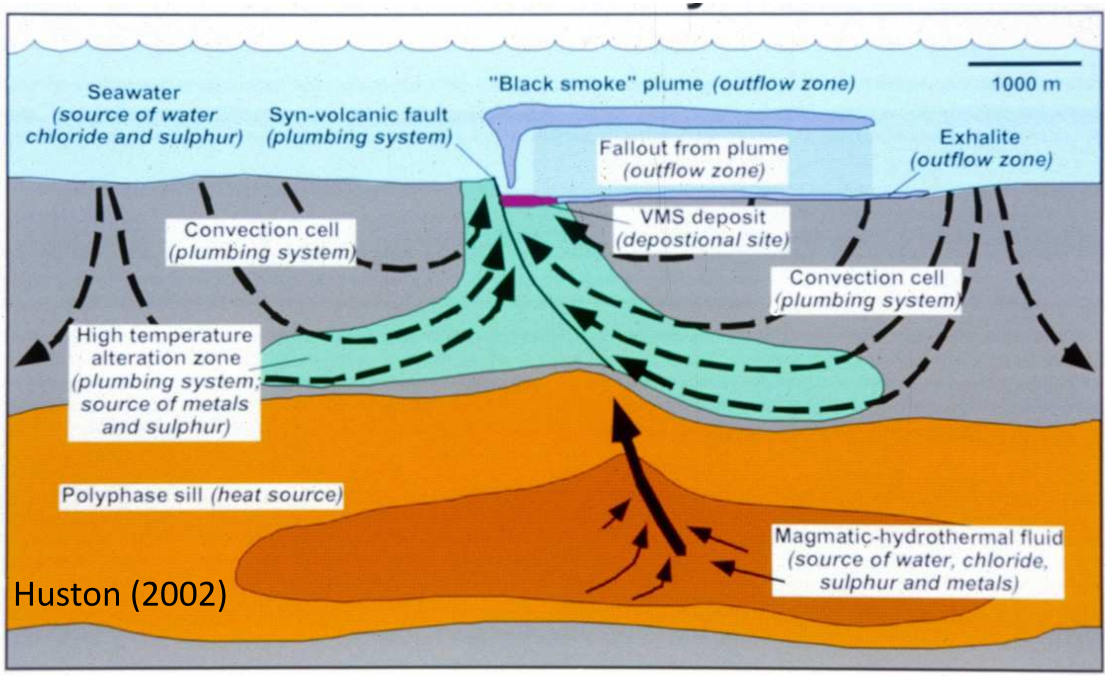
- Early Ordovician extension
- Hydrothermal cell driven by magmatism (MORB)
- Fluid from magma, seawater, sediments
- Metal precipitation as cooled by seawater in sediment pile
  - Subseafloor replacement
- Exhalites are spent fluids



Huston (2002)

Mineralisation - how did it form?

- A syngenetic origin – volcanic-associated massive sulfide (VAMS)
  - Mafic-siliclastic[1] or pelitic–mafic-hosted (Besshi-type) Cu[2]
- Preservation aided by sediment pile and ongoing sedimentation
- Deformed in Benambran Orogeny
  - Remobilisation of chalcopyrite, not hot enough to effect pyrite



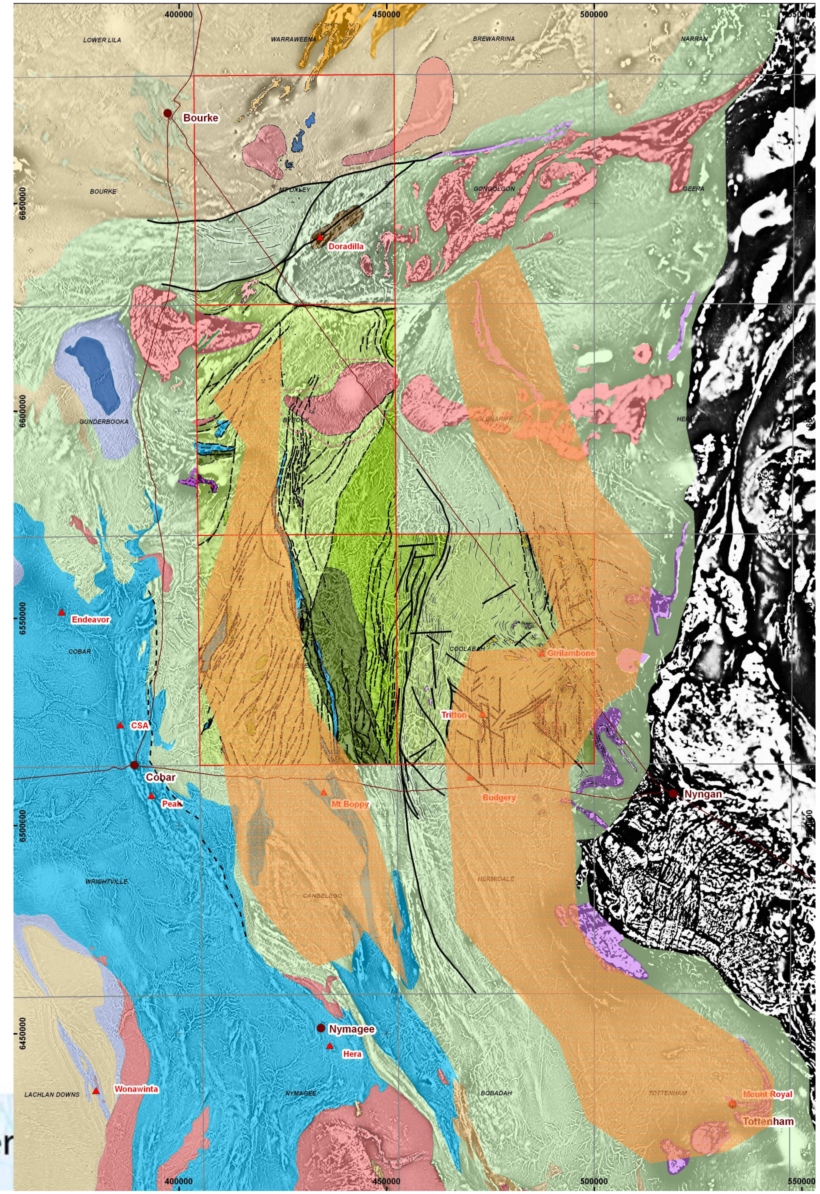
Huston (2002)

Source: 1 – Piercey (2007), Downes et al. (2011)

So how do you find one … an exploration guide

- Stratigraphic corridor
  - Look in the Narrama Formation
    - FW – mafic (MORB not OIB)
    - HW – quartzite, exhalative
  - Use regional magnetic data
    - Most likely exhalative horizons
    - Look at REE, Eu, Cu, S-isotopes
  - Electrical geophysics
    - AEM / DHEM (e.g. Collins 2001)

- Structure
  - Regional-scale (F3) folding
    - Structural repeats?
  - Ore body geometry



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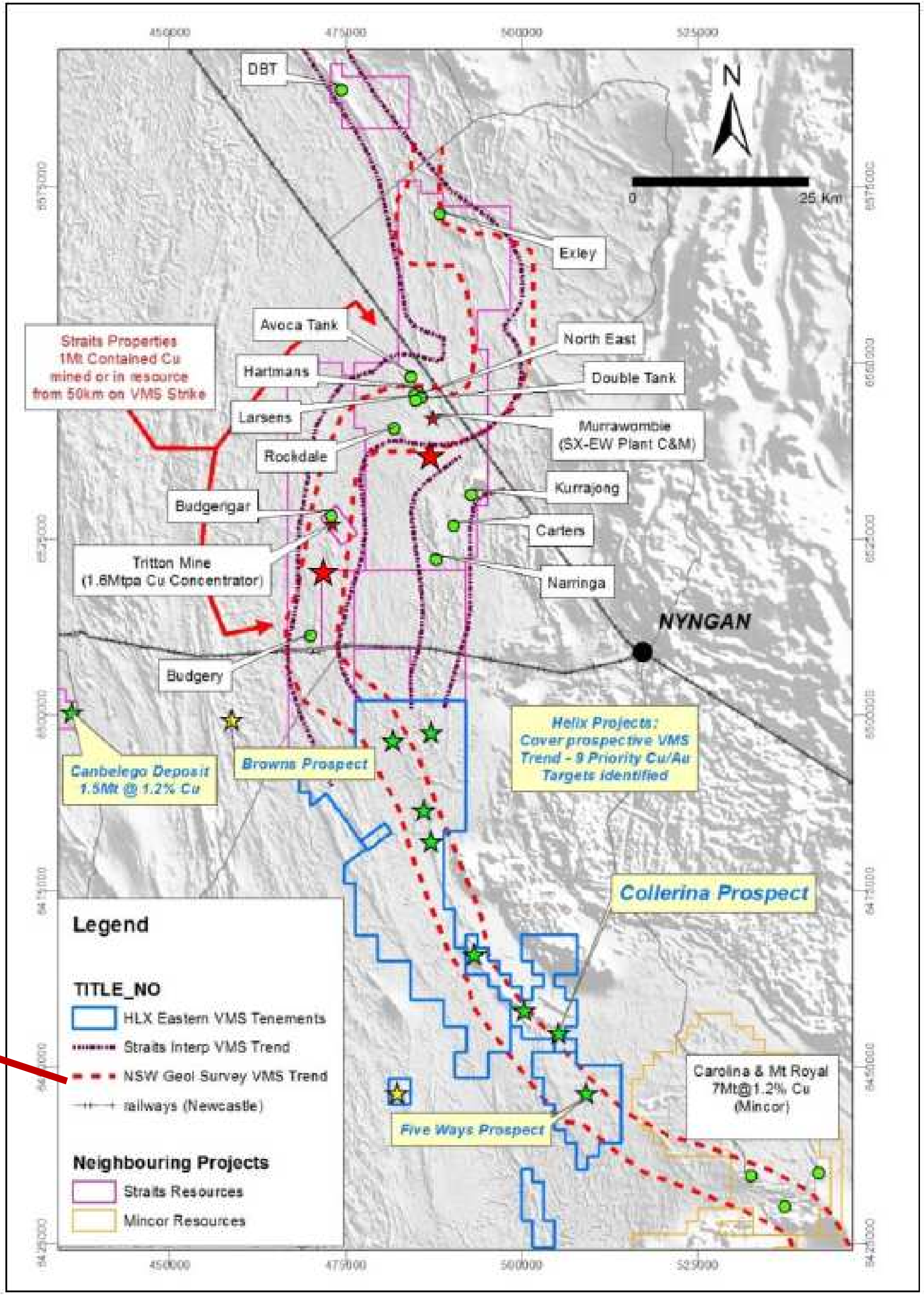
Exploration guide

- Helix Resources Limited discovered Collerina VAMS in 2014
- Between Budgery and Tottenham
- GSNSW trend used to identify potential targets under cover



Source: Helix, ASX announcement 01/04/2015

Summary

- Girilambone Group hosts significant VAMS mineralisation
- Understanding the setting and style of mineralisation is critical to develop exploration models for further discovery
- Integration of geoscientific observations at different scales
- Communication between geologists
    - Government
    - Industry
    - Academia

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