



Proterozoic Mafic-Ultramafic Magmatic Events: Implications for Nickel Mineralisation

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Lynton Jaques
& Mike Huleatt**



Australian Government
Geoscience Australia

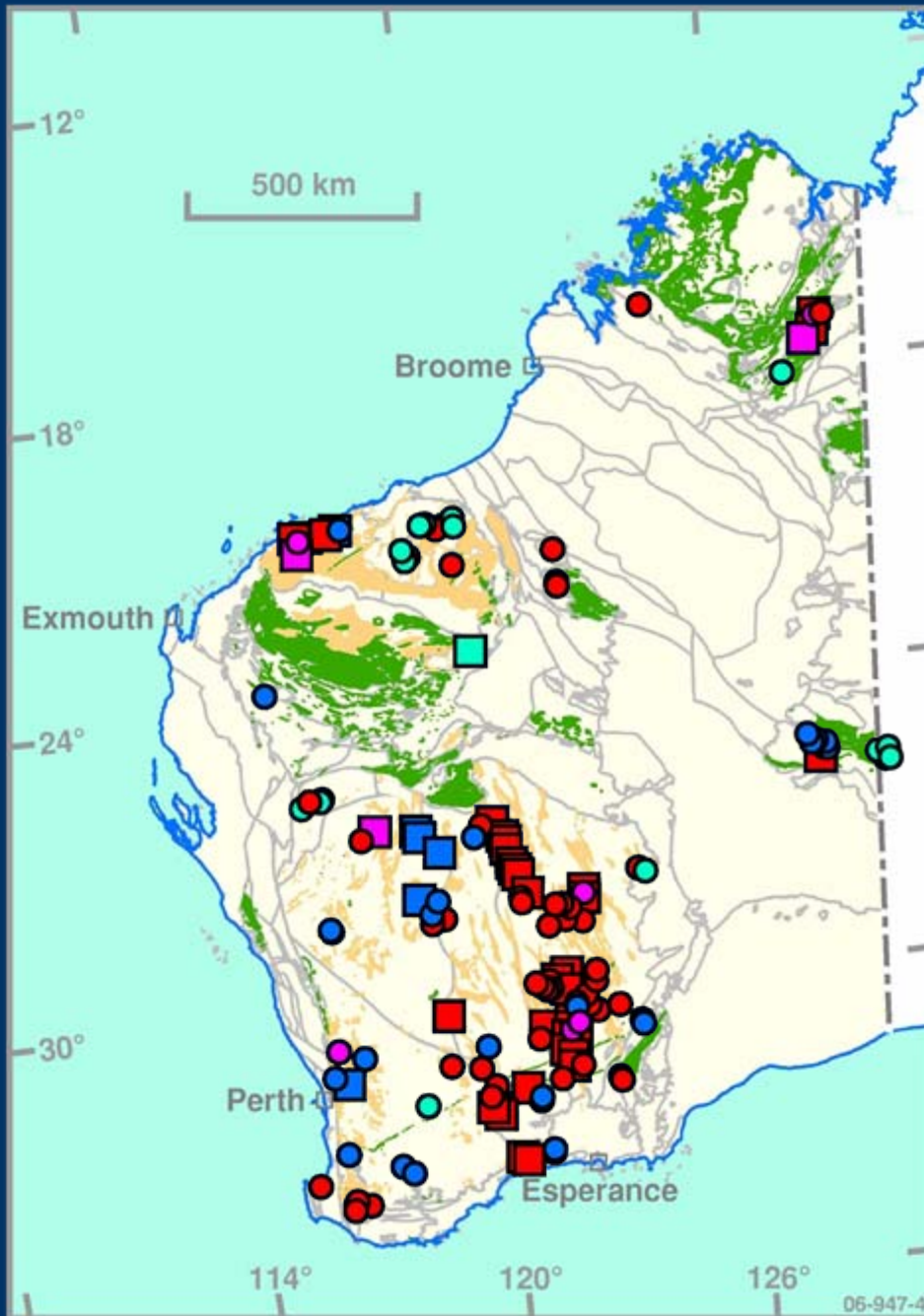
Australian Nickel Conference
18-19th October 2006

Panton intrusion (1855 Ma), E. Kimberleys: Oswald-Jacobs



Outline

- **Context of Australia's nickel sulphide industry**
- **Rationale & strategies of the 'MUM' Project**
- **'Proterozoic Time Walk': Mineralised magmatic events of Western Australia**
- **Implications for nickel mineralisation**

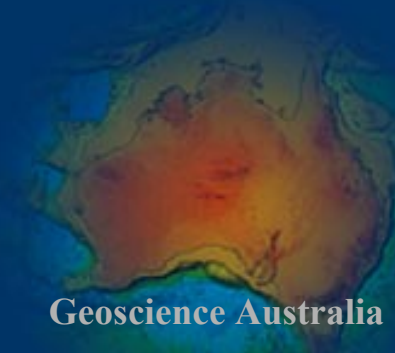


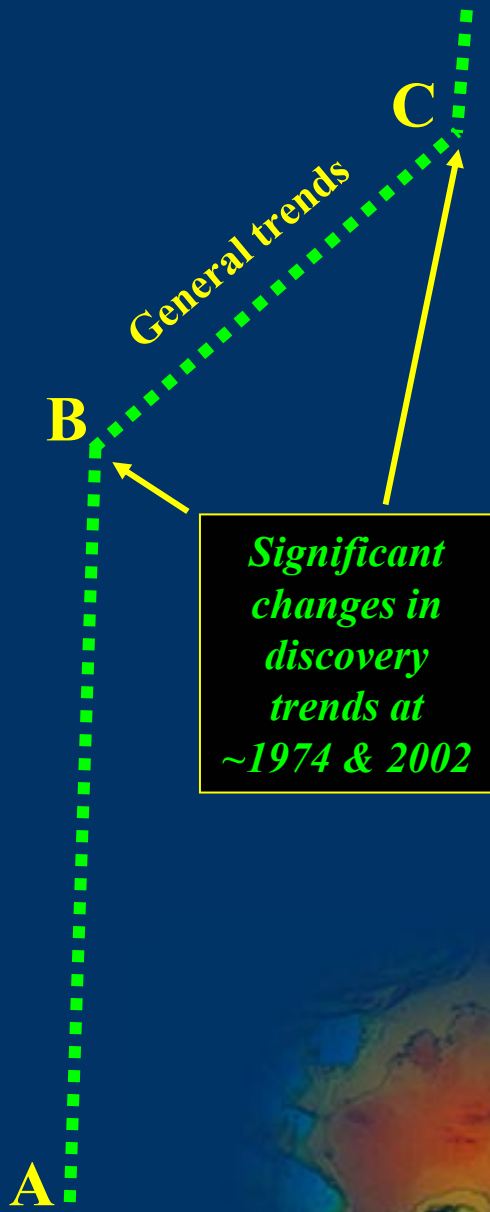
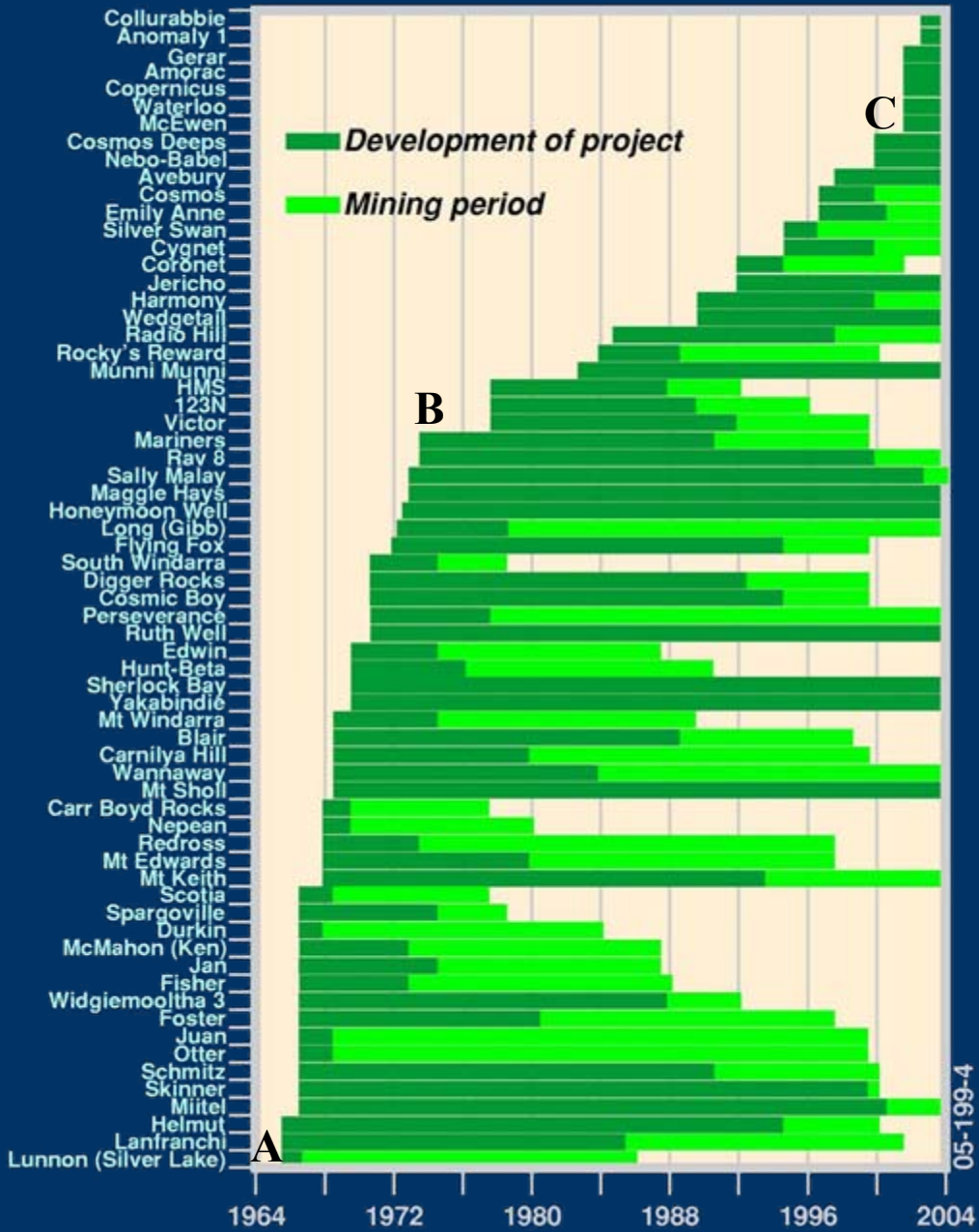
Distribution of Precambrian mafic and ultramafic rocks, mineral deposits and occurrences

- Proterozoic*
- Archean*
- Province boundary*

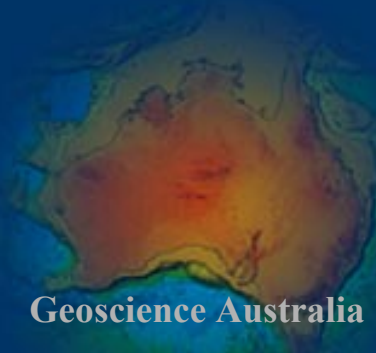
Deposit Occurrence

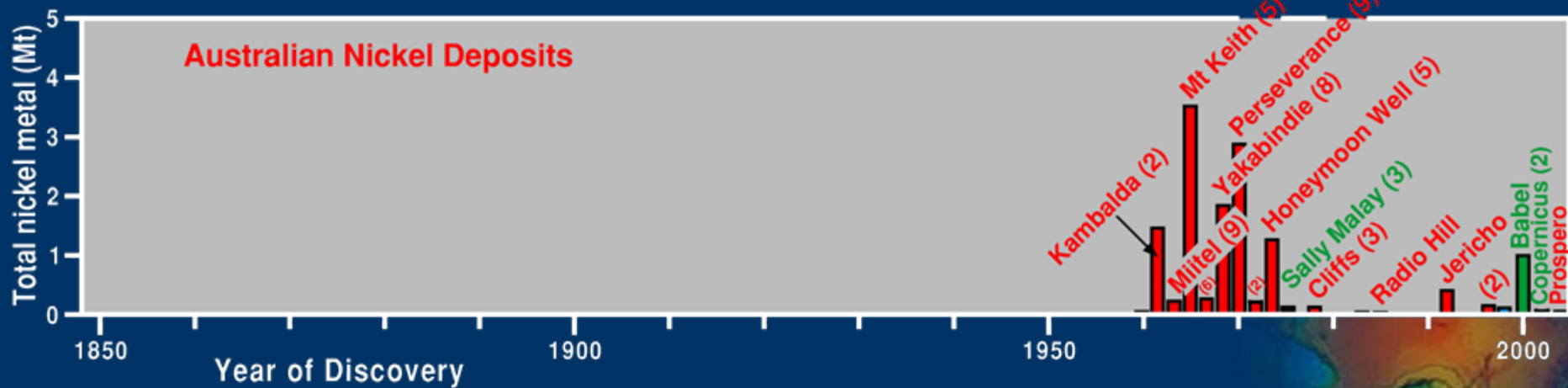
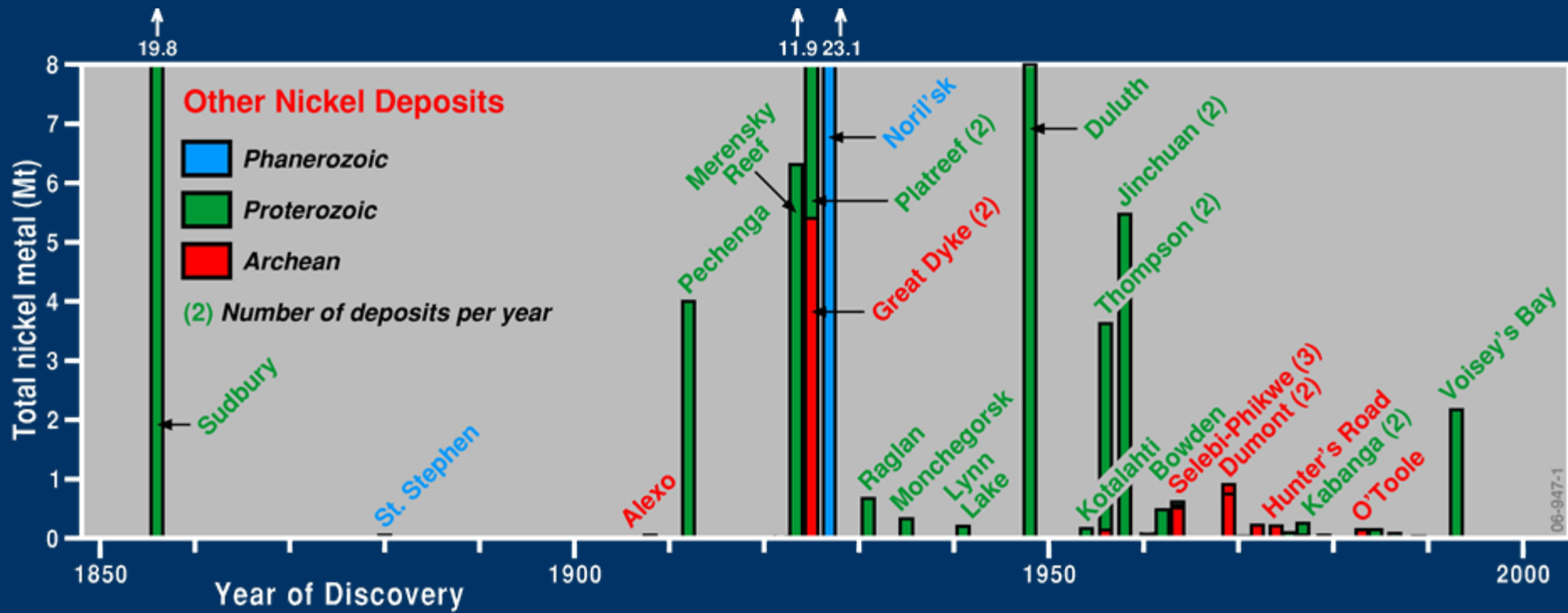
- Nickel*
- Chromium*
- Platinum-Group Elements*
- Vanadium and/or Titanium*





Significant changes in discovery trends at ~1974 & 2002





A New Initiative by Geoscience Australia to Assist Australian Nickel Explorers

Characterisation and Metallogenesis of Proterozoic Mafic-UltraMafic ('MUM') Rocks

National focus:

Phase 1 (*completed*): Western Australia

Phase 2 (06-07): South Australia, Northern Territory

Phase 3 (07): Eastern Australia

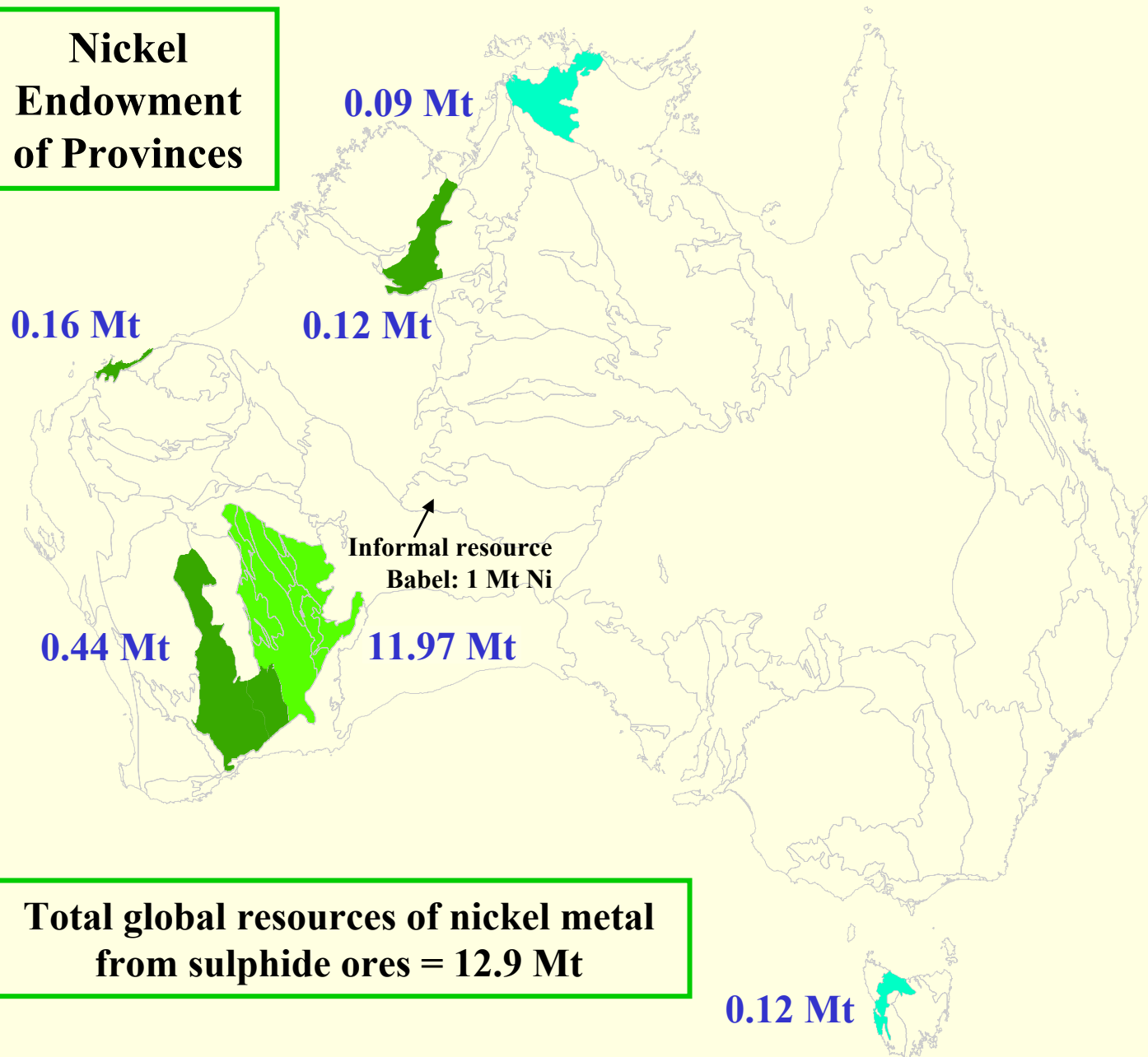
Phase 4?: Mineral potential assessment of Aust 'MUM' rocks

Why the Proterozoic and initially Western Australia?

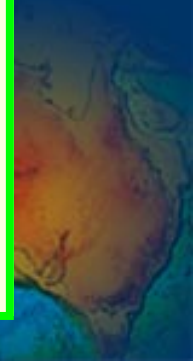
1. Abundance of high-potential mafic-ultramafic rocks that are often poorly exposed and have received limited exploration
2. WA accounts for ~80% of the nation's Ni-Co exploration of \$146 m & contains >95% of Australia's Ni sulphide resources

(ABS 2006)

**Nickel
Endowment
of Provinces**



**Total global resources of nickel metal
from sulphide ores = 12.9 Mt**



Methodology of 'MUM'

MAGMATIC EVENTS MAP: WESTERN AUSTRALIA

- **Characterisation:** Province, Formation, Age, Rock Types, Bulk Composition, Setting, Mode of Occurrence, Thickness, Country Rocks, Deposit Types. Datasets linked by STRATNO (ARC GIS 9)
- **Magmatic Event Criterion:** Published, reliable (>75% U-Pb zirc/badd) *absolute* age of mafic or ultramafic rock that has a 'valid temporal context' with surrounding rocks, structures, deformations, etc
- **Datasets:** *Geochron*–OZCHRON (GA), GA-GSWA bulletins, reports, records, scientific publications, company reports, theses; *Deposits*–OZMMIN (GA); *Geophysics*–GADDS (GA)
- **GSWA Base Maps:** *Rock Polygons*–1:0.5 M Interpreted Bedrock Geology WA Map; *Province Boundaries*–1:2.5 M Tectonic Units of WA; *Dolerite Dykes*–1:2.5 M Geological Map of WA

Major Magmatic Events

-  ME 15 (m): ~510 Ma
(Kalkarindji Event)
-  ME 14 (m)1: ~755 Ma
(Mundine Well Event)
-  ME 13 (m): ~825 Ma
(Gairdner Event)
-   ME 12 (mu): ~1070 Ma
(Warakurna Event)
-  ME 11 (m): ~1210 Ma
(Marnda Moorn Event)
-  ME 10 (mu): ~1300 Ma
(Fraser Event)
-  ME 9 (m): ~1465 Ma
(Bangemall Event)
-  ME 8 (m): ~1790 Ma
(Hart Event)
-   ME 7 (mu): ~1860 - 1830 Ma
(Sally Malay Event)
-   ME 6 (m)1: ~1880 - 1860 Ma
(Bow River Event)
-  ME 5 (m): ~1910 Ma
(Narracoota Event)
-  ME 4 (m): ~2010 Ma
(Paraburdoo Event)
-  ME 3 (m): ~2210 Ma
(Turee Creek Event)
-   ME 2 (m): ~2420 Ma
(Widgiemooltha Event)
-  ME 1 (m): ~2450 Ma
(Weeli Wollie Event)
-  Undefined

ME 1 : Magmatic Event 1

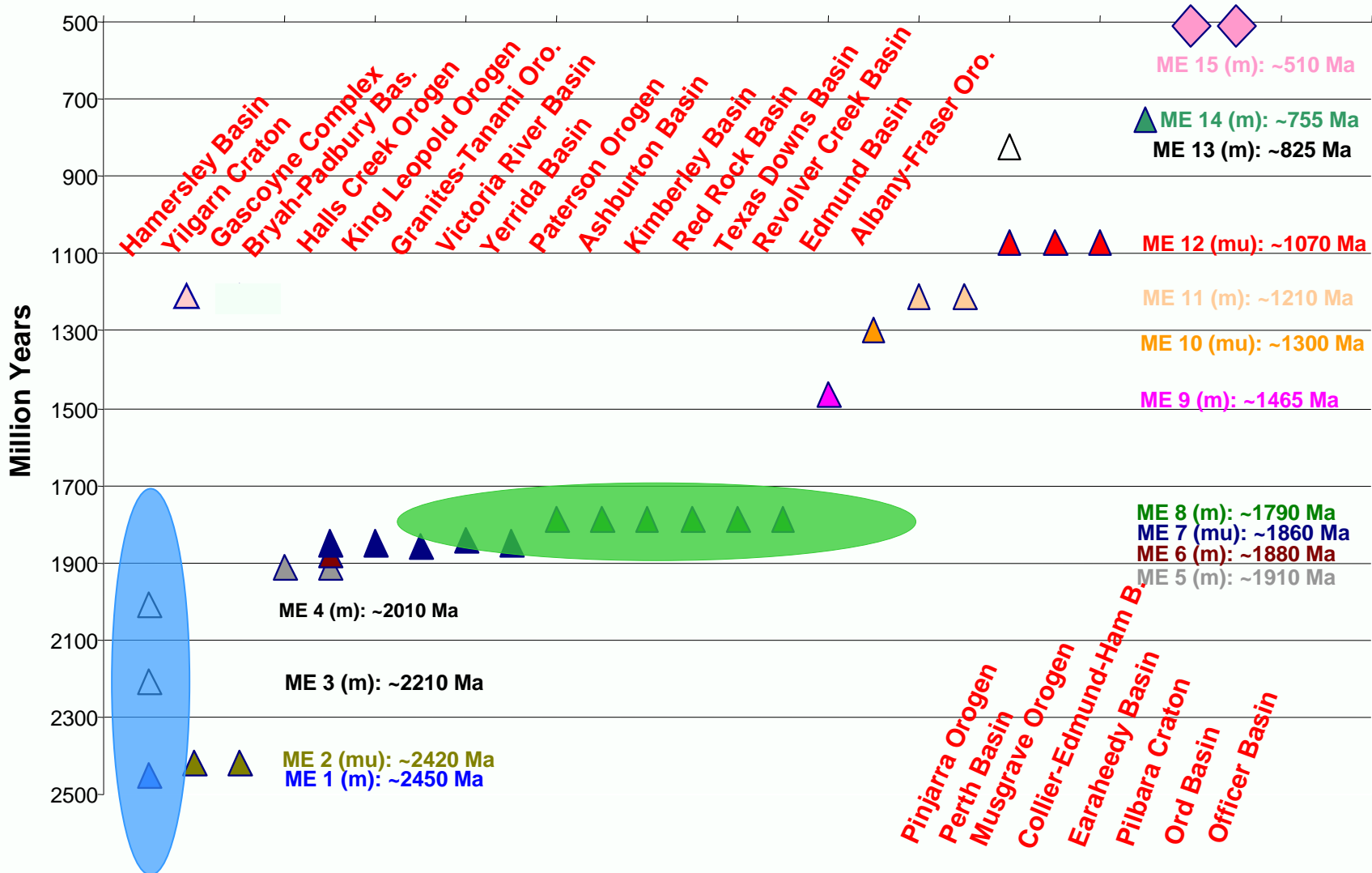
m: mafic only

mu: mafic and ultramafic

Weeli Wollie Event: Informal Event name



Summary of Major Magmatic Events





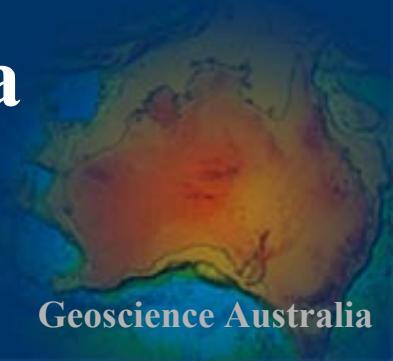
Proterozoic Time Walk: Mineralised Magmatic Events

ME 2: Widgiemooltha Event ~2420 Ma

ME 6: Bow River Event ~1880-1860 Ma

ME 7: Sally Malay Event ~1860-1830 Ma

ME 12: Warakurna Event ~1070 Ma





ME 2: Widgiemooltha Event ~2420 Ma

Province: Yilgarn Craton

Examples: Jimberlana (2411 Ma)-Binneringie (2418 Ma)-Celebration-King of the Hills Dykes

Form: Layered & massive dykes

Rock Types: Norite, gab, ol gab, dunite, harzburg, granophyre

Size: Small to large bodies; up to 3 km thick & 650 km strike extent

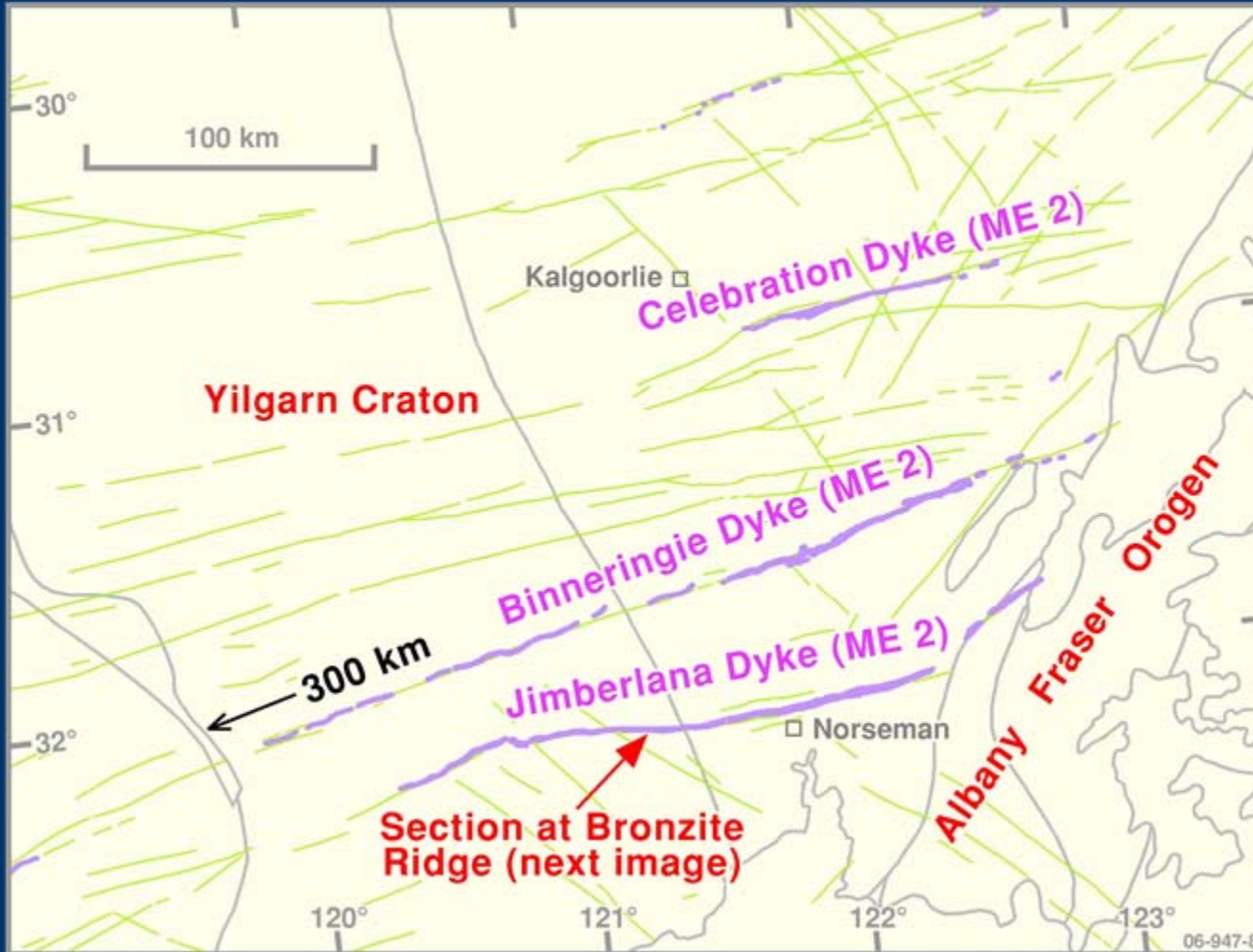
Country rocks: Archean granite, greenstone

Mineralisation: Diverse: stratabound PGE-Ni-Cu; basal contact Ni-Cu, off-set Ni-Cu, & breccia pipe Ni-Cu

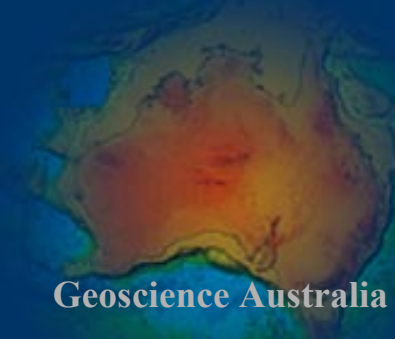
Status: Prospect

Analogues: Great Dyke of Zimbabwe (2587 Ma), Munni Munni (2925 Ma), (potential for Voisey's Bay (1333 Ma), Radio Hill (2892 Ma))

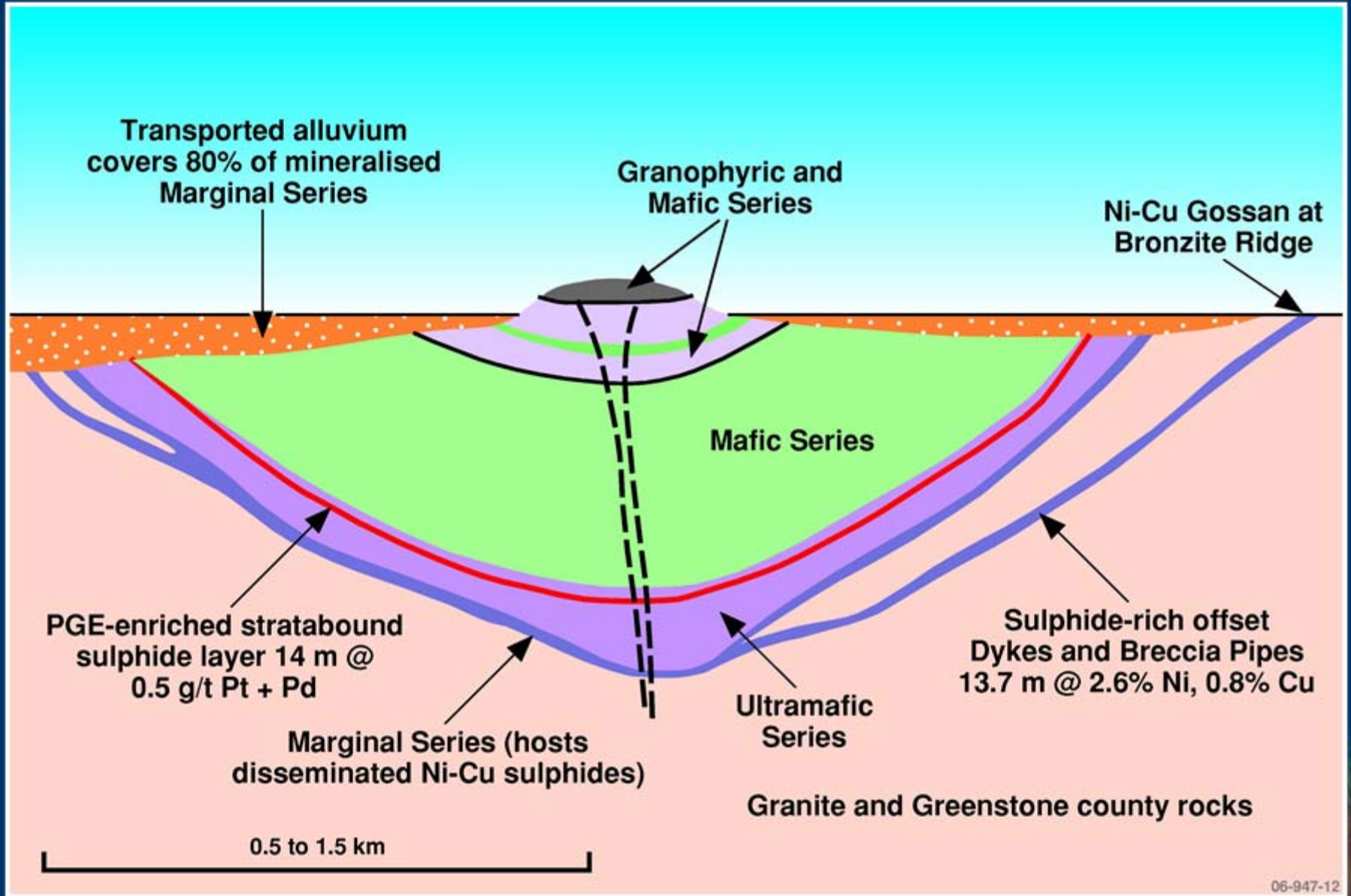
ME 2: Widgiemooltha Dyke Swarm (~2420 Ma)



-  2420: ME 2 (mu)
 -  Interpreted dolerite dykes and sills
 -  Province boundary
- ME 2 : Magmatic Event 2
mu: mafic and ultramafic



ME 2: Jimberlana Dyke (2411 Ma)



ME 6: Bow River Event ~1880-1860 Ma

Province: Halls Creek Orogen

Examples: Tickalara Metamorphics; Biscay Fm; Bow River-Norton-?Corkwood-?Keller Ck Intrusions

Form: Sill, dyke, massive intrusion, lava

Rock Types: Mafic granulite, amphibolite, metagabbro, basalt

Country rocks: Proterozoic pelite, psammite, migmatite, granite

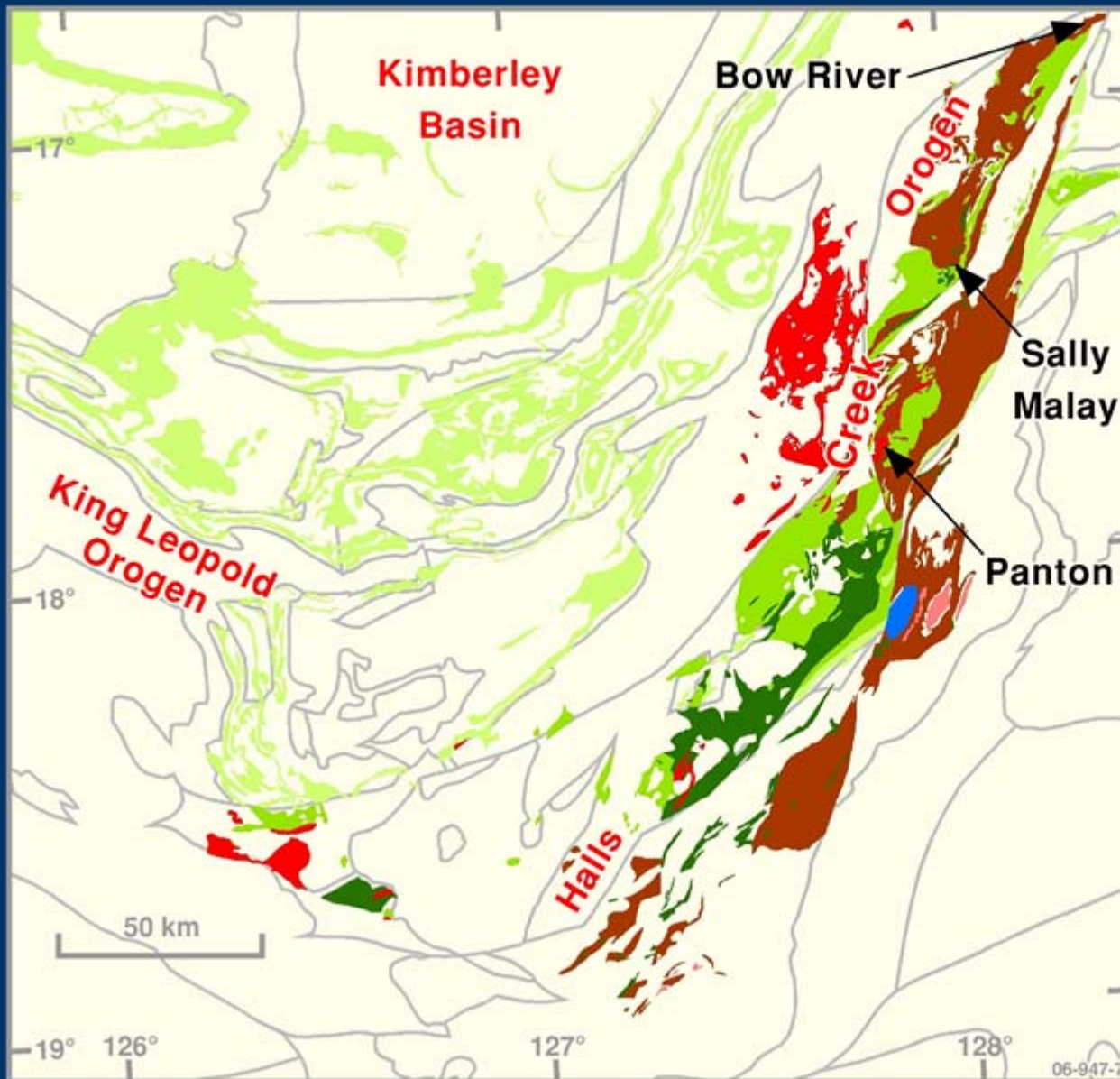
Size: Small to medium bodies; up to 1 km thick

Mineralisation: Basal contact and remobilised Ni-Cu

Status: Prospects

Analogues: Metamorphosed variant of Radio Hill (2892 Ma), Sally Malay (1844 Ma), *Voisey's Bay* (1333 Ma)

ME 6: Bow River Event ~1880-1860 Ma



Ages and Events

- 1790: ME 8 (m)
- 1830: ME 7 (mu)
- 1840 - 1845: ME 7 (mu)
- 1855 - 1857: ME 7 (mu)
- 1880: ME 6 (m)
- 1907: ME 5 (m)
- 1912: ME 5 (m)

— Province boundary

ME 5 : Magmatic Event 5
m: mafic only
mu: mafic and ultramafic

ME 7: Sally Malay Event ~1860-1830 Ma

Provinces: Halls Creek Orogen; Victoria River Basin; ?King Leopold Orogen

Examples: Sally Malay (1844 Ma)-Panton (1855 Ma)-Springvale (1856 Ma) Intrusions; Woodward Dolerite; Koongie Park Fm (1843 Ma)

Form: Layered mafic±ultramafic intrusion, sill, dyke, lava

Rock Types: Gab, ol gab, troctolite, anorthosite, perid, dunite, chr

Country rocks: Proterozoic pelite, psammite, migmatite, amphib

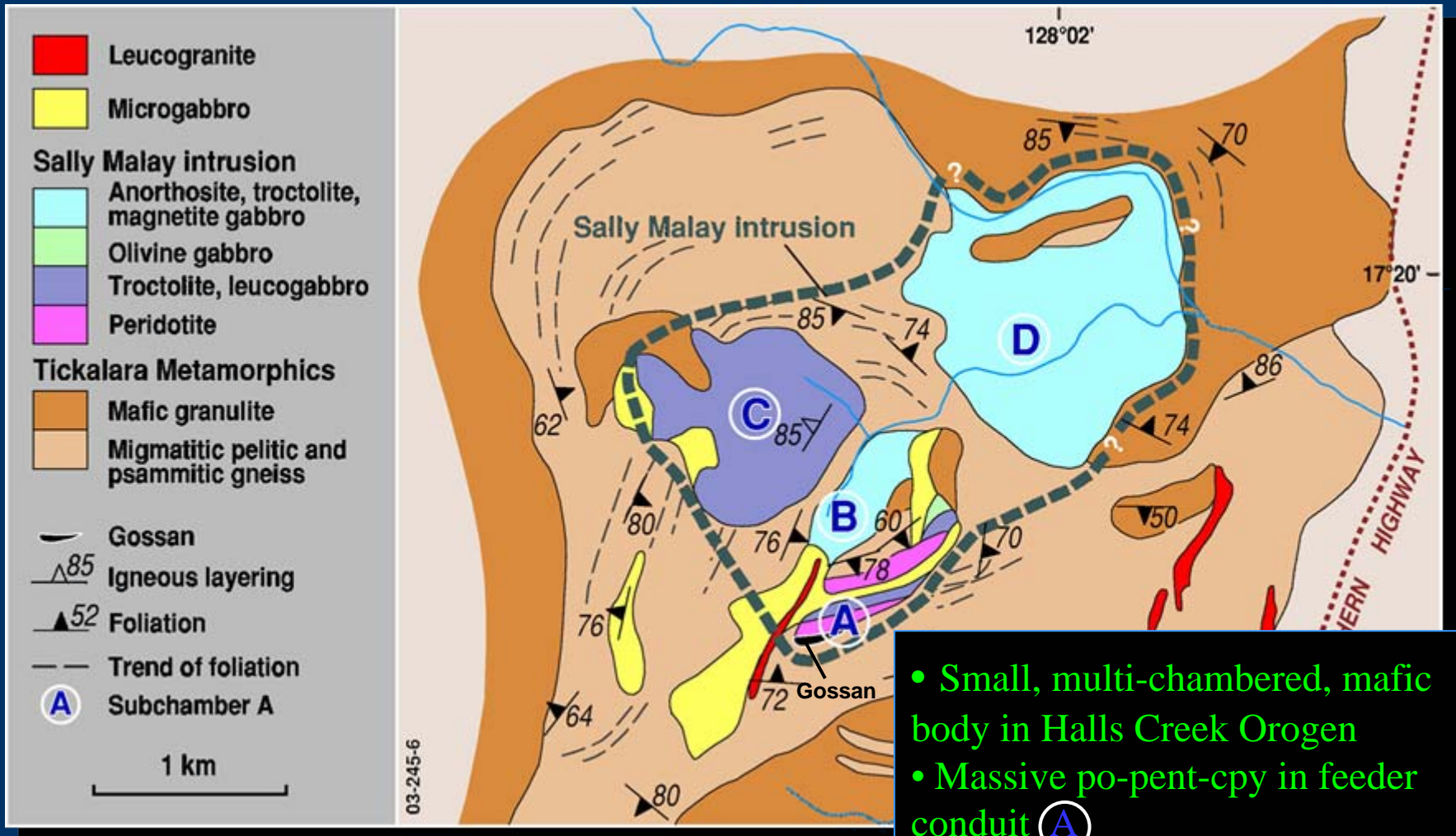
Size: Small to medium bodies; up to 2.5 km thick

Mineralisation: Basal contact Ni-Cu-Co; stratabound PGE-Ni-Cr

Status: Mine, prospects

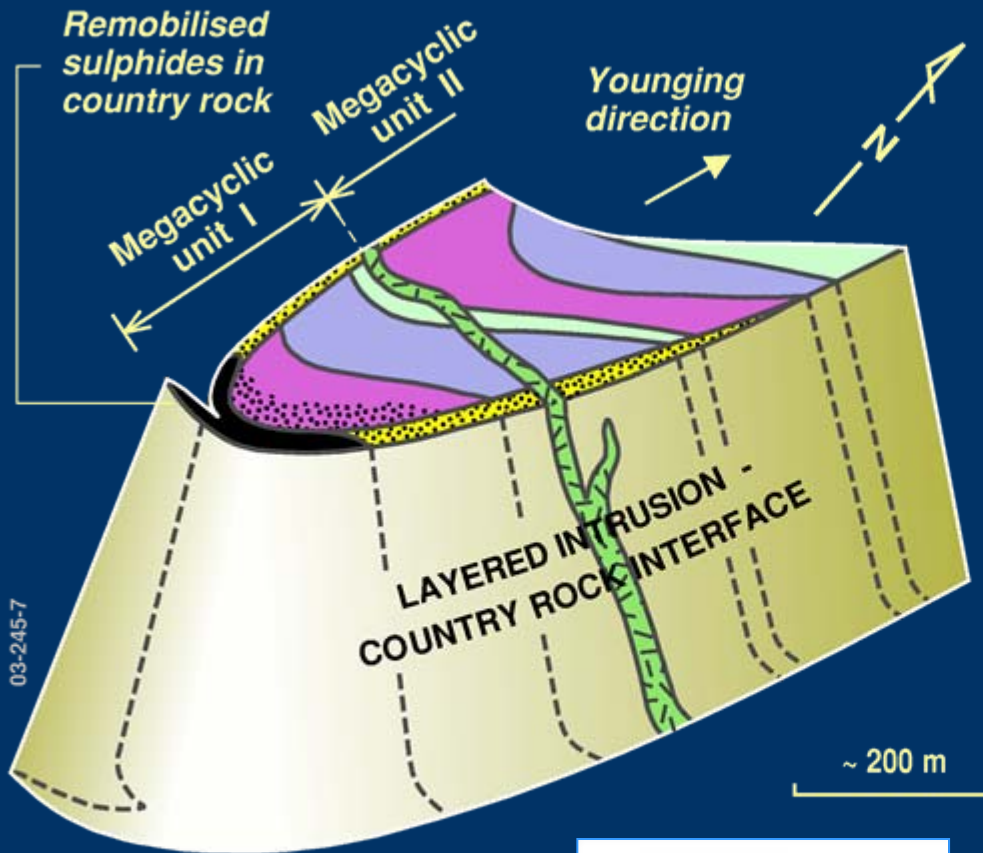
Analogues: Voisey's Bay (1333 Ma), Radio Hill (2892 Ma), UG-2 (2060 Ma)









ME 7: Sally Malay Intrusion (1845 Ma)



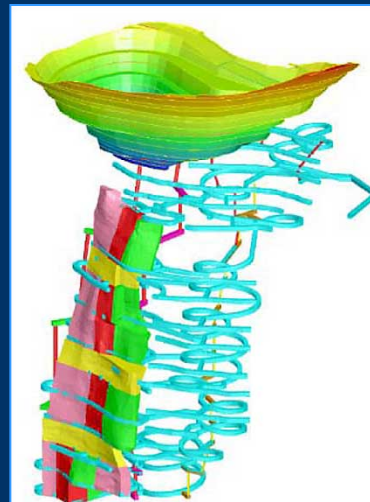
- Small, multi-chambered, mafic body in Halls Creek Orogen
- Massive po-pent-cpy in feeder conduit **A**
- 3.7 Mt @ 1.7% Ni, 0.7% Cu, 0.1% Co
- Voisey's Bay analogue

Source: AGSO Bulletin 246: Hoatson & Blake



- Sally Malay intrusion - lowest subchamber (A)**
- Megacyclic unit II**
-  Olivine gabbro
 -  Troctolite, anorthosite
 -  Peridotite
- Megacyclic unit I**
-  Olivine gabbro
 -  Troctolite, anorthosite
 -  Peridotite and disseminated sulphides
 -  Marginal gabbroic rocks and massive sulphides
-  Microgabbro dyke

- Massive sulphides accumulate in lowest part of stratigraphy beneath thickest sequence of cumulates
- Embayments along basal contact/feeder conduit



ME 12: Warakurna Event ~1070 Ma

Provinces: Collier-Edmund-Hamersley-Earaheedy Basins;
Musgrave Orogen

Examples: Giles Complex (1078 Ma); Bangemall dolerites (1070 Ma); Glenayle Dolerite (1066 Ma); Prenti Dolerite (1050 Ma)

Form: Sill, dyke, plug, layered mafic±ultramafic intrusion

Rock Types: Dolerite, gab, granophyre, troct, perid, dun, pyrox

Country rocks: Shale, sandst, chert; granulite, migmatite, gneiss

Size: Small to large bodies; dykes up to 0.8 km thick; Giles intrusions up to 8 km thick

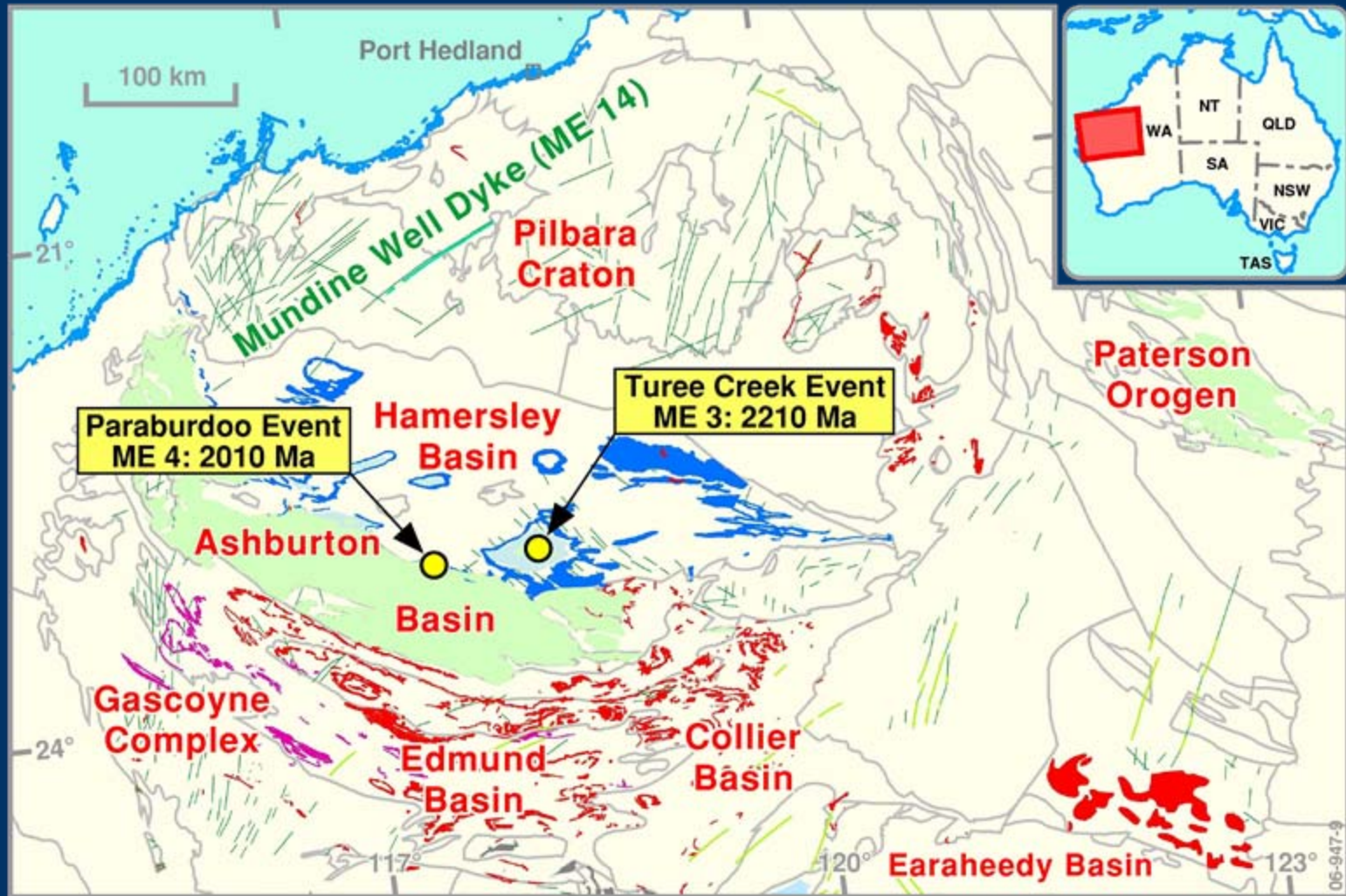
Mineralisation: Basal contact Ni-Cu-Co; stratabound PGE-Ti

Status: Prospects

Analogues: Voisey's Bay (1333 Ma); Noril'sk (251 Ma)

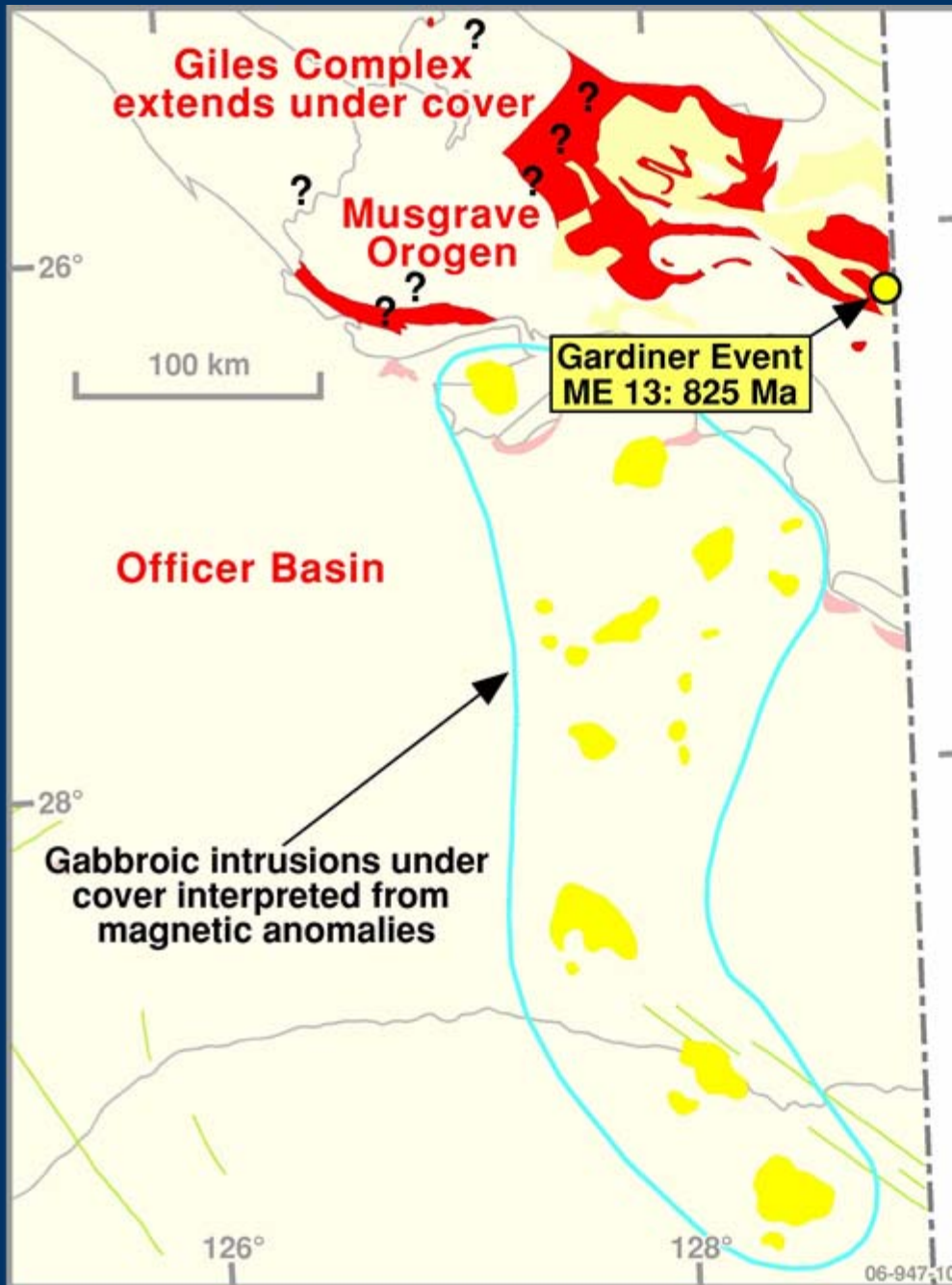


ME 12: Warakurna Event ~1070 Ma



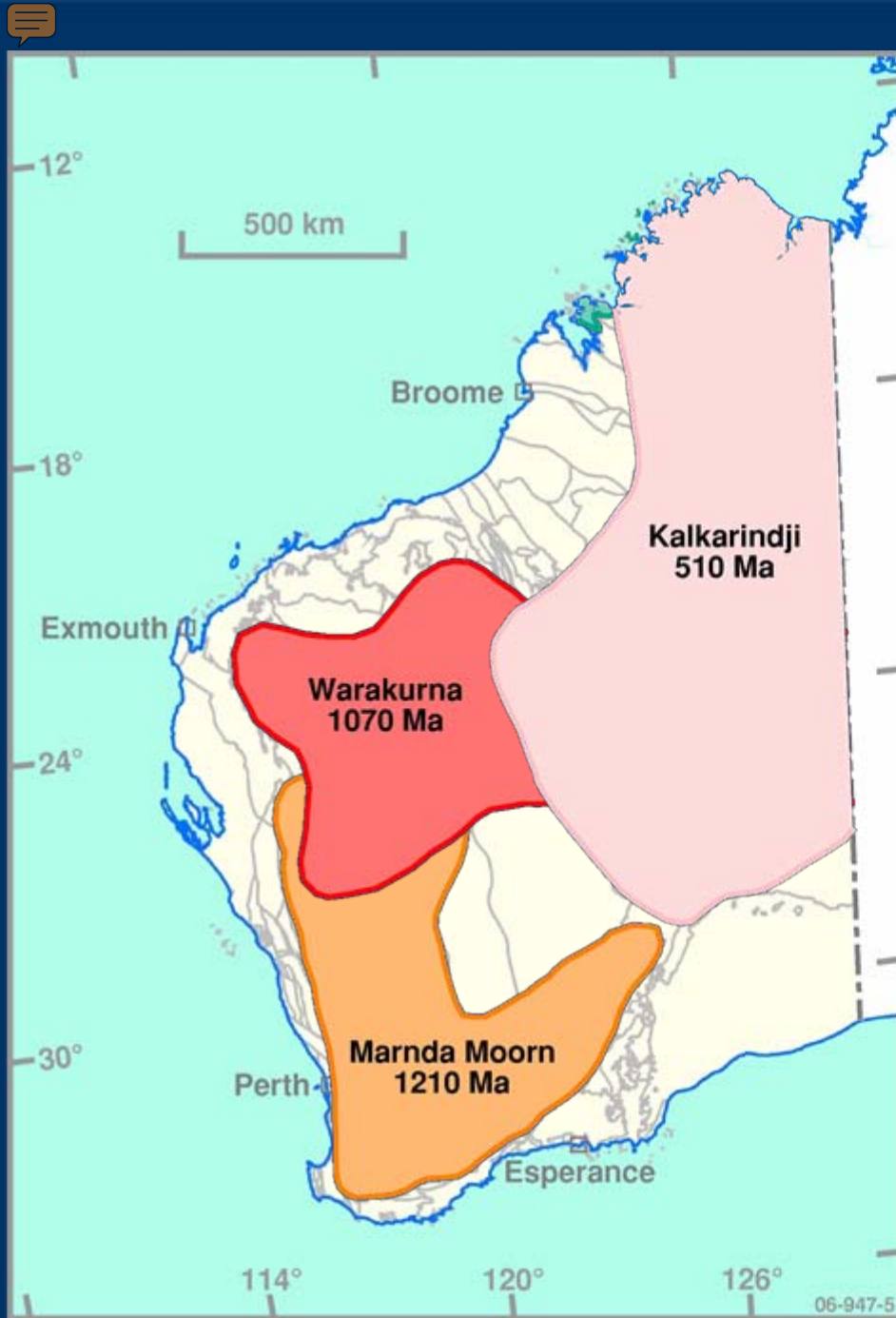


ME 12: Warakurna Event ~1070 Ma



- 510: ME 15 (m)
- 1070: ME 12 (mu)
- Undefined
- Undefined
- Interpreted dolerite dykes and sills
- Province boundary

ME 12 : Magmatic Event 12
 m: mafic only
 mu: mafic and ultramafic

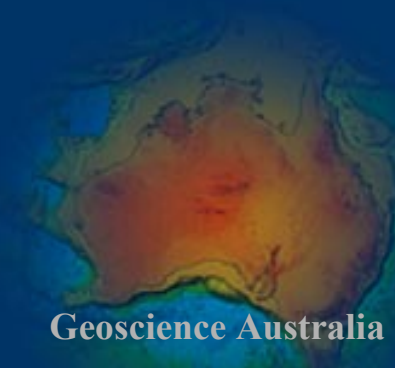


Large Igneous Provinces (LIPs)

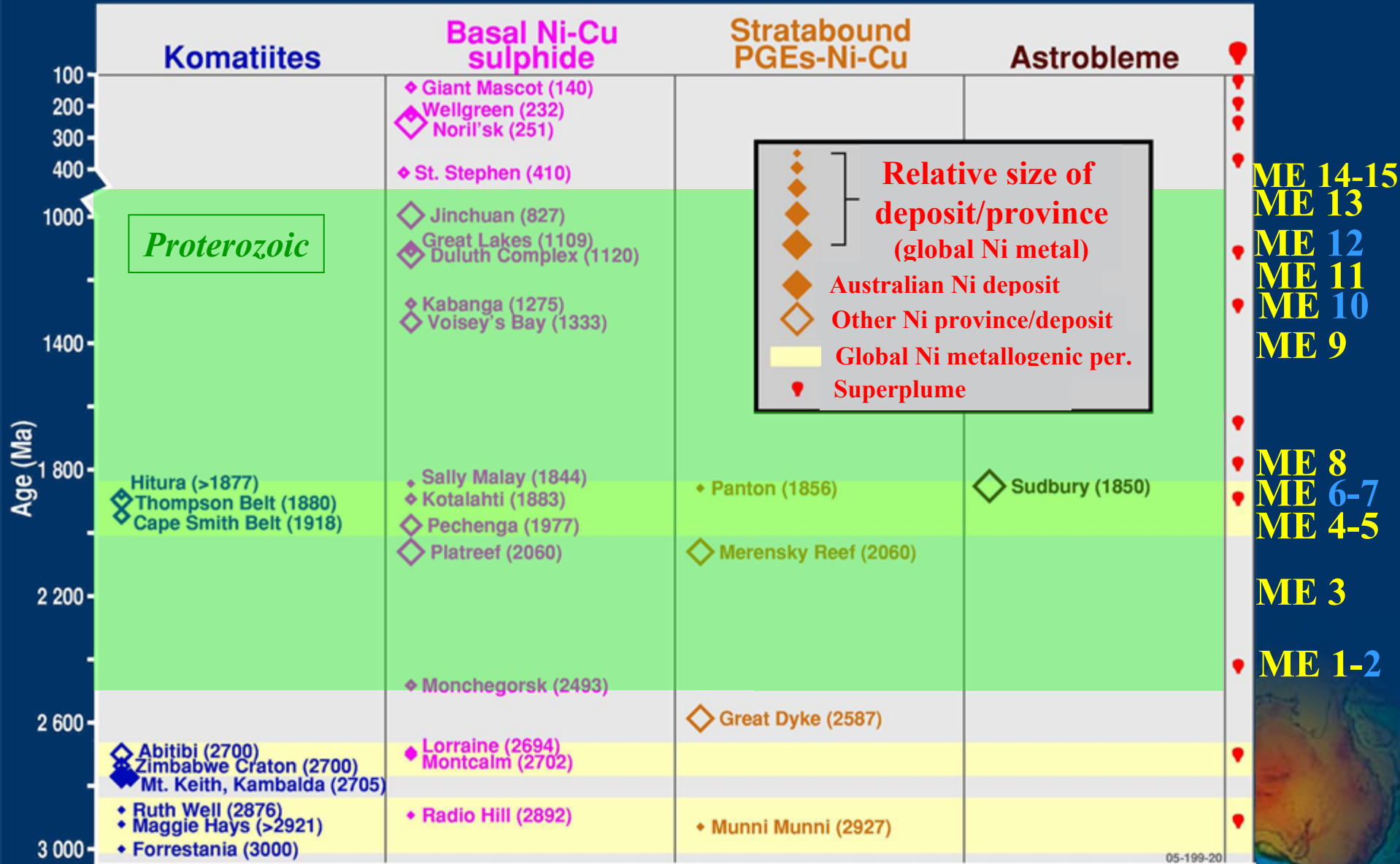
Large volumes of coeval mafic magmas (giant dyke swarms, flood basalt-sill provinces, layered intrusions); mantle-plume origin

- ~510 Ma Kalkarindji (ME 15)
- ~1070 Ma Warakurna (ME 12)
- ~1210 Ma Marnda Moorn (ME 11)
- ~1790 Ma Hart - Carson (ME 8)
- Province boundary

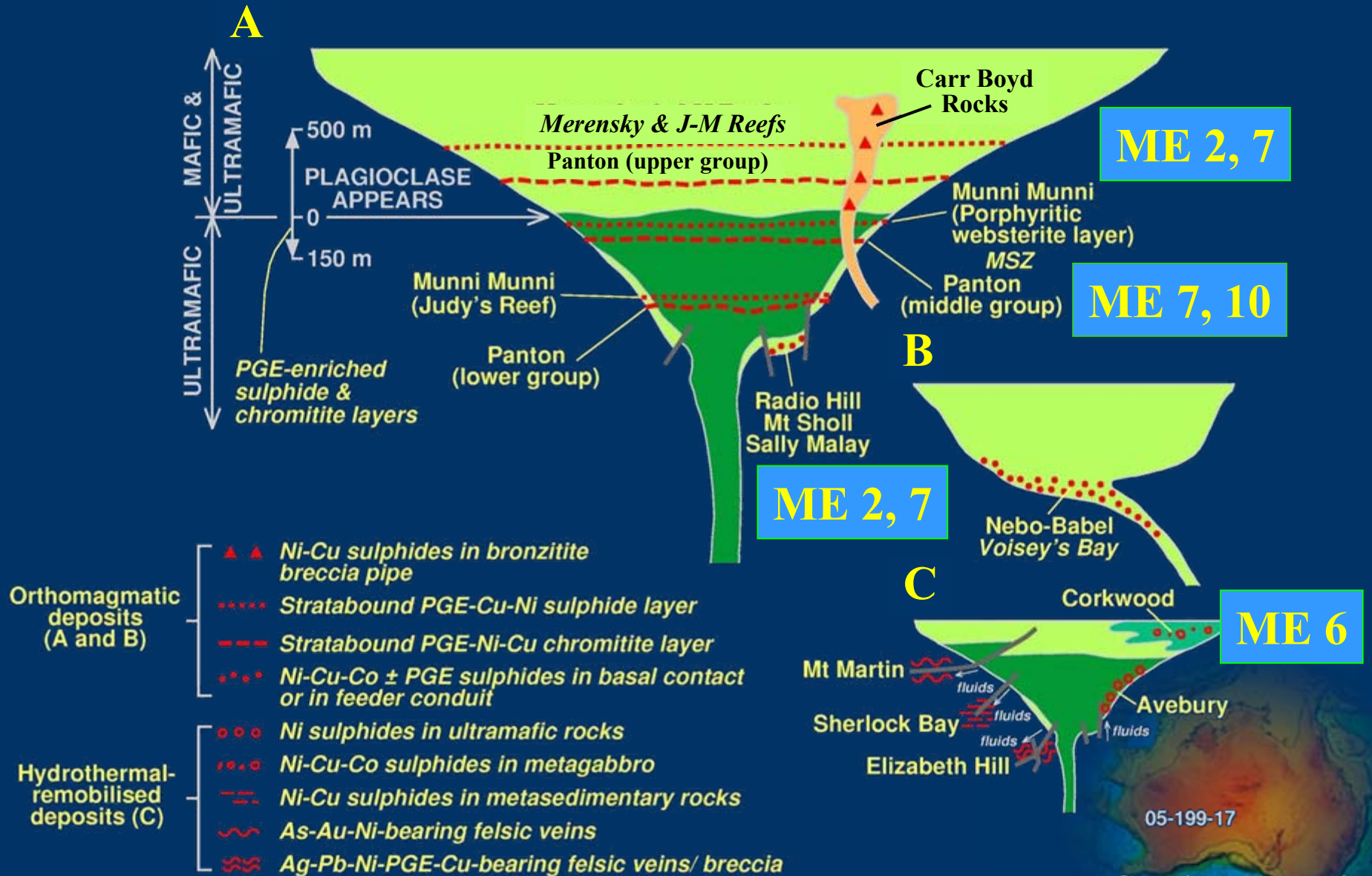
ME 8 : Magmatic Event 8



Correlation of Proterozoic Magmatic Events

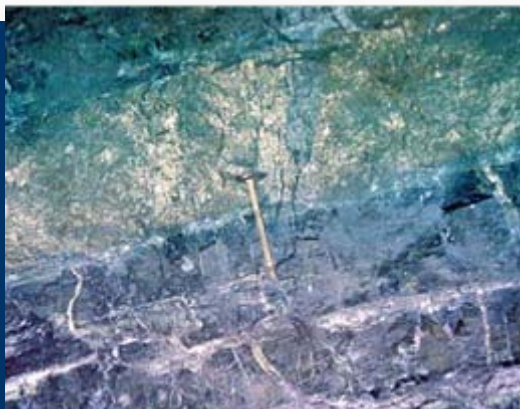
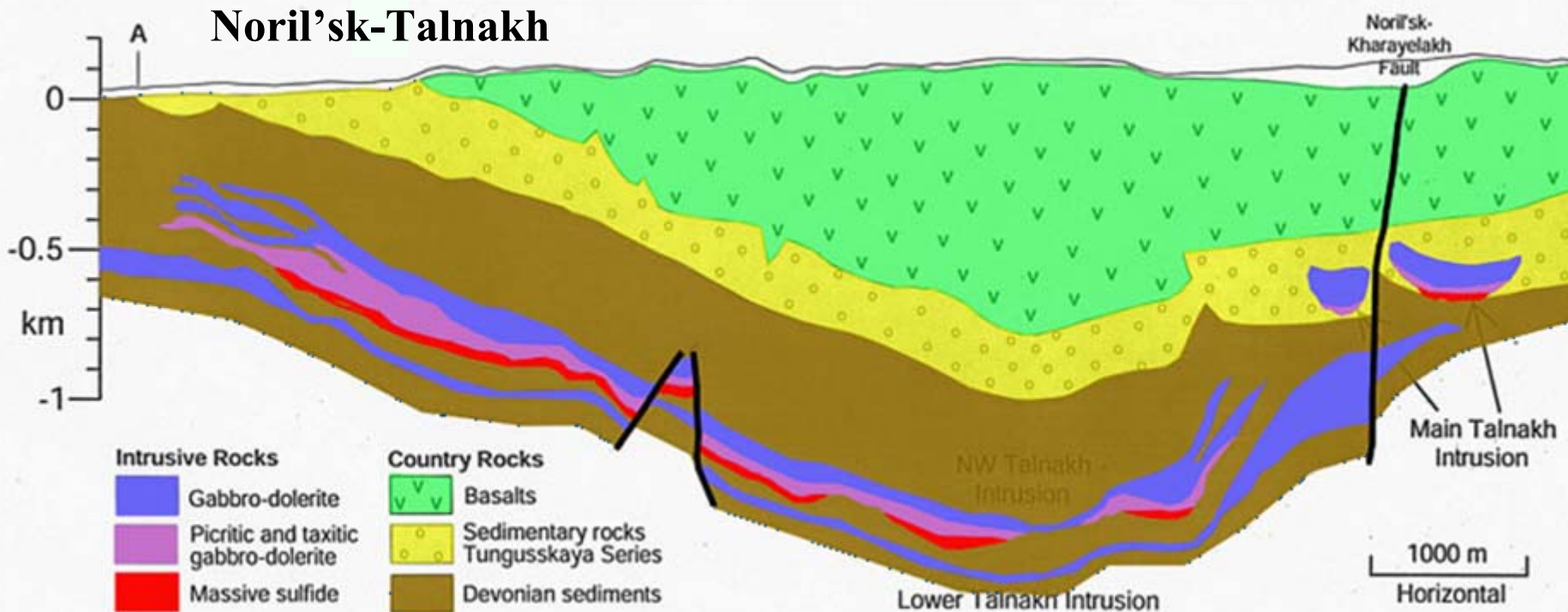


(1) Tholeiitic and Hydrothermal Mineralising Systems



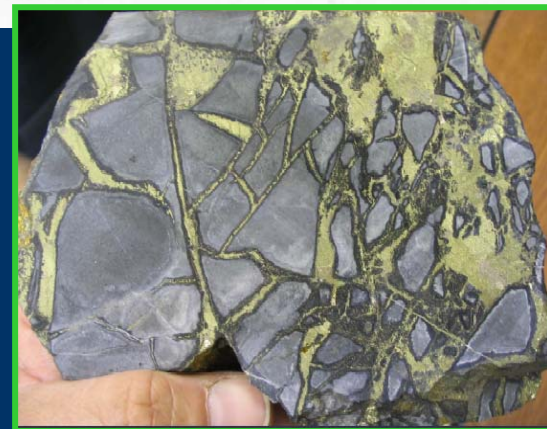
(2) Noril'sk-type Mineralising Systems-LIPS

Noril'sk-Talnakh



ME 8-9, 11-15

Images: Lightfoot (2005) and Naldrett



Preliminary Findings from 'MUM': Implications for Exploration (1)

- **Fifteen major Proterozoic magmatic events recognised in WA;** tholeiitic mafic >> ultramafic; komatiitic systems are absent
- **Multiple events within province** (Hamersley Basin), and **same event in different provinces** (ME 6: 1790 Ma-Paterson Orogen, Kimberley-Ashburton-Red Rock-Texas Downs-Revolver Ck Basins)
- **Five major regional thermal events** (LIP systems) over extensive areas $>1 \times 10^6$ km²:
 - ~1790 Ma – Kimberley Basin (Hart-Carson LIP)
 - ~1465 Ma – Edmund Basin
 - ~1210 Ma – Yilgarn Craton (Marnda Moorn LIP)
 - ~1070 Ma – Edmund-Collier Basins & Musgrave (Warakurna LIP)
 - ~510 Ma – Ord-Officer Basins (Kalkarindji LIP)
- **Mineralised magmatic events correlate with superplumes?**

Preliminary Findings from 'MUM': Implications for Exploration (2)

- **Highest potential - tholeiitic mafic mineralising systems:**

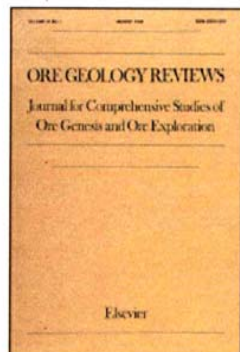
- 1. Basal Ni-Cu-Co sulphides (*Voisey's Bay-Sally Malay-Nebo-type*)**

Opportunities: Proterozoic orogenic belts contain many under-explored S-saturated mafic intrusions; determine pre-deformational geometries & younging directions to locate favourable mineralised environments, e.g., structural irregularities in basal contacts & entry locations of feeder conduits

- 2. Flood basalt-associated Ni-Cu-PGE sulphides (*Noril'sk-type*)**

Opportunities: LIPS (1790-510 Ma) cover >60% of WA; define localised feeder systems, magma flow dynamics, crustal source of S, significance of crustal contamination (Ni-Cu-PGE signatures, etc)

Other: Stratabound PGE-Cr-Ni; hydrothermal-remobilised Ni-Cu-Pd



**ORE GEOLOGY
REVIEWS**
'Hot off the Press'

The official journal of the
International Association
on the Genesis of
Ore Deposits (IAGOD)



'Nickel sulfide deposits in Australia: Characteristics, resources, and potential'

by Dean Hoatson, Subhash Jaireth, Lynton Jaques

Ore Geology Reviews Vol 29 (October issue), No 3/4, 177-241

Comprehensive review summarising the diverse settings & resources of Australia's nickel sulphide deposits & addresses the question 'what makes magmatic systems fertile?'

Soaring nickel prices, depleting stocks, and the challenges of finding the 'big-one'; come and visit Geoscience Australia's booth #10 and web site.



Thank you

Contact: Dean.Hoatson@ga.gov.au; 02 6249 9593

Free GA products to assist nickel explorers at:

<http://www.ga.gov.au/minerals/research/pubspres.jsp>