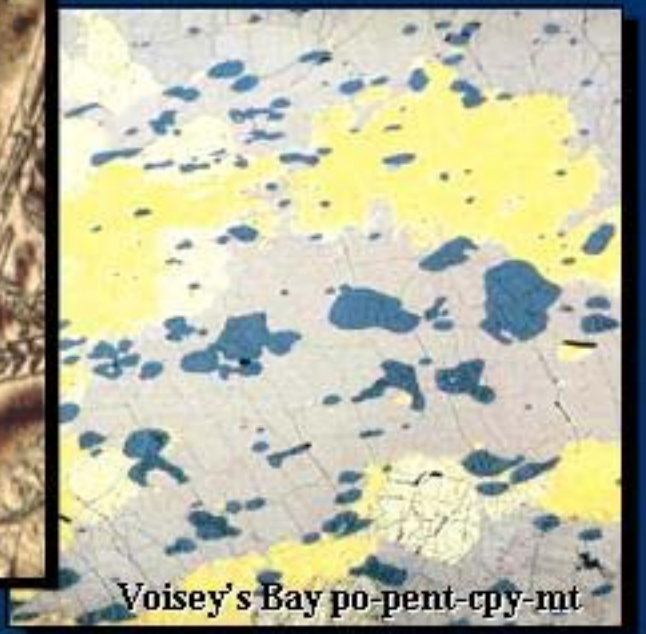
# Nickel Sulphide Deposits in Australia: Challenges and New Opportunities


Panton intrusion, Kimberleys


Comb spinifex in komatiite


Voisey's Bay po-pent-cpy-mt


**Dean Hoatson**

*With contributions from:*

Subhash Jaireth, Lynton Jaques & Mike Huleatt

Australian Government

Geoscience Australia



Australian Nickel Conference
Perth, 19-20th October 2005

# Outline

- Australia's status in the global nickel industry
- Challenges for the nickel industry
- Komatiitic, tholeiitic, hydrothermal mineralising systems: Kambalda, Collurabbie, Radio Hill, Munni Munni, Avebury
- Favourable mineralising elements
- New opportunities

# Australia's Status in the Global Nickel Industry

- Australia produces 14% (~199 000 t) of the world's nickel (~1.4 Mt from sulphide-laterite sources, ABARE 2005); #2 after Russia (23%)
- Global resources of nickel metal (total production+reserves+resources from sulphide ores) of ~12.6 Mt & 5 world-class deposits (>1 Mt Ni)
- Production from komatiitic (82%), laterite (15%), tholeiitic mafic-ultramafic intrusion (3%) deposits. Resources dominated by laterite (70%) deposits
- ~90% of Australia's nickel resources in WA
- Total Ni-Co exploration expenditure in 2004/05 was up 90% to $159 million (ABS 2005)

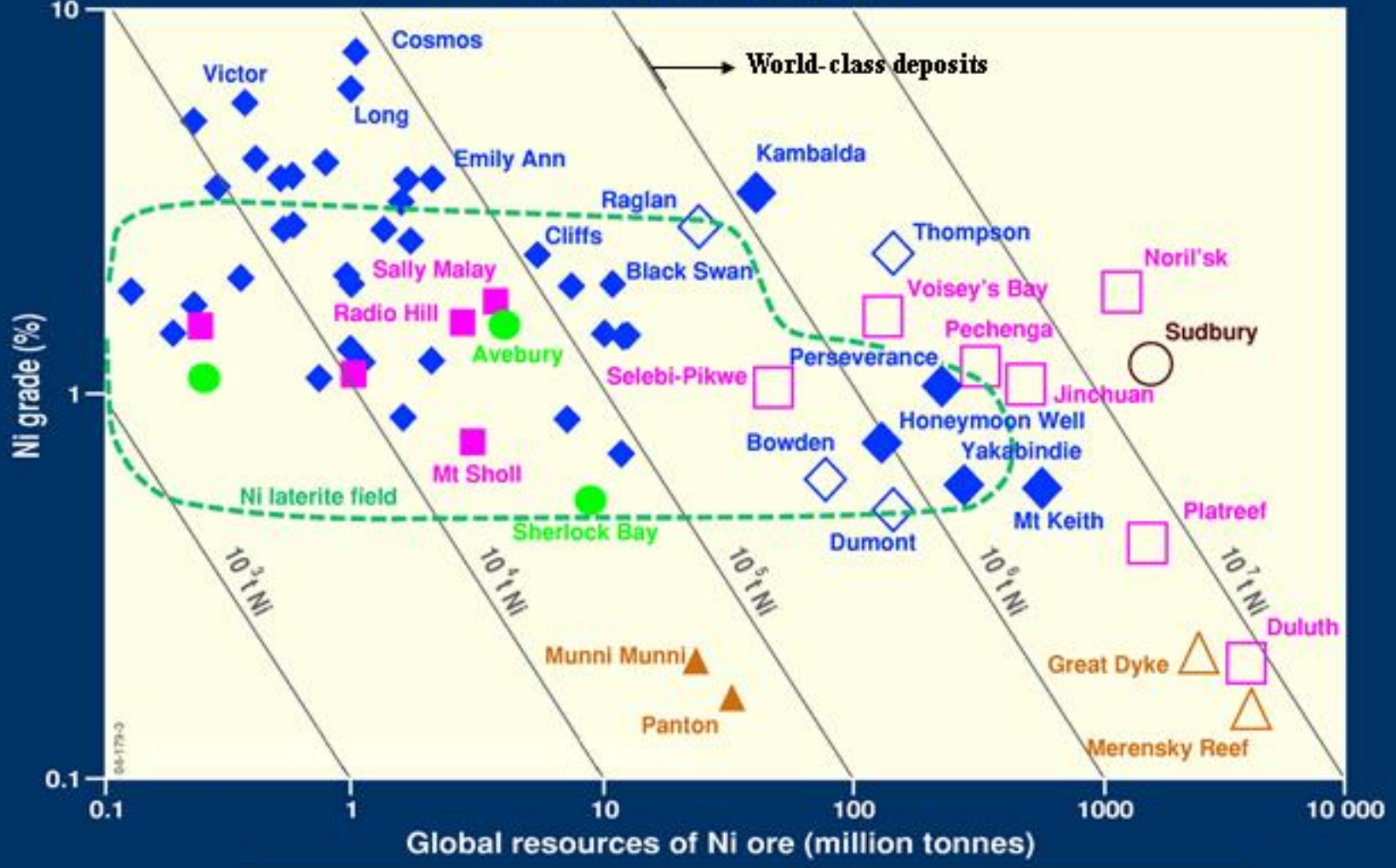
# Australia's Nickel Sulphide Deposits

**Most deposits are associated with ultramafic and/or mafic igneous rocks in three geotectonic settings:**

Economic Importance ↑

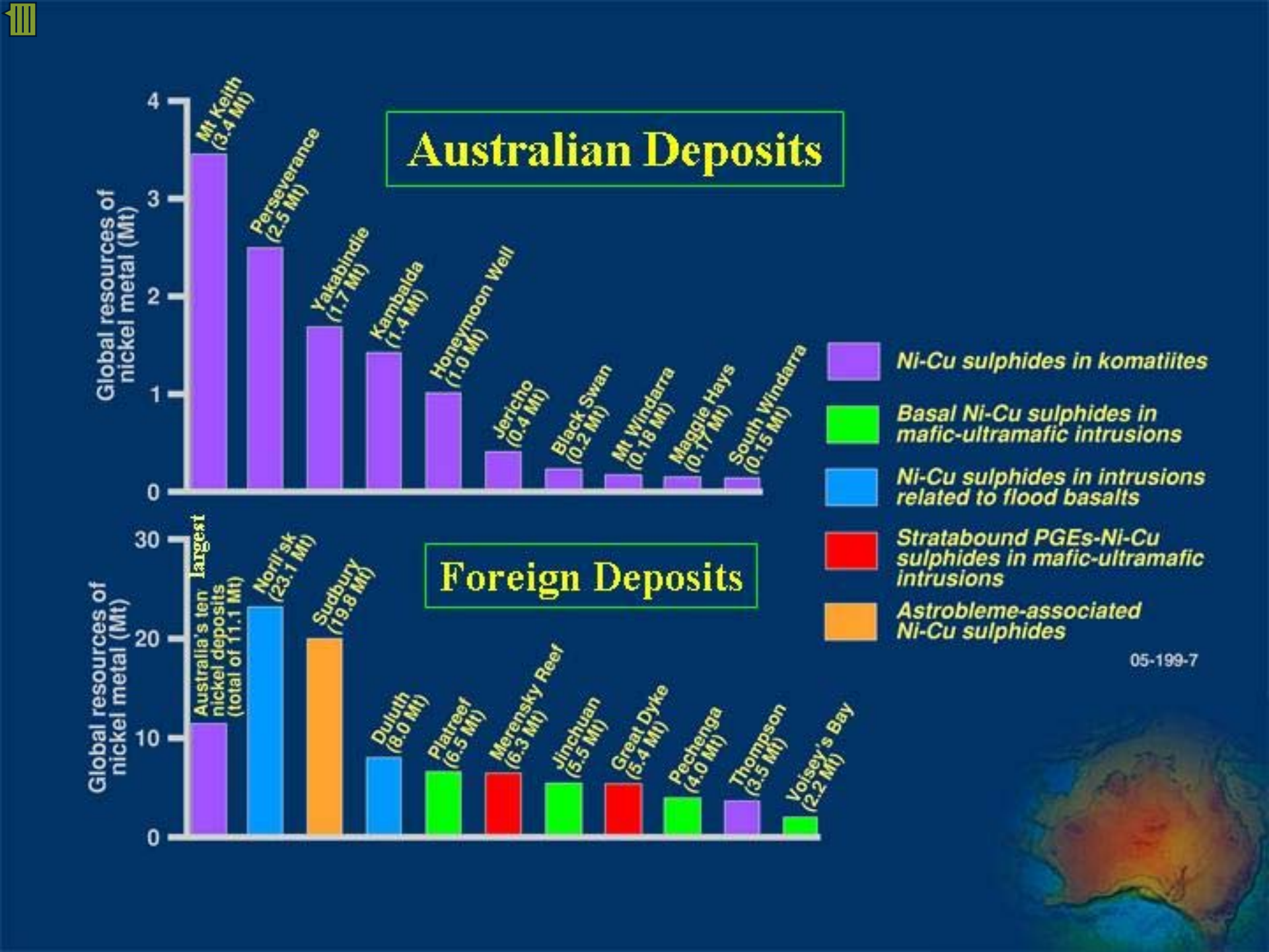
1. **Archaean komatiites in granite-greenstone belts**
2. **Precambrian tholeiitic mafic-ultramafic intrusions emplaced in former rift zones in Archaean cratons or Proterozoic orogens**
3. **Hydrothermal-remobilised deposits of varying ages and settings**

# Australia's Status




| Australian Deposits | Other Deposits | |
|---|---|---|
| ◆ | ◇ | Ni-Cu sulphides in komatiites |
| ■ | □ | Basal Ni-Cu sulphides in mafic-ultramafic intrusions |
| ▲ | △ | Stratabound PGEs-Ni-Cu in mafic-ultramafic intrusions |
| | ○ | Astrobleme-associated Ni-Cu sulphides |
| ● | | Hydrothermal-remobilised |

Data: OZMIN 2005; Naldrett 2002

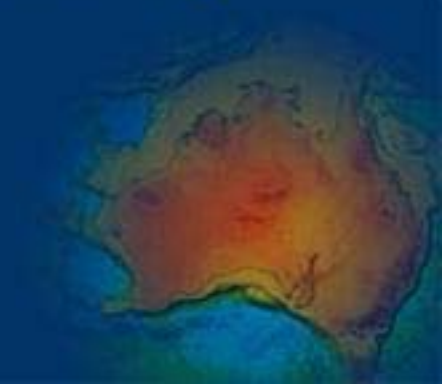

Australian Deposits
Global resources of nickel metal (Mt)
0
1
2
3
4
Mt Keith (3.4 Mt)
Perseverance (2.5 Mt)
Yakabindie (1.7 Mt)
Kambalda (1.4 Mt)
Honeymoon Well (1.0 Mt)
Jericho (0.4 Mt)
Black Swan (0.2 Mt)
Mt Windarra (0.18 Mt)
Maggie Hays (0.17 Mt)
South Windarra (0.15 Mt)
Foreign Deposits
Global resources of nickel metal (Mt)
0
10
20
30
Australia's ten largest nickel deposits (total of 11.1 Mt)
Noril'sk (23.1 Mt)
Sudbury (19.8 Mt)
Duluth (8.0 Mt)
Platreef (6.5 Mt)
Merensky Reef (6.3 Mt)
Jinchuan (5.5 Mt)
Great Dyke (5.4 Mt)
Pechenga (4.0 Mt)
Thompson (3.5 Mt)
Voisey's Bay (2.2 Mt)
Ni-Cu sulphides in komatiites
Basal Ni-Cu sulphides in mafic-ultramafic intrusions
Ni-Cu sulphides in intrusions related to flood basalts
Stratabound PGEs-Ni-Cu sulphides in mafic-ultramafic intrusions
Astrobleme-associated Ni-Cu sulphides
05-199-7

# Challenge 1: Rarity of Deposit

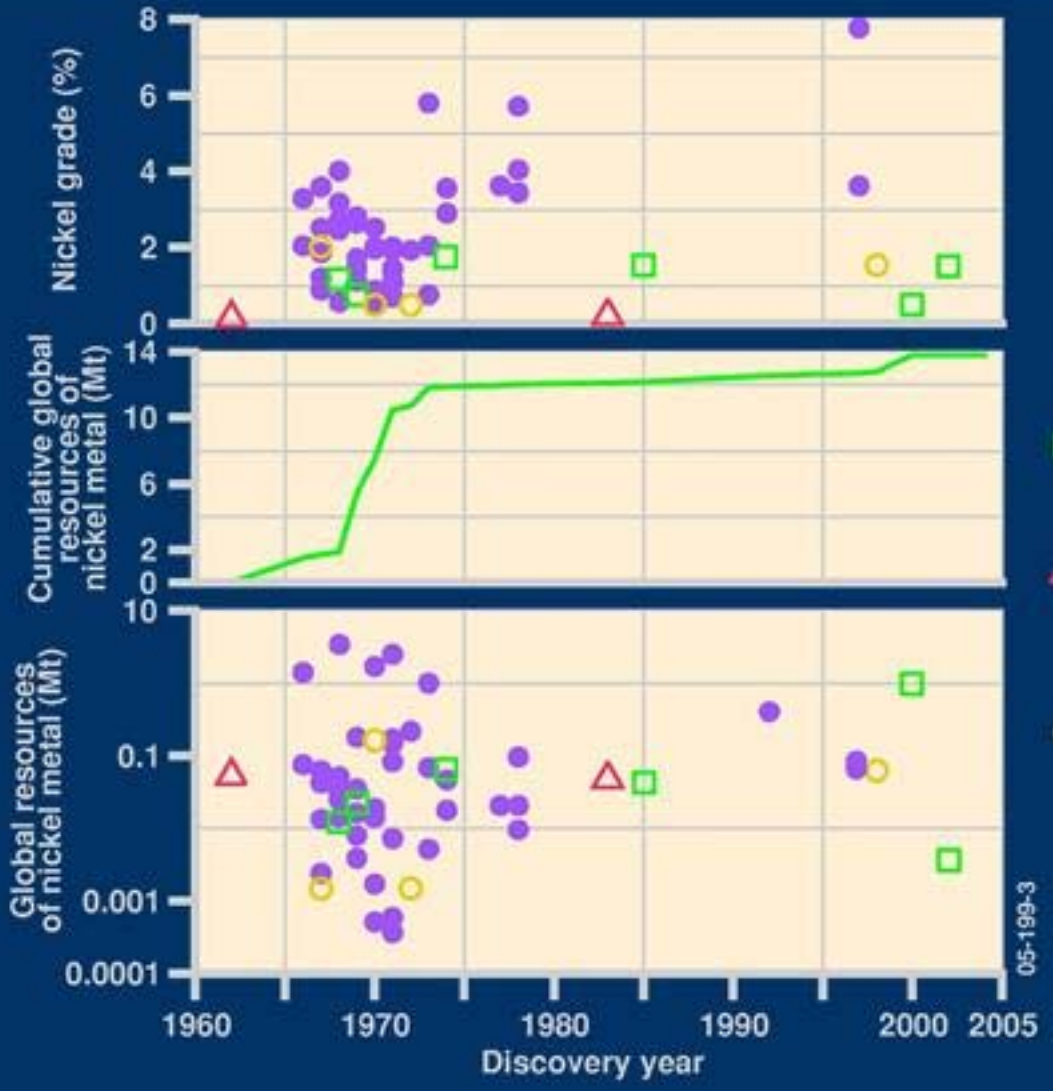
*"Relative to other deposit types, magmatic Ni-Cu-PGE deposits are rare; in total there are only 142* such deposits in the world that contain more than 100 000 tonnes of resources and/or production."*

Hulbert & Eckstrand: GSC (PDAC 2005)

*Australia has 12 of these deposits

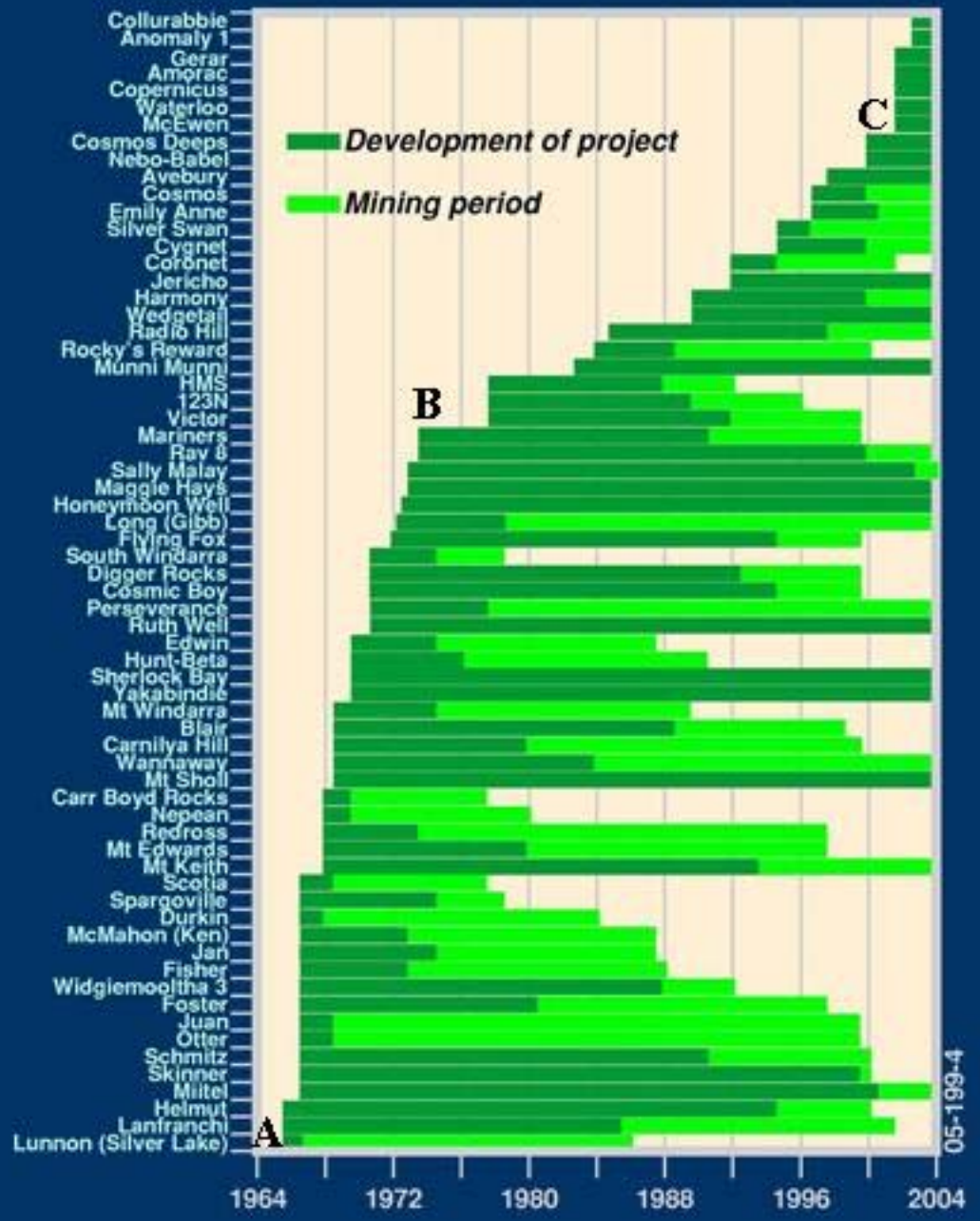


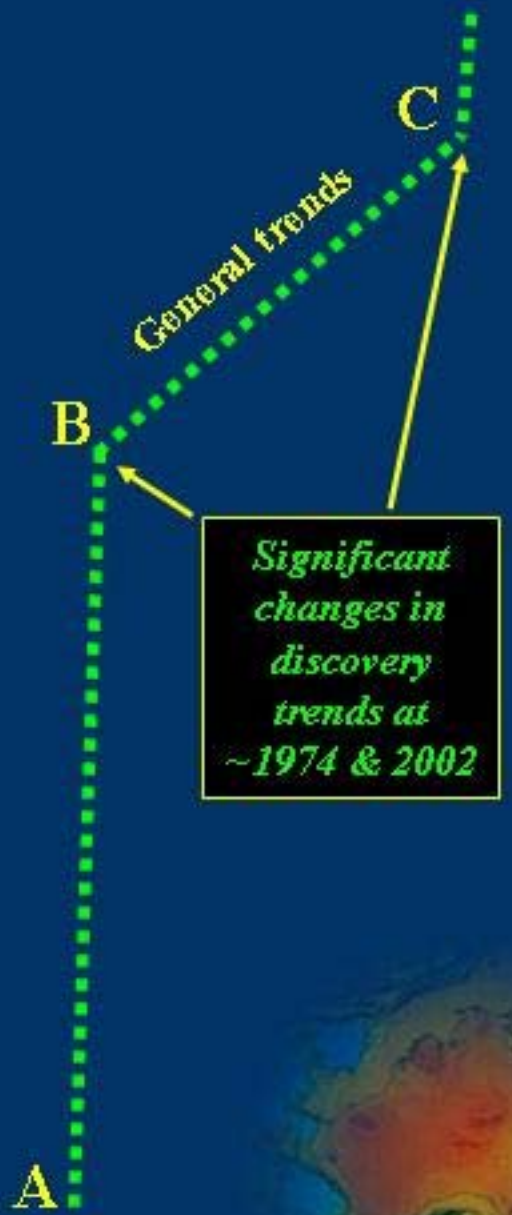
# Challenge 2: Decline in Discoveries




More than 90% of Australia's nickel sulphide resources discovered from 1966 to 1973

- *Ni-Cu sulphides in komatiites*
- *Basal Ni-Cu sulphides in mafic-ultramafic intrusions*
- *Stratabound PGEs-Ni-Cu sulphides in mafic-ultramafic intrusions*
- *Hydrothermal-remobilised*

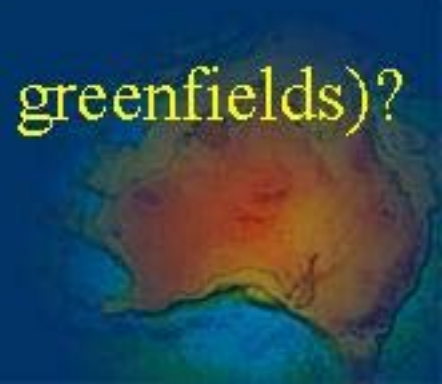

Collurabbie
Anomaly 1
Gerar
Amorac
Copernicus
Waterloo
McEwen
Cosmos Deeps
Nebo-Babel
Avebury
Cosmos
Emily Anne
Silver Swan
Cygnet
Coronet
Jericho
Harmony
Wedgetail
Radio Hill
Rocky's Reward
Munni Munni
HMS
123N
Victor
Mariners
Rav 8
Sally Malay
Maggie Hays
Honeymoon Well
Long (Gibb)
Flying Fox
South Windarra
Digger Rocks
Cosmic Boy
Perseverance
Ruth Well
Edwin
Hunt-Beta
Sherlock Bay
Yakabindie
Mt Windarra
Blair
Carnilya Hill
Wannaway
Mt Sholl
Carr Boyd Rocks
Nepean
Redross
Mt Edwards
Mt Keith
Scotia
Spargoville
Durkin
McMahon (Ken)
Jan
Fisher
Widgiemooltha 3
Foster
Juan
Otter
Schmitz
Skinner
Mitel
Helmut
Lanfranchi
Lunnon (Silver Lake)
Development of project
Mining period
A
B
C
1964
1972
1980
1988
1996
2004
05-199-4


C
General trends
B
A
Significant changes in discovery trends at ~1974 & 2002

# Decline in Discoveries: Why?

**Discovery rates decreased, average size of new deposits decreased, & discovery costs have risen:**

- Technical/scientific barriers (deeper drilling, more challenging terranes, regolith cover) to discovery?
- Maturing of traditional exploration provinces?
- Change of exploration focus (brownfields to greenfields)?



# 'Tyranny of Cover & Depth'



**Yandal Belt: produces ~10% of Australia's gold, 3 world-class gold mines**

**Under-explored below 300 m: drill deeper & more often**

Proterozoic

Granitoid

Greenstone

80 km

Source: Champion de Crespigny 2002

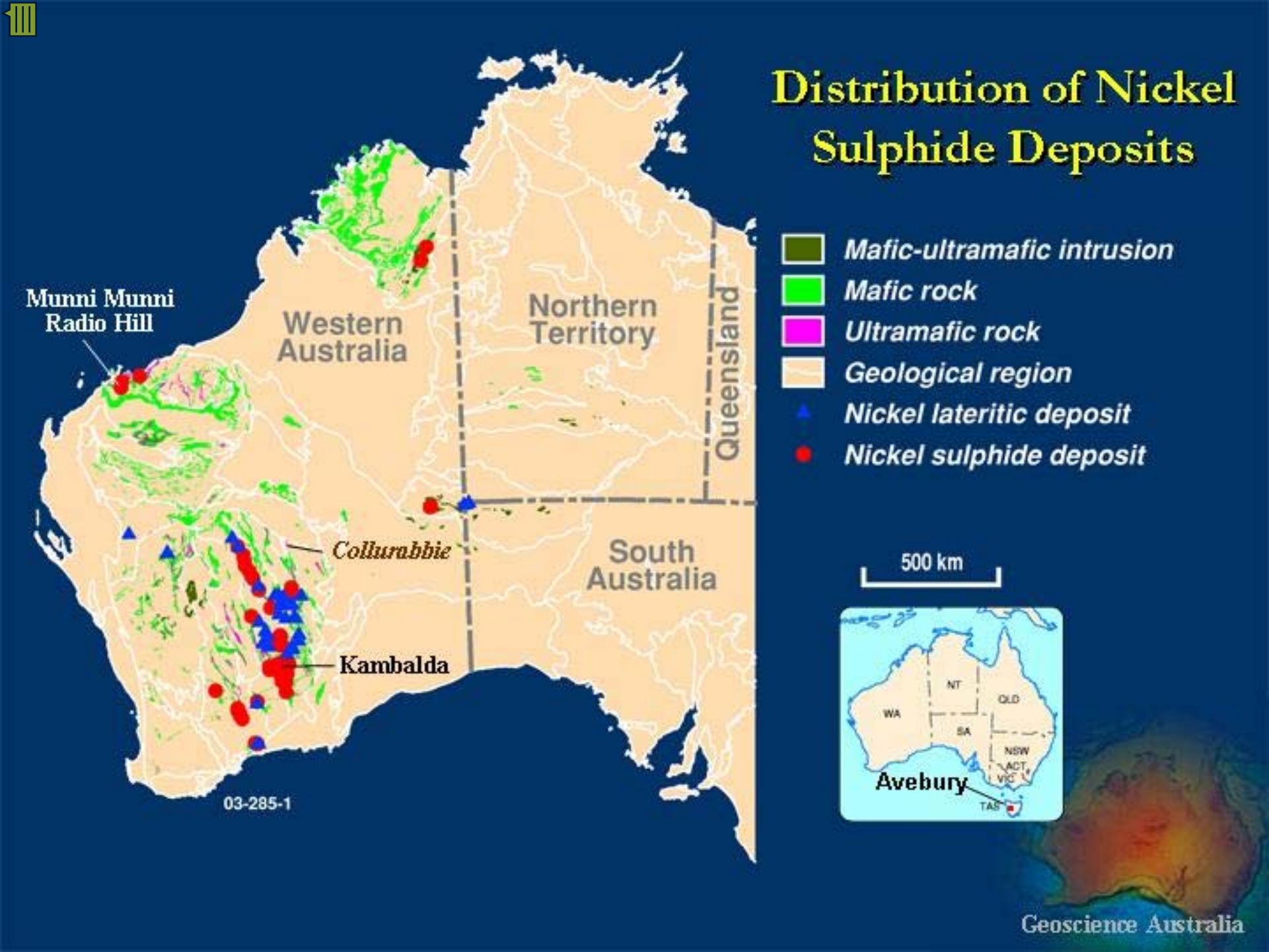
# Mature Exploration Provinces?

| Province | Area ($km^2$) | Number of drill holes | Holes/100 $km^2$ |
|---|---|---|---|
| **Musgrave Block** (NT component) | 33 000 | 157 | 0.5 |
| **Litchfield** | 9 000 | 1 300 | 14 |
| **Arunta** (western & central) | 94 000 | 16 800 | 18 |
| **Tennant Creek** (extension of Mineral Field) | 3 400 | 645 | 19 |
| **McArthur Basin** (northeastern) | 30 000 | 465 | 1.5 |

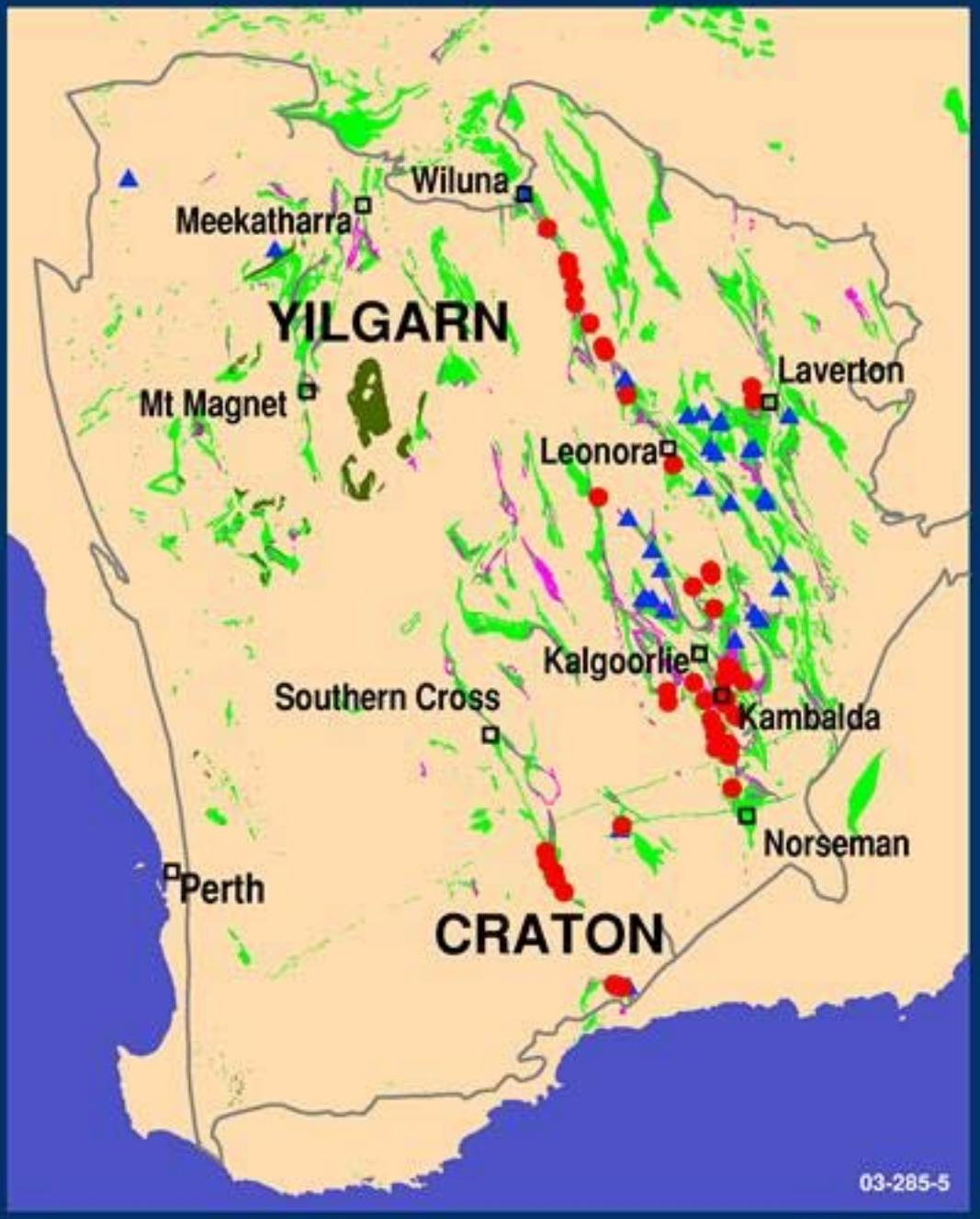
- Musgrave Province (NT) is one of the most under-explored Proterozoic provinces (1 drill hole/200 $km^2$)
- Potential for Giles Complex under cover

Data: Scrimgeour et al. 2005

# Distribution of Nickel Sulphide Deposits



# Kambalda (2700 Ma): Yilgarn Craton

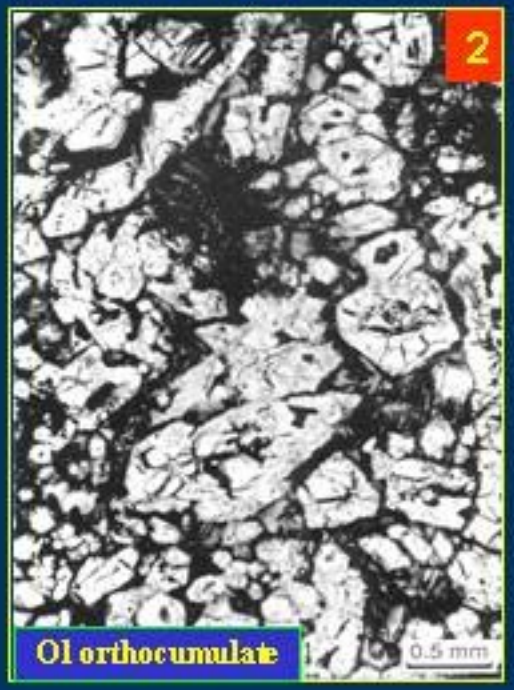



- Mafic-ultramafic intrusion
- Mafic rock
- Ultramafic rock
- Nickel lateritic deposit
- Nickel sulphide deposit

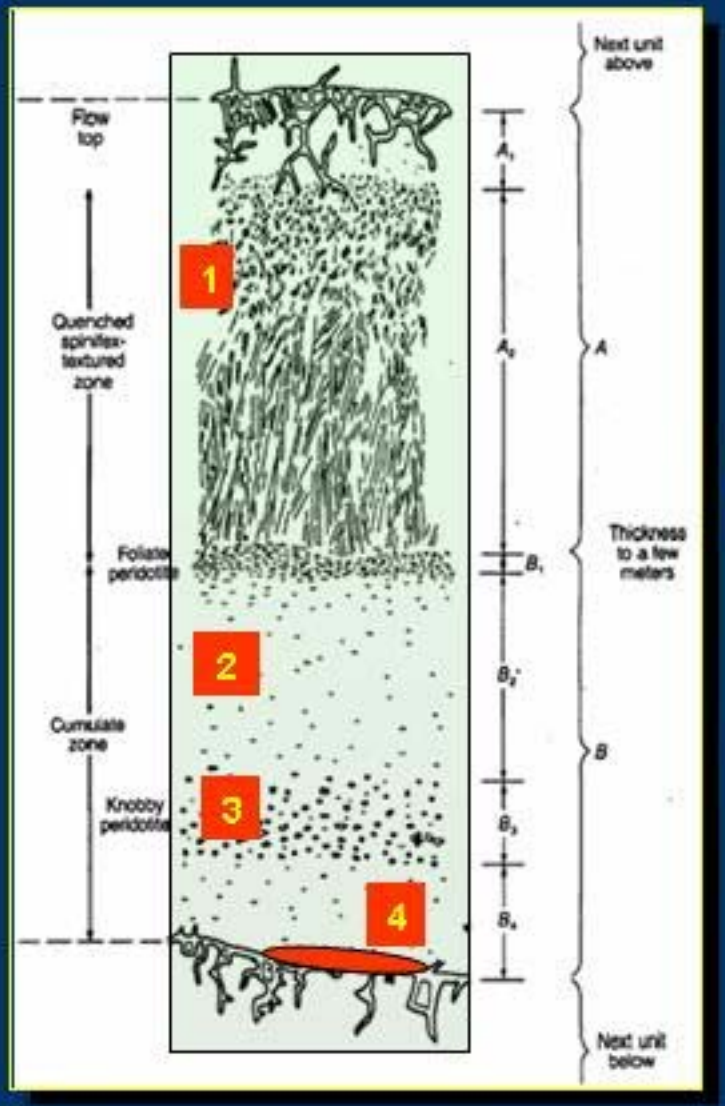
250 km

# Komatiitic Rocks

Random spinifex



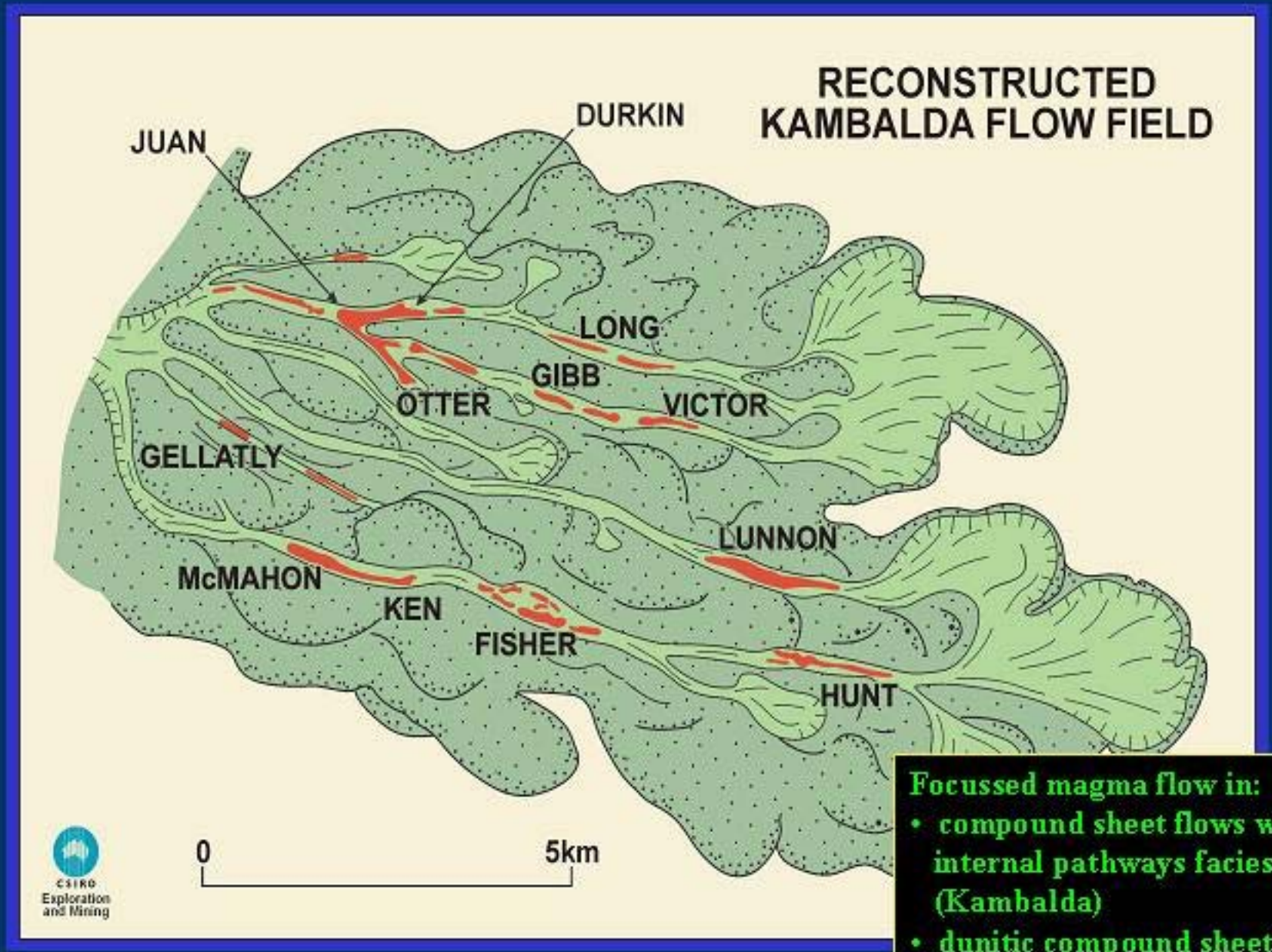
Ol orthocumulate




Photographs: Steve Barnes (CSIRO, Perth)

Ol adcumulate

Basal massive sulphides

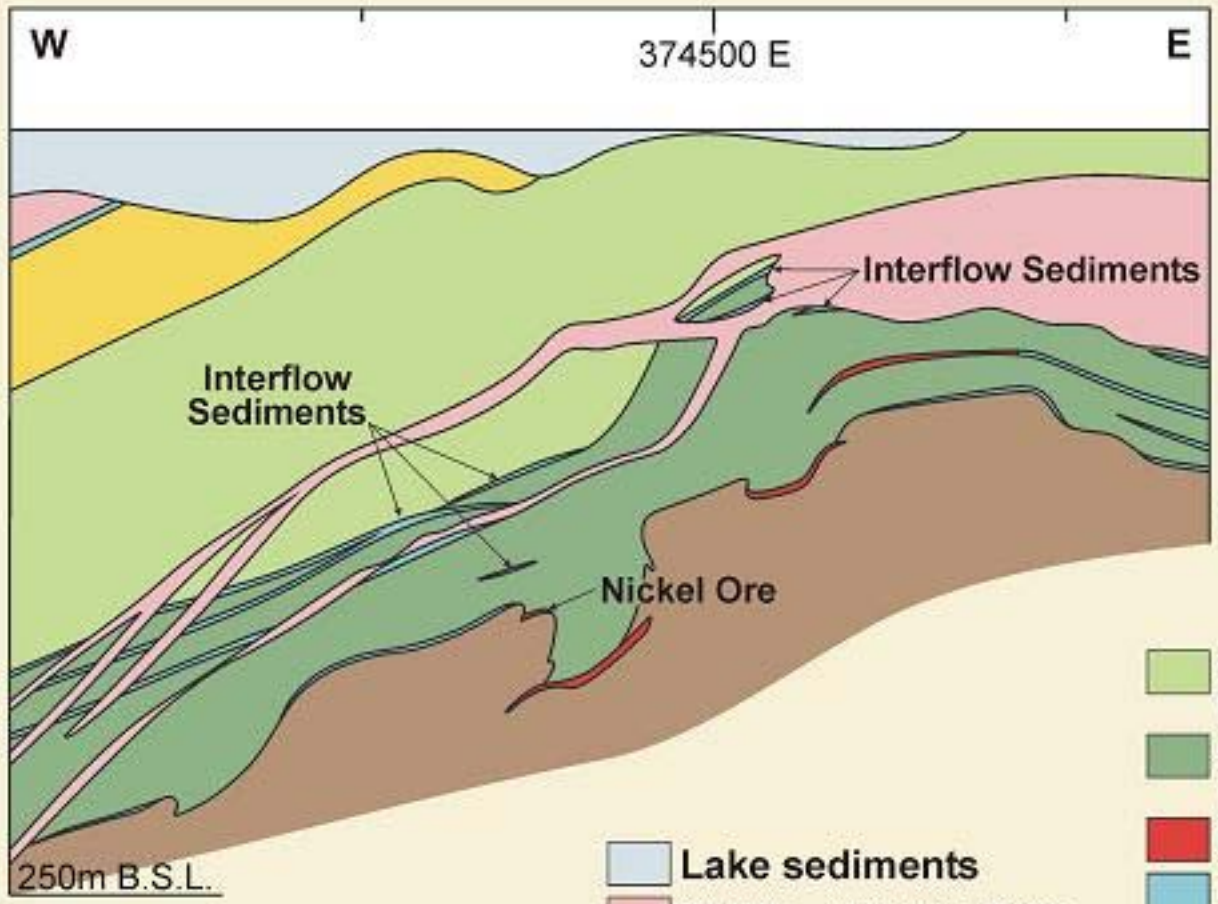



Focussed magma flow in:

- compound sheet flows with internal pathways facies (Kambalda)
- dunitic compound sheet flow facies (Mt Keith)

Modified from Barnes et al. 1999; Barnes 2004

# Typical Mineralised Environment – Kambalda Deposits




- Embayments & structural traps along basal contacts of channel facies
- Sulphide-bearing footwall rocks

0 250m

Tripod Hill Member
Silver Lake Member
Kambalda Komatiite
Nickel Ore
Interflow Sediments
Lunnon Basalt
Fault

Lake sediments
Felsic - intermediate intrusives
Devon Consols Basalt

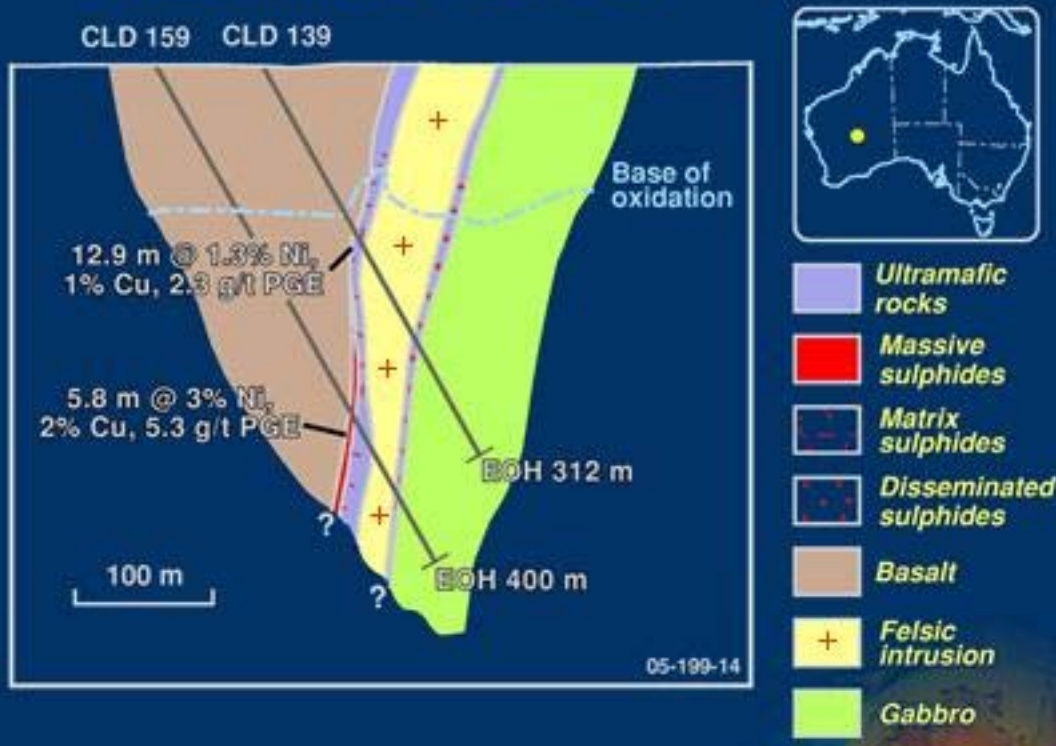
CSIRO Exploration and Mining

Modified from Gresham 1986; Cowden & Roberts 1990; Barnes et al. 1999; Barnes 2004

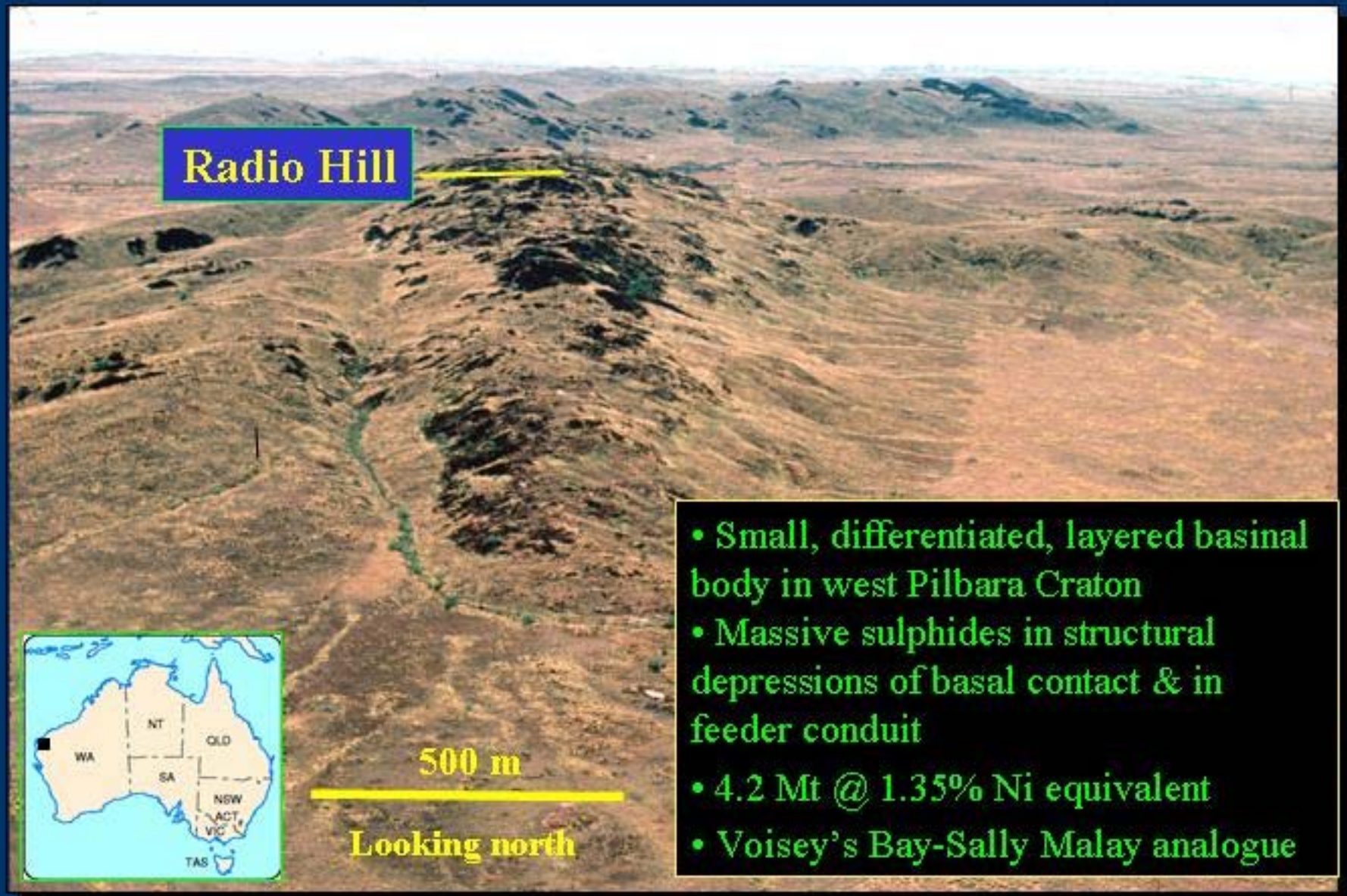
# ‘Unusual’ Recent Komatiite Discoveries

- Low Ni/Cu (<4) & high PGEs (2 to 5 g/t: *Collurabbie, ?Daltons*)
- Exceptionally high Ni (5 to 8% Ni) – richest in the world (*Cosmos, Flying Fox-T5*)
- Normal Ni/Cu ratios (7-19) & high PGE grades (*Waterloo*)
- Associated ?comagmatic flood basalts (*Beasley*)

**Collurabbie Ni-Cu-PGEs**

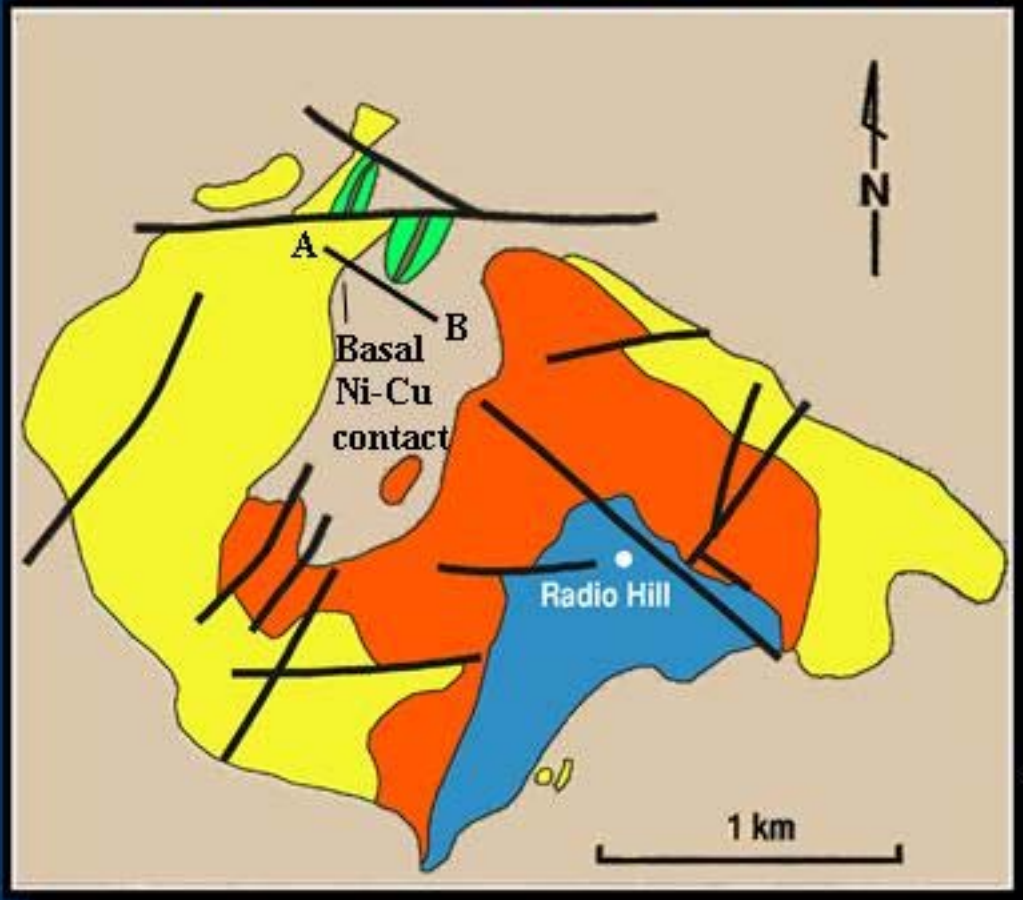


# Radio Hill Intrusion (2890 Ma): Pilbara Craton




- Small, differentiated, layered basinal body in west Pilbara Craton
- Massive sulphides in structural depressions of basal contact & in feeder conduit
- 4.2 Mt @ 1.35% Ni equivalent
- Voisey's Bay-Sally Malay analogue

# Radio Hill Intrusion (2890 Ma): Pilbara Craton

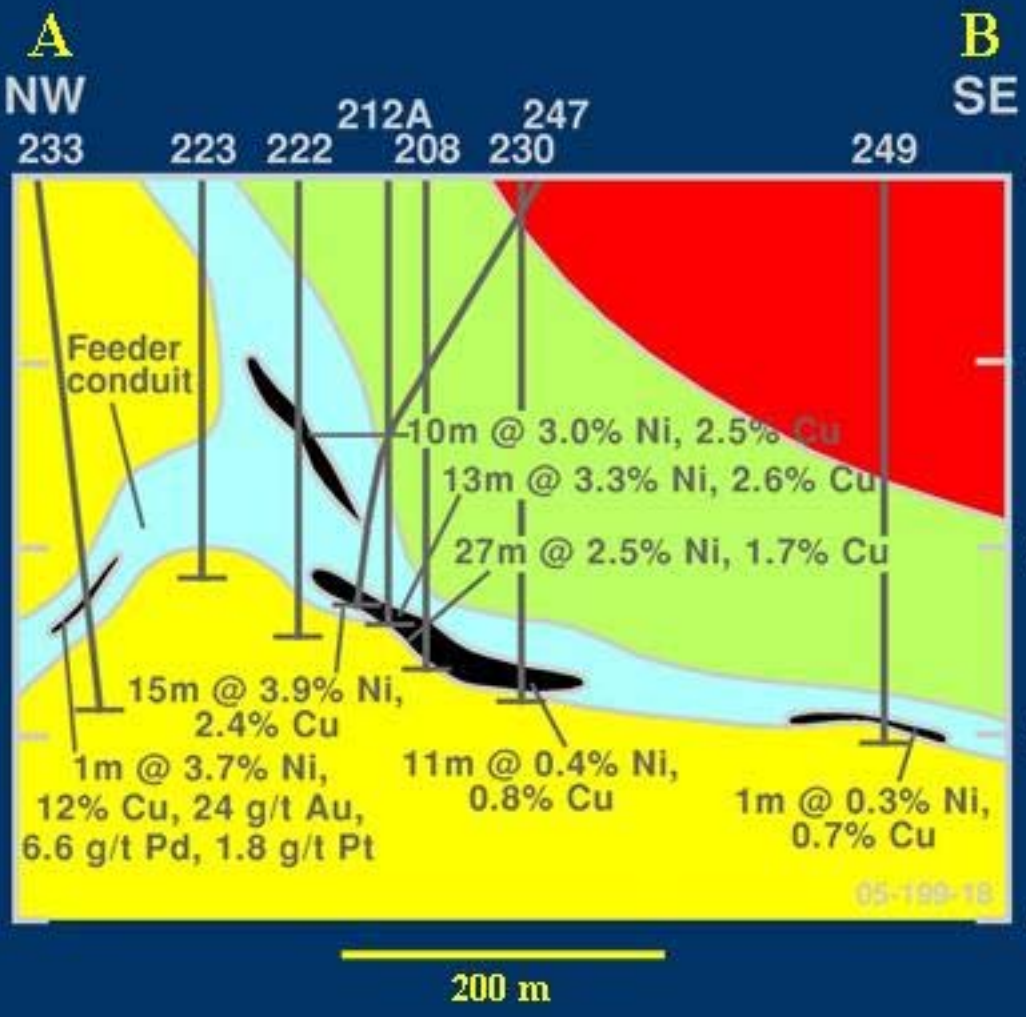

Quartz gabbro

Olivine gabbronorite

Peridotite & pyroxenite
Ni-Cu sulphides in
marginal gabbro

Basement
metavolcanics

A
B
Drill section




*Olivine gabbronorite and olivine gabbro*

*Interlayered dunite, lherzolite and olivine websterite*

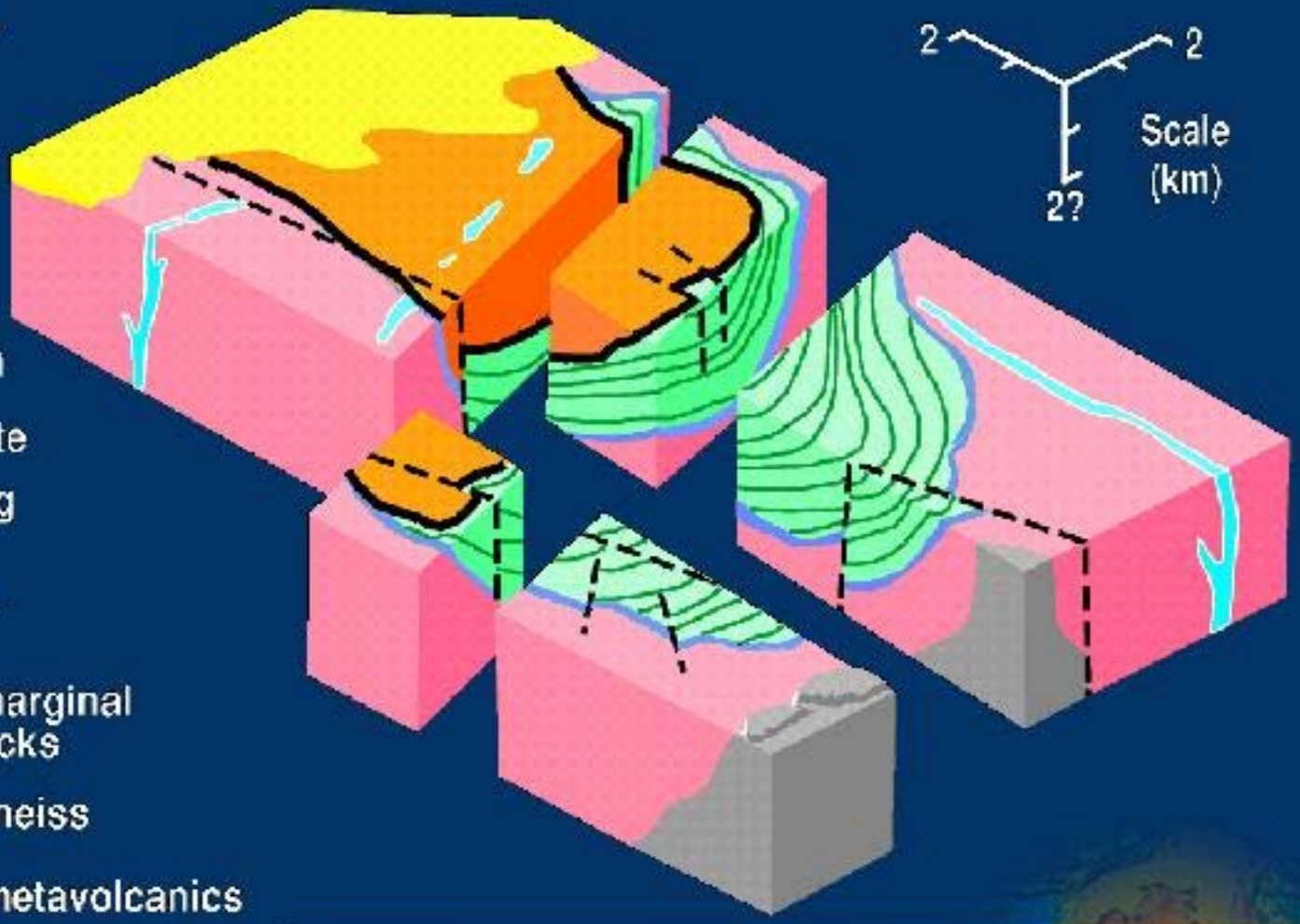
*Gabbronorite and plagioclase websterite containing massive Ni-Cu sulphide zones*

*Basement metavolcanics*

**Massive po-pent-cpy**

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

# Munni Munni Intrusion (2925 Ma): Pilbara Craton



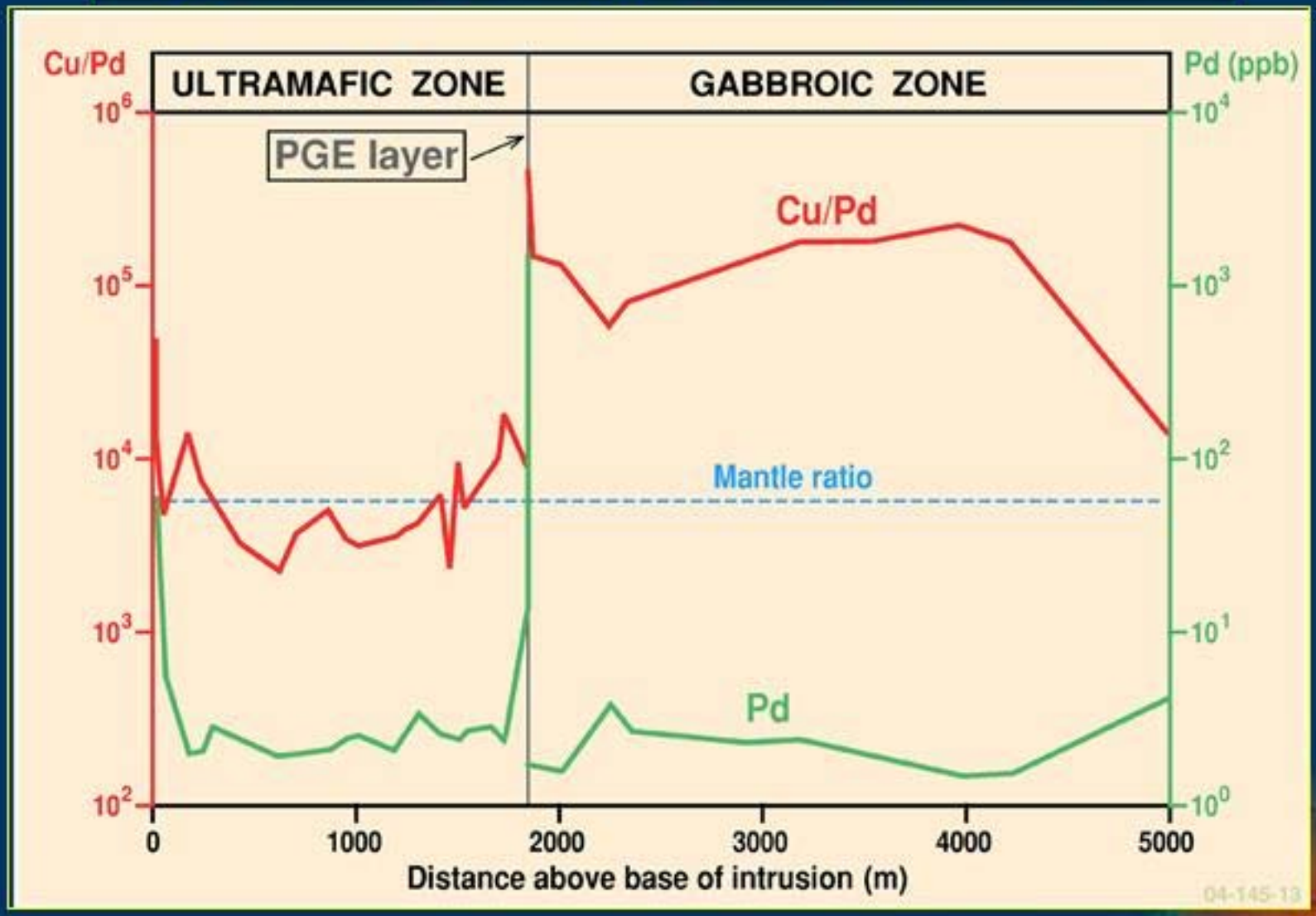

MUNNI MUNNI C

- Fortescue GP Platform
- Gabbronorite
- PGE-bearing websterite
- Peridotite & pyroxenite
- S-bearing marginal gabbroic rocks
- Granite & gneiss
- Basement metavolcanics

**Largest resource of PGEs in Australia**
**Significant Ni resource (~50 000 t) despite low-grade**
**24 Mt @ 2.9 g/t PGE+Au, 0.3% Cu, 0.2% Ni**

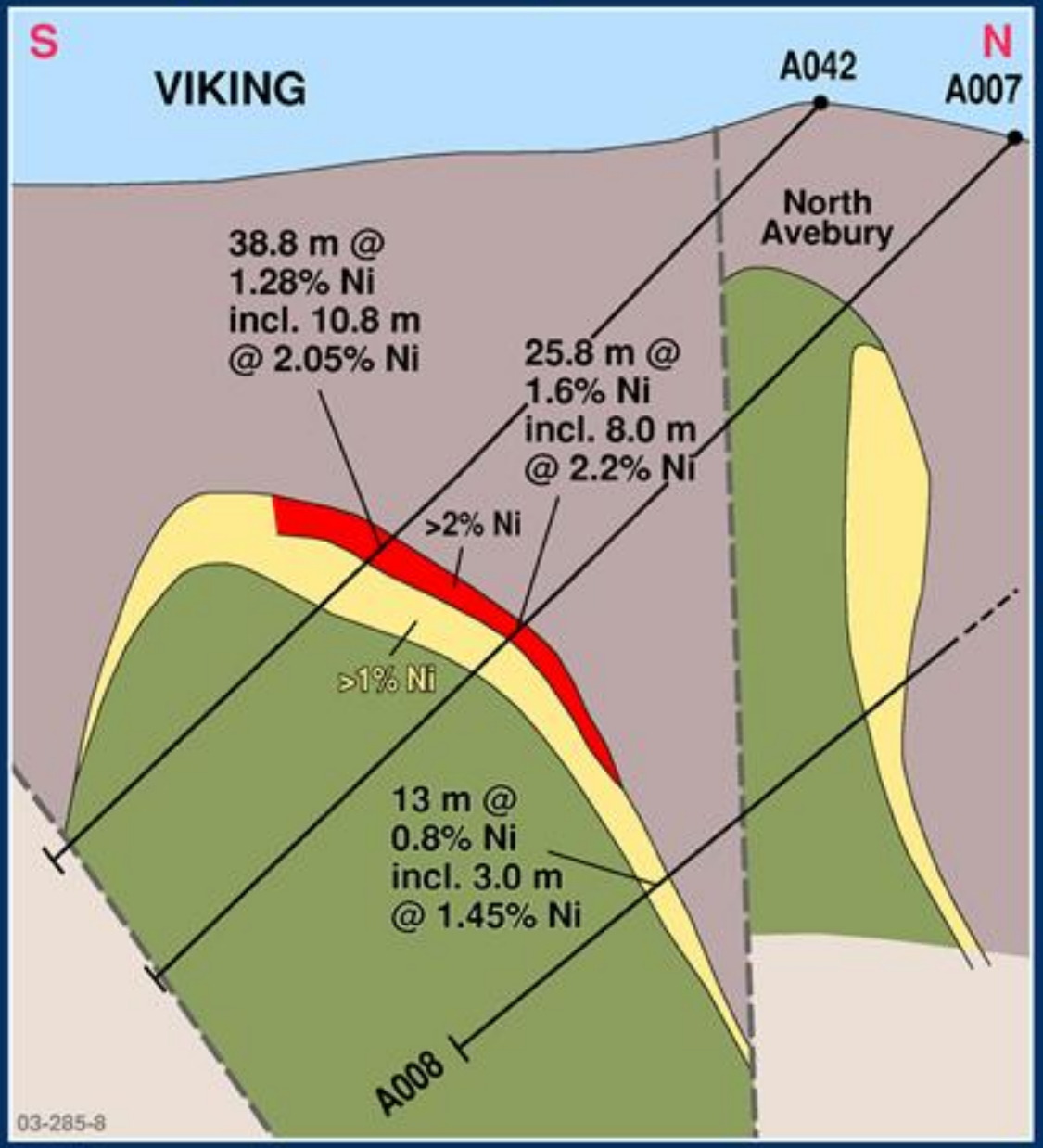
Source: Hoatson et al. 1992

# Exploration Strategies from Munni Munni




Cu/Pd, Cu/Zr, Pt/S (Hoatson & Keays 1989): now widely used in Canada, South Africa, Russia

# Avebury (Late Devonian): Western Tasmania



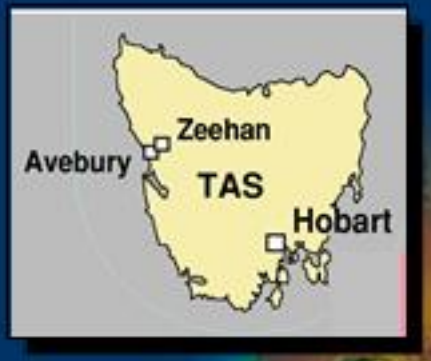

- Unusual Late Devonian hydrothermal deposit
- Ni remobilised by granite & redeposited in trap sites of altered ultramafic body
- Coarse pent-mt; S-poor, Fe-rich system
- 4 Mt @ 1.5% Ni; proposed mining in ~2006

Serpentinite

Sedimentary rock

Fault

100 m




Modified from: Allegiance Mining NL 2002 Annual Report

# Fertile *versus* Barren Komatiitic Provinces

**Increasing metal endowment (fertility)** ←

| | Eastern Goldfields | Thompson Belt | Abitibi Belt | Cape Smith Belt | Zimbabwe Craton | Southern Cross | 'Barren'* Provinces x 4 -Barberton -Pilbara -Gawler -Brazil |
|---|---|---|---|---|---|---|---|
| Ni (Mt) | 11.9 (63%) | 4.2 (22%) | 1.1 (6%) | 0.7 (4%) | 0.5 (3%) | 0.4 (2%) | |
| Deposits | Kambalda Mt Keith | Thompson Bowden | Dumont Sheband-owan | Raglan Expo-Ungava | Hunter's Rd Shangani | Maggie Hays Emily Ann | None |
| Age (Ga) | 2.7 | 1.88 | 2.7 | 1.92 | 2.7 | 3-2.9 | 3.5, 3.3-2.9, 2.5, 2.8 |
| Magma Type | AUDK ADK | AUDK | AUDK ADK | AUDK | AUDK | ADK AUDK | ADK x 4 |
| Volcanic Facies | CSF | ? | CSF | ?CSF LLLS | TDF ?CSF | TDF CSF | TDF x 4 LLLS x 4 |

AUDK: Al-undepleted komatiite ($Al_2O_3/TiO_2$ = 15-25)
ADK: Al-depleted komatiite ($Al_2O_3/TiO_2$ = <15)
*No known economic deposits

CSF: Compound sheet flows/pathways
TDF: Thin differentiated flows
LLLS: Layered lava lakes/sills

# Fertile *versus* Barren Tholeiitic Intrusion/Provinces

**Increasing metal endowment (fertility)** ←

| | Kaapvaal Craton | Sino-Korean Craton | Zimbabwe Craton | Baltic Shield | Torngat Orogen | Halls Creek Orogen | Pilbara Craton |
|---|---|---|---|---|---|---|---|
| Ni (Mt) | 12.9 (42%) | 5.5 (18%) | 5.4 (18%) | 4.3 (14%) | 2.2 (7%) | 0.1 (0.5%) | 0.1 (0.5%) |
| Deposits | Merensky Reef Platreef | Jinchuan | Great Dyke | Pechenga Moncheg-orsk | Voisey's Bay | Sally Malay Panton | Radio Hill Munni Munni |
| Age (Ga) | 2.06 | 0.83 | 2.59 | 1.98, 2.49 | 1.33 | 1.85 | 2.9 |
| Setting | Intracon. rift | Rifted continent. margin | Intracon. rift | Rifted continent. margin | Orogenic belt | Orogenic belt | Intracon. rift |
| Parent Magma(s) | High-Mg basalt, boninite | High-Mg basalt | High-Mg basalt | Ferropicrite | ?High-Al basalt | Olivine & quartz tholeiite | Siliceous high-Mg basalt |
| Basement Rocks | Sediments granite volcanics | Migmatite gneiss marble | Granite gneiss BIF | Sediments gneiss schist | Gneiss psammite | Migmatite granite granulite | Granite volcanics |

# Favourable Mineralising Elements: Komatiites

- Regionally extensive and primitive (>32% MgO; >$Fo_{85}$) AUDK sequences
- ~2.7, 2.9, (1.9) Ga
- Rift basins of high-crustal extension
- Thickened komatiite sequences
- Compound sheet flows & lava pathways
- S-source: sulphidic footwall rocks
- Trap: embayments/structural traps along basal contacts of channel facies

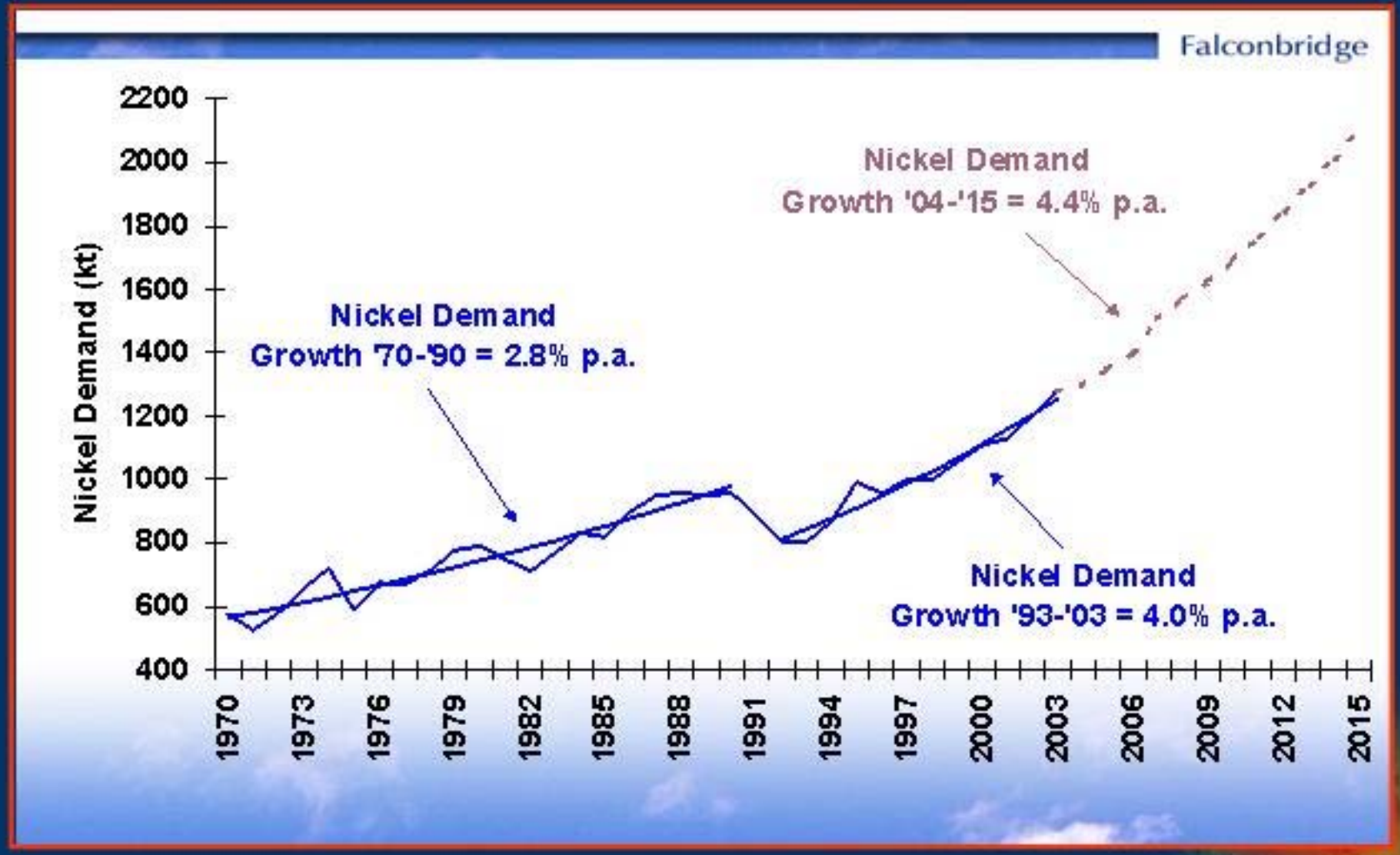
# Favourable Mineralising Elements: Tholeiitic Mafic Intrusions

- Small to medium, massive or layered mafic intrusions
- Archaean to at least late Prot (2.9-0.8 Ga)
- Proterozoic mobile/collisional zones or former rift zones of Archaean cratons
- Early S saturation of magma (in conduit by crustal contamination)
- Focussed magma flow-*dynamic* systems
- Preserved feeder conduit/basal contact

# Exploration Merit

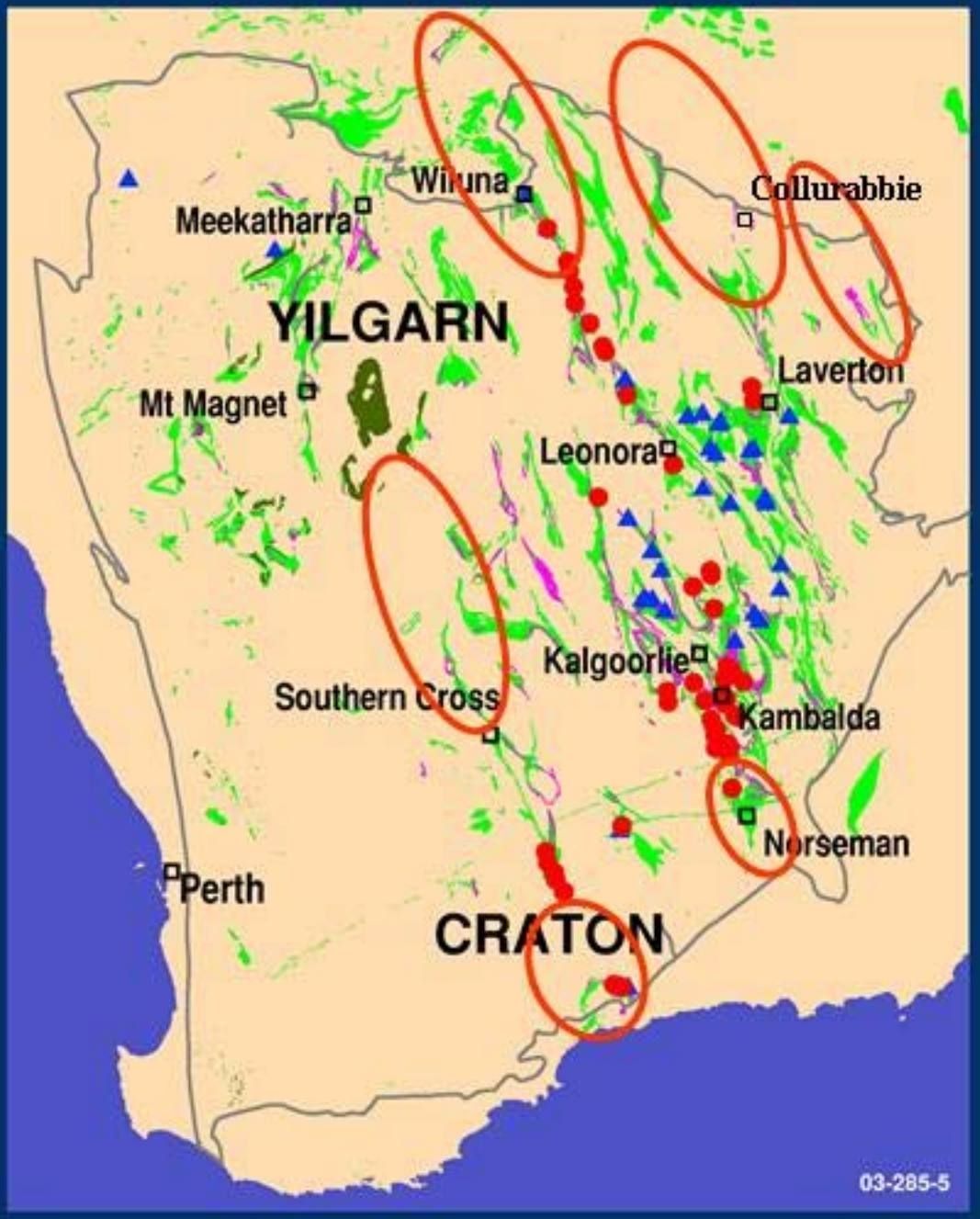
| **Basal Ni-Cu-Co sulphides** *Voisey's Bay-type* | *vs* | **Stratabound PGEs-Ni-Cu** *Merensky Reef-type* |
|---|---|---|
| Some economic deposits (Radio Hill, Sally Malay, ?Nebo-Babel); many foreign examples | | No economic deposits (best Munni Munni, Weld Range); few deposits o/s (MR, J-M Reef, Great Dyke) |
| Hosted by small to medium (<3 km thick) mafic-dominated intrusions; very common in Aust | | Hosted by large, thick (>5 km), differentiated layered mafic-ultramafic intrusions; rare in Aust |
| S-saturated stratigraphy; common, since most intrusions are evolved & crustally contaminated | | Part of stratigraphy is S-undersaturated; rare (<5% of 88 intrusions studied by GA) |
| Massive sulphides concentrated in structural depressions of basal contacts and/or in feeder conduits | | Economic status dependent on lateral continuity of mineralised layers (constant grades & widths) |
| Massive sulphides: strong geophysical-geochemical signatures | | Disseminated sulphides (<2% vol): weak geophysical-geochemical sign. |

# New Opportunities: Positive Long-Term Outlook?




Modified from Rae 2005

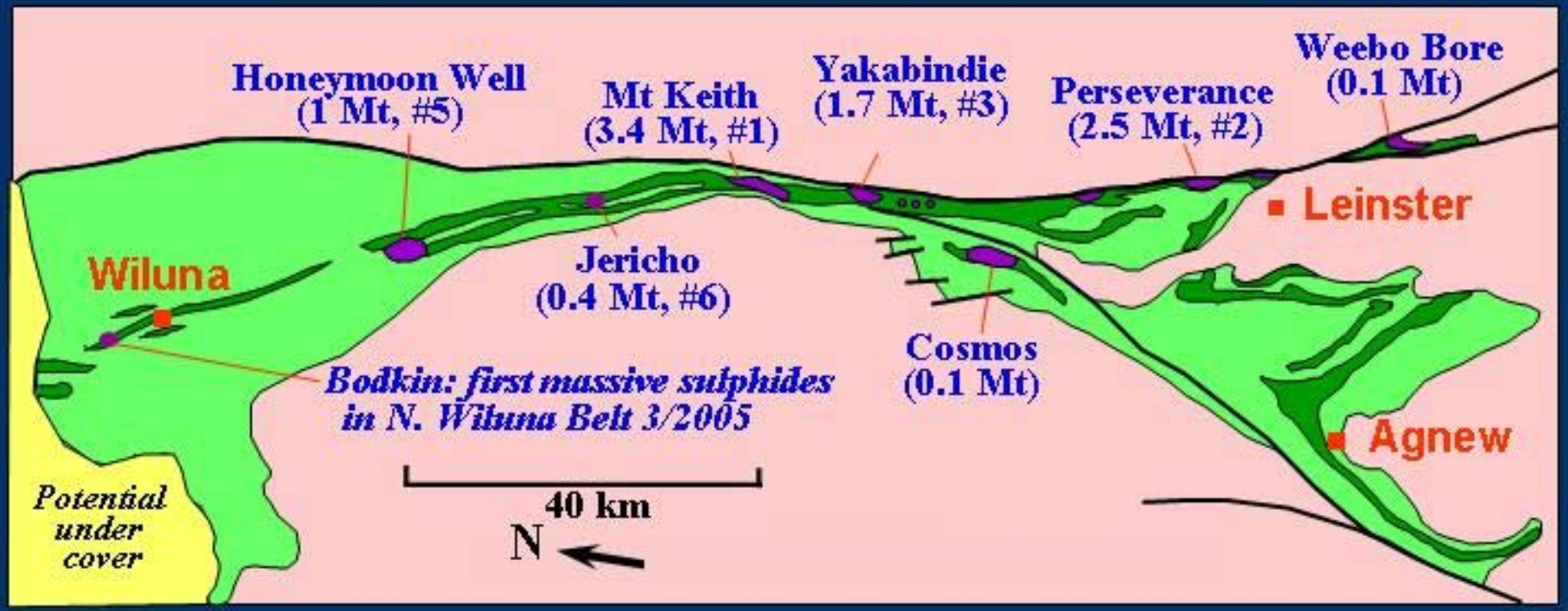
# 'Prospective' Komatiites Under Cover (1)




- Mafic-ultramafic intrusion
- Mafic rock
- Ultramafic rock
- Nickel lateritic deposit
- Nickel sulphide deposit

250 km

# 'Prospective' Komatiites Under Cover (2)

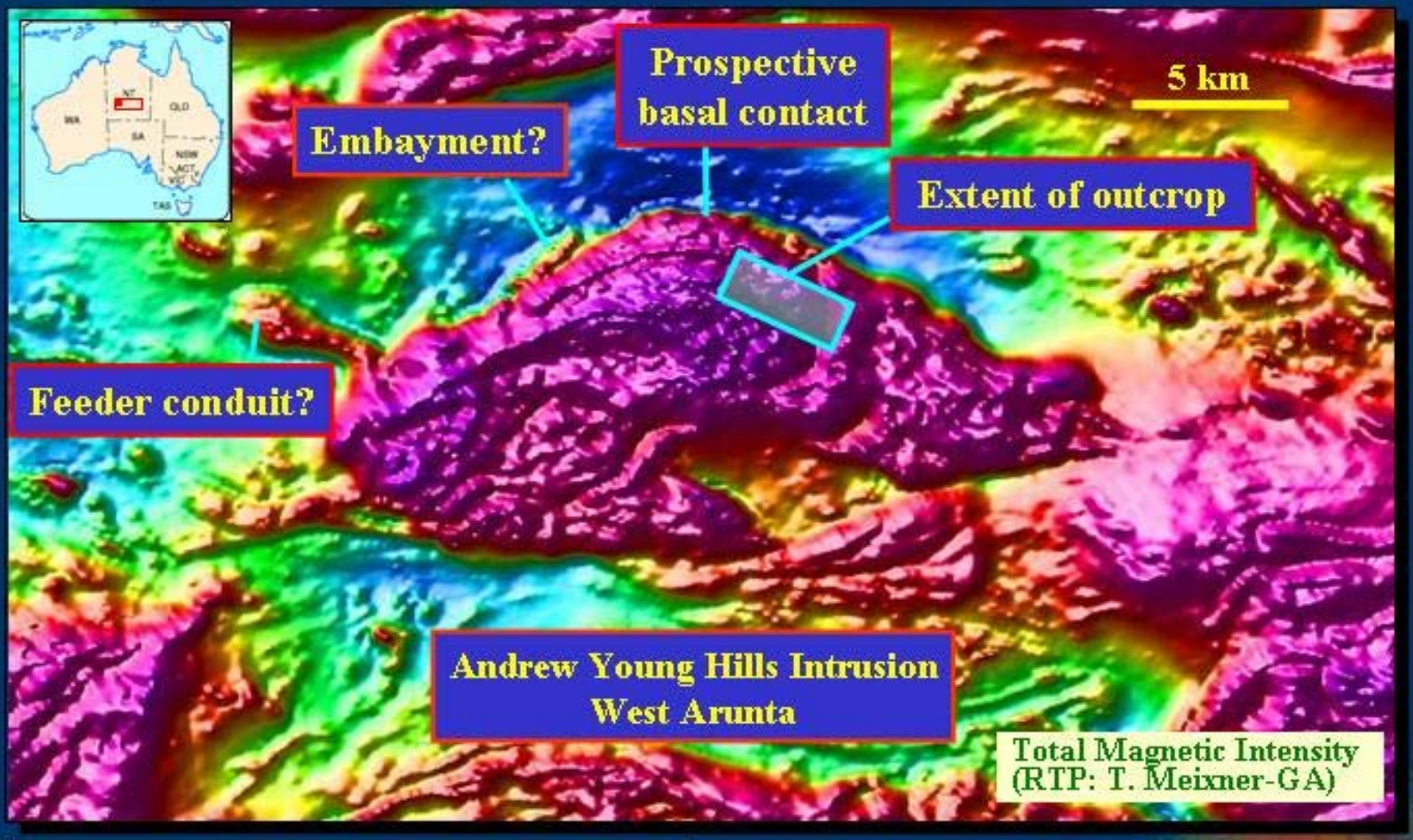



- Prot. cover
- Granite
- Greenstone
- Komatiite
- Dunite

- Richest nickel-komatiite belt in world
- Five of the six largest nickel sulphide deposits in Australia
- Four world-class deposits (>1 Mt)
- Global Ni metal resource of ~9.2 Mt

Potential for mineralised komatiites under Proterozoic cover

# 'Prospective' Mafic Intrusions Under Cover




Synclinal S-saturated body younging to SW; focus: feeder conduit entering chamber, irregularities in basal contact

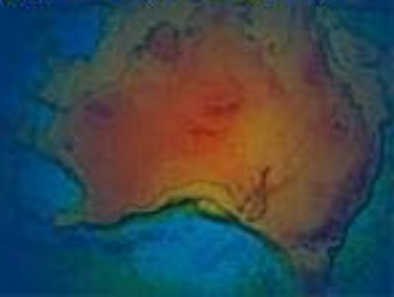
'Bleed' your geophysical data to determine geometry of intrusion

# Other Potential Nickel Targets

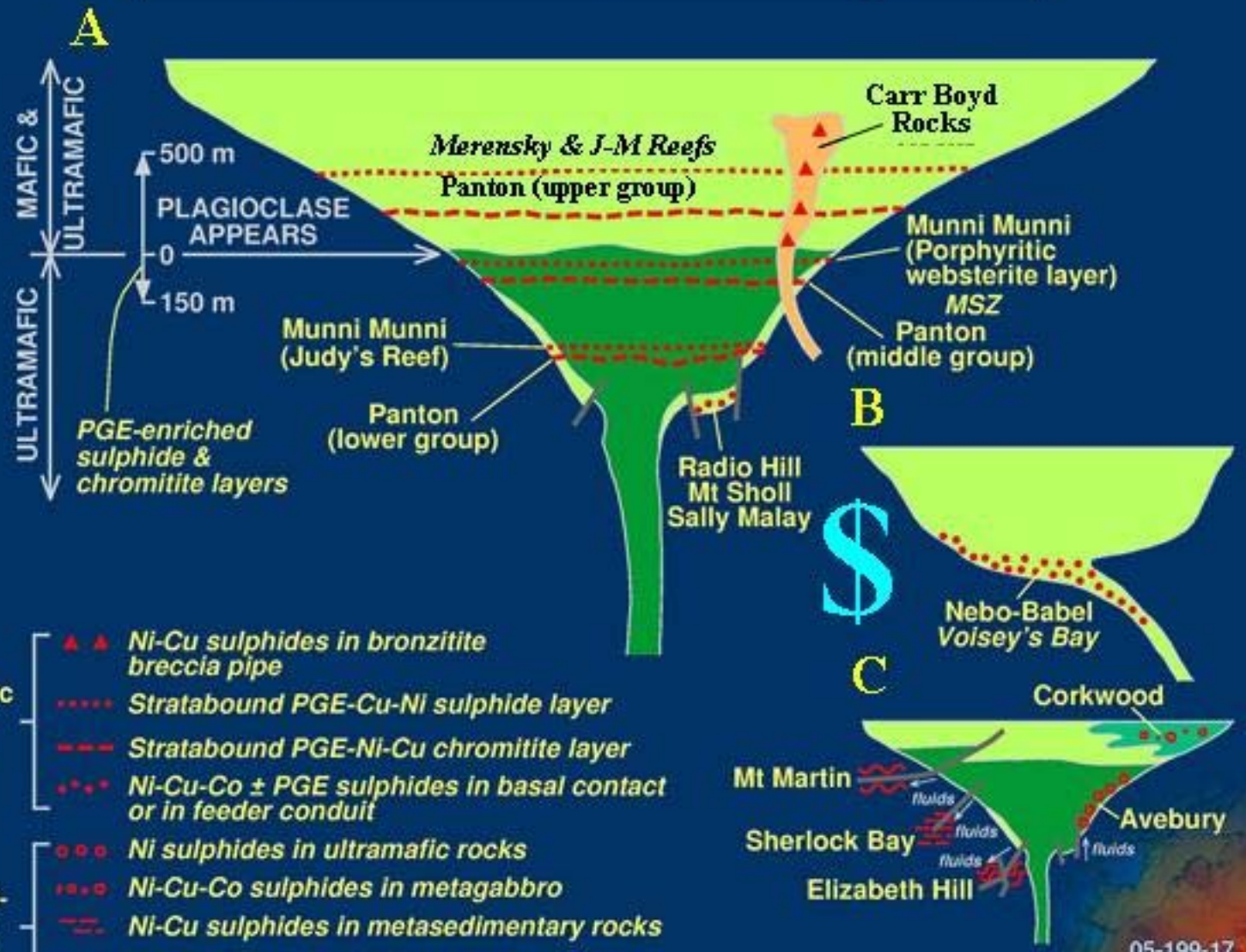
- 'Noril'sk-type' Ni-Cu-PGE systems: In western & northern Australia e.g., early Cambrian Kalkarindji Flood Basalts; Mesoproterozoic Warakurna igneous province; Fortescue Volcs; Hart-Woodward & Zamu-Oenpelli Dolerites, ?Eastern Creek Volcs

  *Exploration criteria:*
  - large flood basaltic provinces/rift environments
  - major faults, magma plumbing system, feeder zones
  - depletion of Ni, Cu, & PGEs → S-saturated magmatic systems
  - geochemical signatures (La/Sm, Nb/Th) of crustal contamination

- Phanerozoic provinces of E. Australia (Allegiance Mining, Inco, Anglo, BHPB), e.g. hydrothermal targets (Avebury-type)



# Distribution of Nickel Deposits



# Thank you

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