PALAEOZOIC GRANITE METALLOGENESIS OF EASTERN AUSTRALIA

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Introduction

Granites (s.l.) and related rocks of eastern Australia can be classified according to metallogenic potential using a scheme based on compositional character, degree of compositional evolution, degree of fractionation, and oxidation state. The scheme is based on empirical and theoretical considerations and satisfactorily describes the known distribution of granite-related mineralisation (Figure 1).

Granitic rocks of eastern Australia range from unevolved, mantle compatible compositions to highly evolved and fractionated. They exhibit age- and region-specific variations in silica content, compositional evolution and oxidation state (Blevin et. al., 1996). The most unevolved intrusive igneous rocks comprise those of the Ordovician of the Lachlan Orogen (LO), and the Devonian of the New England Orogen (NEO). Strongly fractionated and evolved I-type granites occur in western Tasmania, the southern NEO, and far north Queensland. Other fractionated suites tend to occur relatively rarely in the LO (eg. the Boggy Plain and Koetong Supersuites) and elsewhere (e.g. Tuckers Supersuite in north Qld).

Oxidation states of granites vary markedly throughout eastern Australia. The most consistently oxidised rocks occur in the Ordovician of the central LO, the Urannah Batholith and Devonian of the northern NEO. The Carboniferous I-types of the northeastern LO are consistently more oxidised than other Siluro-Devonian I-types of the LO. The oxidation states of granites in some areas appear to be influenced by wall rocks.

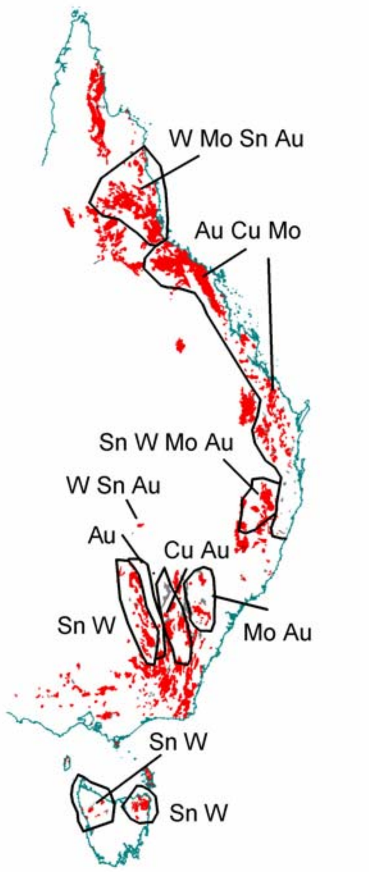

Fig. 1 Distirbution of some igneous-metallogenic associations in eastern Australia

Northern Queensland

Both the Cape York Granites and Coastal Ranges (Georgetown-Herberton) Province are relatively felsic with the majority of granites containing more than 70 % SiO_2. Only the granites of the Coastal Ranges Province have members that are strongly fractionated. The granites of Cape York are very similar in many regards to the similarly aged Siluro-Devonian granites of the LO (and Siluro-Devonian of the Ravenswood Batholith), and their metallogenic potential is considered to be similar. Sn-, W- and Mo-centred systems are widespread in the Carboniferous to Permian Coastal Range and related granites. A significant break in the compositional character of granite magmatism occurs just north of Townsville from more evolved in the north to less evolved and fractionated granites to the south. Cu-Mo-Au centred systems dominate in the oxidised, more unevolved Permian of the Ravenswood Batholith.

Northern New England Orogen

Devonian igneous rocks of the NNEO (Mount Morgan Tonalite Complex) share with the Ordovician of the LO the most unevolved compositions and highest K/Rb ratios of all intrusive igneous units in eastern Australia. The MMTC has trace element and REE signatures indicative of an island arc derivation. The absence of HREE depletion precludes garnet as a residual phase in the source. Sr contents are modest and the low Al_2O_3 nature of the MMTC suggests that plagioclase was a residual phase. The presence of a reasonably continuous compositional range within the MMTC suggests fractionation of basalt as the most likely origin.

Post-Devonian magmatism in the northern NEO comprises moderately evolved compositions (200 < K/Rb < 400). Granites of the Yarrol Province and the Urannah Batholith are on average less compositionally evolved in terms of K/Rb than granites further to the south (i.e. have many units with K/Rb values between 300 and 400). Granites of the Auburn Province (Rawbelle) are clearly less evolved than those of the Moonbi Supersuite of the New England Batholith in the southern NEO with which it is usually compared. Cu-Au mineralisation dominates in the northern NEO from the Devonian to the Cretaceous but tends to be low grade. Intriguingly, oxidation states of most of the intrusive rocks in this region, with the exception of the Urannah Batholith, might not be as high as otherwise expected. More studies are required to establish the veracity of this, but the region retains potential for Au-rich systems, and Ag.

Southern New England Orogen

The granites of the southern NEO fall into two distinct groups in terms of K/Rb. The Clarence River Supersuite (CRSS) has K/Rb ratios around 250 to 350, while all other supersuites have markedly lower K/Rb ratios. In this regard the CRSS granites are more typical of the Yarrol Province and the northern NEO in general than of the south. The Moonbi Supersuite granites are similar in terms of compositional evolution to that of the Carboniferous I-types of the Georgetown-Herberton region of far north Queensland. Marked contrasts between the northern and southern portions of the Moonbi Supersuite are also mirrored in their divergent metallogenic associations. The granites of the southern NEO have a relatively restricted range of oxidation states, with neither strongly oxidised nor strongly reduced examples being present.

The southern NEO remains an enigmatic region of eastern Australia where a very large number of small mines are associated with a large volume of otherwise highly prospective granites. The northern part of the Moonbi Supersuite is highly prospective for Sn and Au deposits. Gold styles like those of Kidston should not be ruled out for systems still buried in Permo-Triassic volcanics or covered by Tertiary basalts. The Clarence River Supersuite is not strongly oxidised, indeed only weakly so, and its prospectivity for porphyry Cu-Au type mineralisation can only be rated as very low. However, these granites should be prospective for Au-Ag associations in both vein and epithermal styles.

Lachlan Orogen: Ordovician

The Ordovician igneous systems of the LO are hosted in four longitudinal belts. More recent petrochemical and geophysical studies have supported a contemporaneous intra-oceanic island arc setting. Ordovician igneous units can be divided into two general compositional types. The majority plot in the trachytic portion of the total alkali-silica (TAS) diagram and fall typically into the very-high-K (shoshonite) field on K_2O-SiO_2 plots. The other group plots along a typical calc-alkaline basalt-andesite-dacite(-rhyolite) (BADR) trend on TAS plots and fall into the medium- to high-K fields on K_2O-SiO_2 plots. Transitional suites between these two trends are not common. Both compositional and isotopic data support an unevolved mantle origin for the Ordovician magmatism. However the mg# of the magmas are relatively evolved and indicate that they represent fusion products of variably enriched mantle materials (Blevin, 2002).

In addition to their unevolved nature, the high relative oxidation state of the Ordovician units clearly distinguishes them from the Siluro-Devonian of the LO (Fig. 2). The major metallogenic association is that of porphyry Cu-Au.

Lachlan Orogen: Siluro-Devonian and Carboniferous

Post-Ordovician granitic magmatism comprises a substantial proportion of the present exposed area of the LO of south-eastern Australia. Although a large number of mineral deposits and occurrences are present, only Sn and W systems are world class in size and these are largely restricted to Tasmania. Numerous metallogenic associations exist however and many have Au present. This provides opportunities for exploration and discovery of new deposits.

The majority of Siluro-Devonian I-type granites are typically too felsic and not strongly oxidised enough for porphyry Cu-Au systems, and not fractionated and oxidised enough for porphyry Mo systems (Fig.2). Sn and Sn-W systems are developed on a world-class scale in reduced and fractionated granites of the central LO and Tasmania.

The granites of the Tasmanian west coast are associated with some of the largest granite-related mineral deposits in south-eastern Australia. These include world-class deposits of Sn (Renison, Cleveland, Mt Bischoff), W (King Island, Kara) and polymetallic zoned systems (Zeehan). These granites are felsic, and mostly highly fractionated and thus are difficult to classify. However, use of chemical, isotopic, and petrographic data enables a satisfactory classification of these granites for the purposes of metallogeny. The granite at Renison is I-type, and long with much of the rest of east Australia, demonstrates that I-type granites have been the major source of Sn in Australia. Taswegian granites are distinct from those of the rest of the LO in that they are generally younger than the main Siluro-Devonian magmatic event and all show the effects of feldspar fractionation (with the exception of the King Island granites). The I-type granites (again with the exception of the Grassy Suite) differ from other LO I-types granites by having higher Zr, Th and U, and being lower in Sr and Pb for any given value of SiO_2 or FeO*. Taswegian Granites are related to intense mineralisation because they are strongly fractionated, fortuitously shallowly exposed and intrude sequences containing reactive carbonates that provide efficient chemical traps for mineralised fluids.

The Carboniferous granites of the northeastern LO have Mo-W, Sn and Au metal associations reminiscent of the Stanthorpe Group of granites within the Moonbi Supersuite (Timbarra); and with the Carboniferous Ootann Supersuite of the far north Queensland (Kidston, Red Dome). While the Carboniferous granites lack the extensive areas of highly fractionated granites as other systems, some strongly fractionated members exist.

References

Blevin, P. L., 2002. The petrographic and compositional character of variably K-enriched magmatic suites associated with Ordovician porphyry Cu-Au mineralisation in the Lachlan Fold Belt, Australia. *Mineralium Deposita*, 37:87-99.

Blevin, P. L., Chappell, B. W., and Allen, C. M., 1996. Intrusive metallogenic provinces in eastern Australia based on granite source and composition. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 87, 281-290.

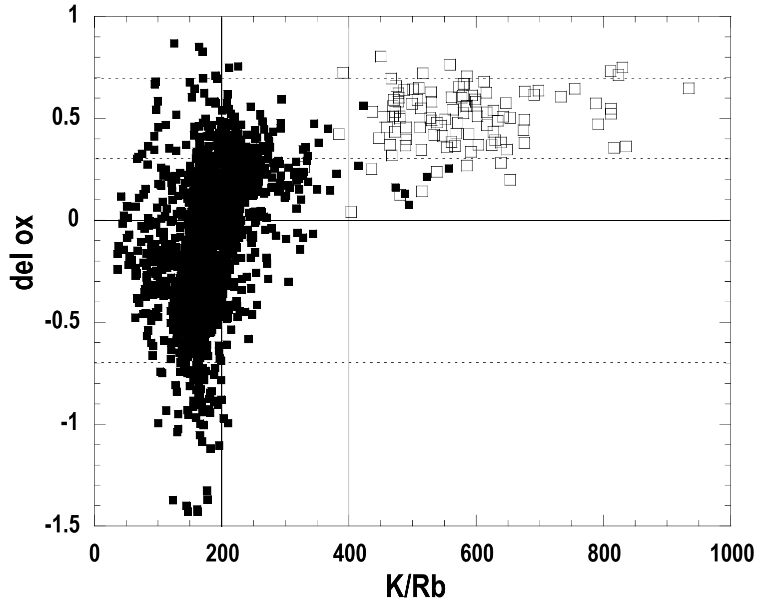

Figure 2. K/Rb ratio versus relative oxidation state for intrusive igneous rocks, Lachlan Orogen. del Ox refers to relative redox states calculated from Blevin (this volume). del Ox > 0 are oxidised. Open squares = Ordovician units, closed squares = Siluro-Devonian units. Ordovician units fall into the field associated with porphyry Cu-Au.

METALLOGENY OF EASTERN AUSTRALIA

Phil Blevin

ISHIHARA SYMPOSIUM

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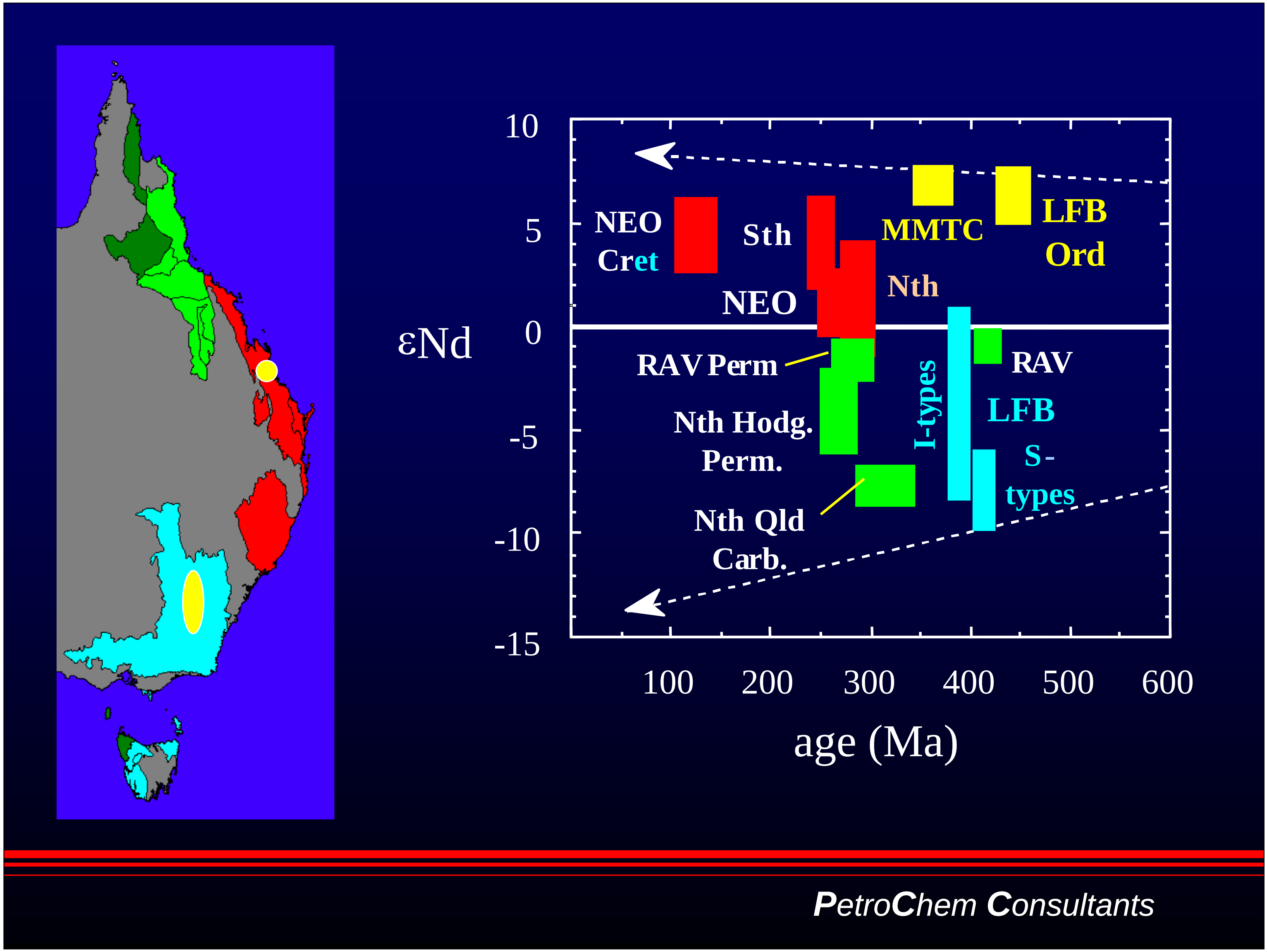
10
5
0
-5
-10
-15
εNd
100
200
300
400
500
600
age (Ma)
NEO
Cret
Sth
NEO
MMTC
Nth
LFB
Ord
RAV Perm
Nth Hodg.
Perm.
Nth Qld
Carb.
I-types
RAV
LFB
S-
types
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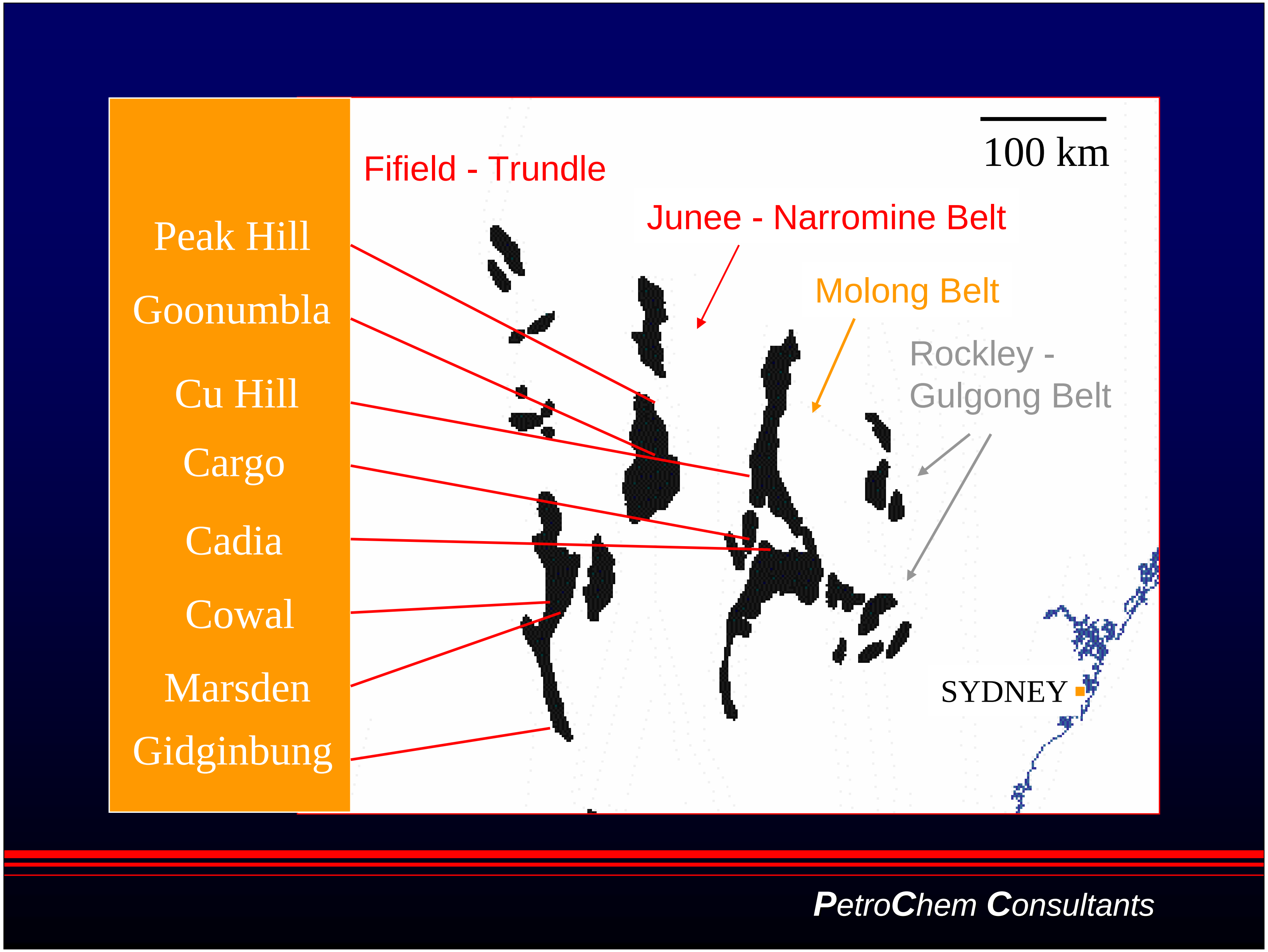
Fifield - Trundle
100 km
Junee - Narromine Belt
Molong Belt
Rockley -
Gulgong Belt
Peak Hill
Goonumbla
Cu Hill
Cargo
Cadia
Cowal
Marsden
Gidginbung
SYDNEY
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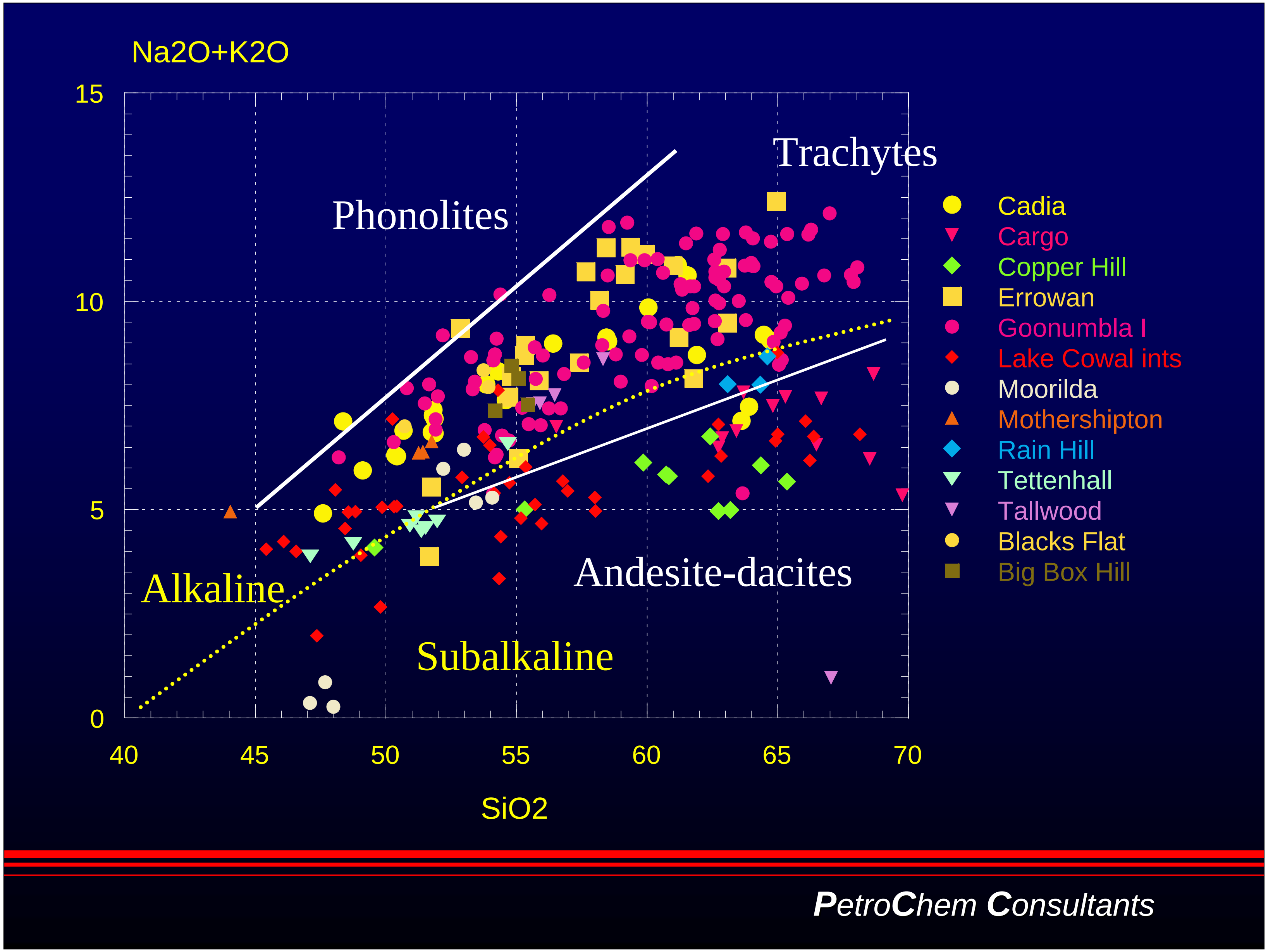
Na2O+K2O
15
10
5
0
40
45
50
55
60
65
70
SiO2
Phonolites
Trachytes
Alkaline
Andesite-dacites
Subalkaline
Cadia
Cargo
Copper Hill
Errowan
Goonumbla I
Lake Cowal ints
Moorilda
Mothershipton
Rain Hill
Tettenhall
Tallwood
Blacks Flat
Big Box Hill
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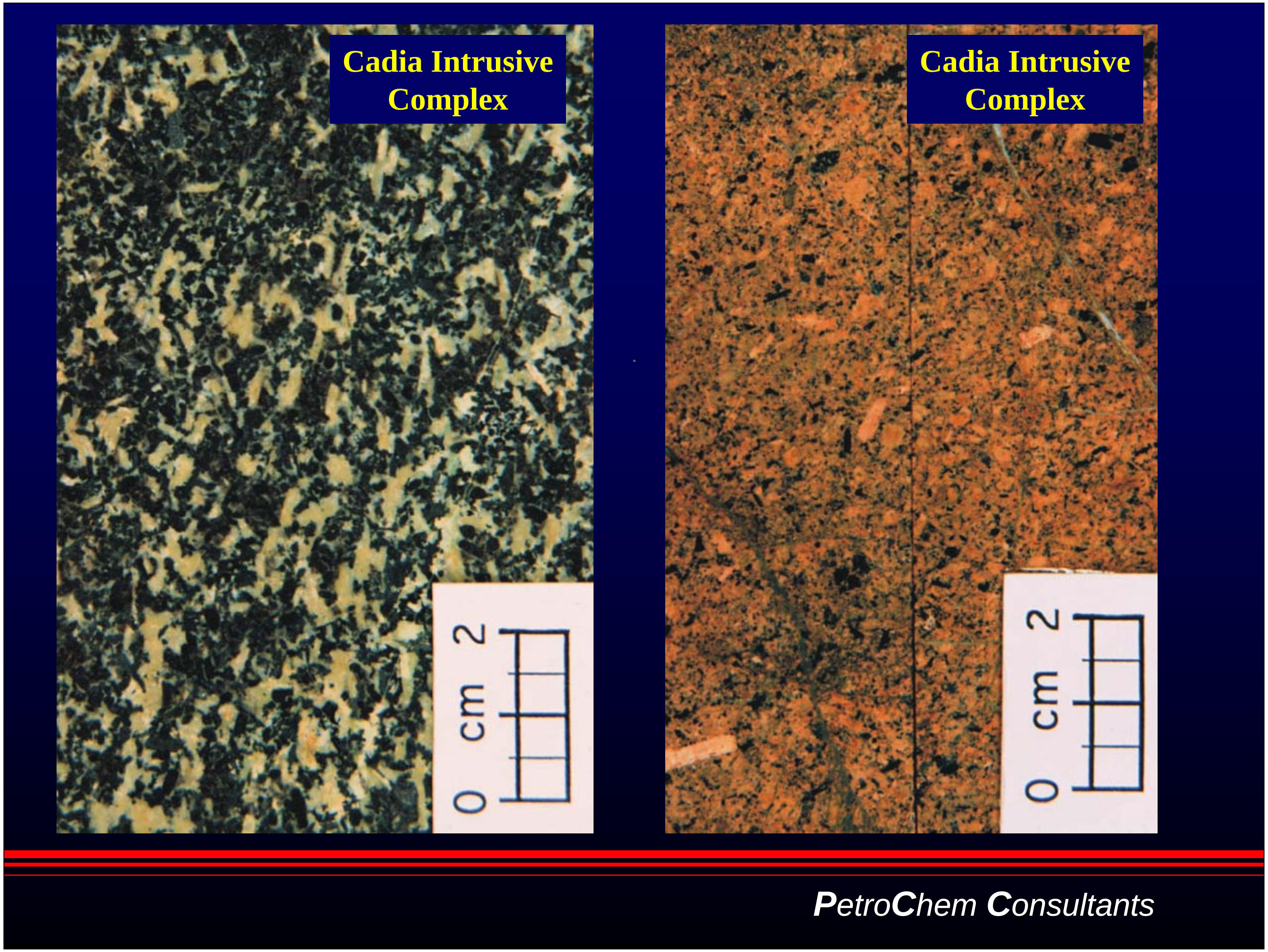
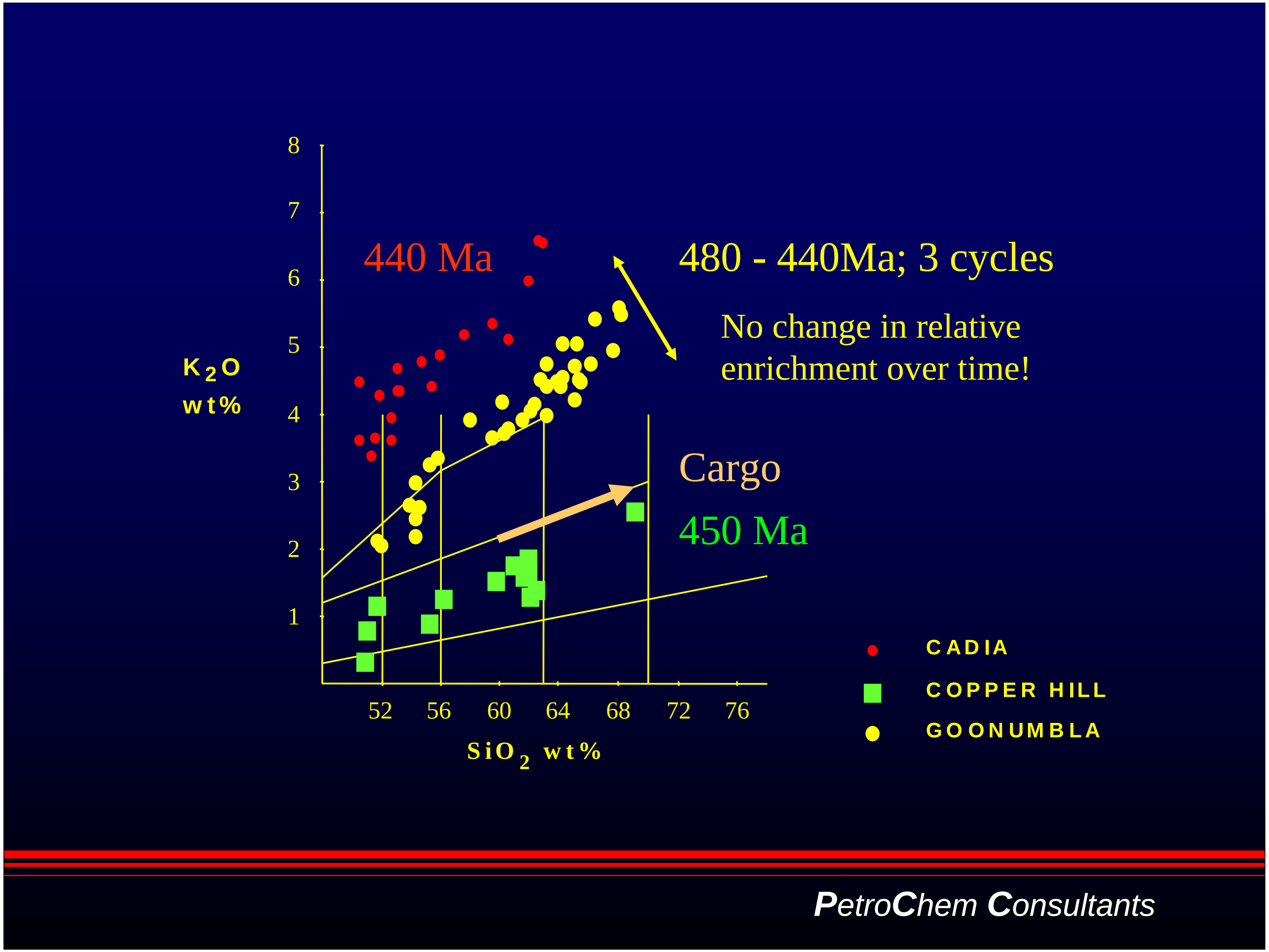
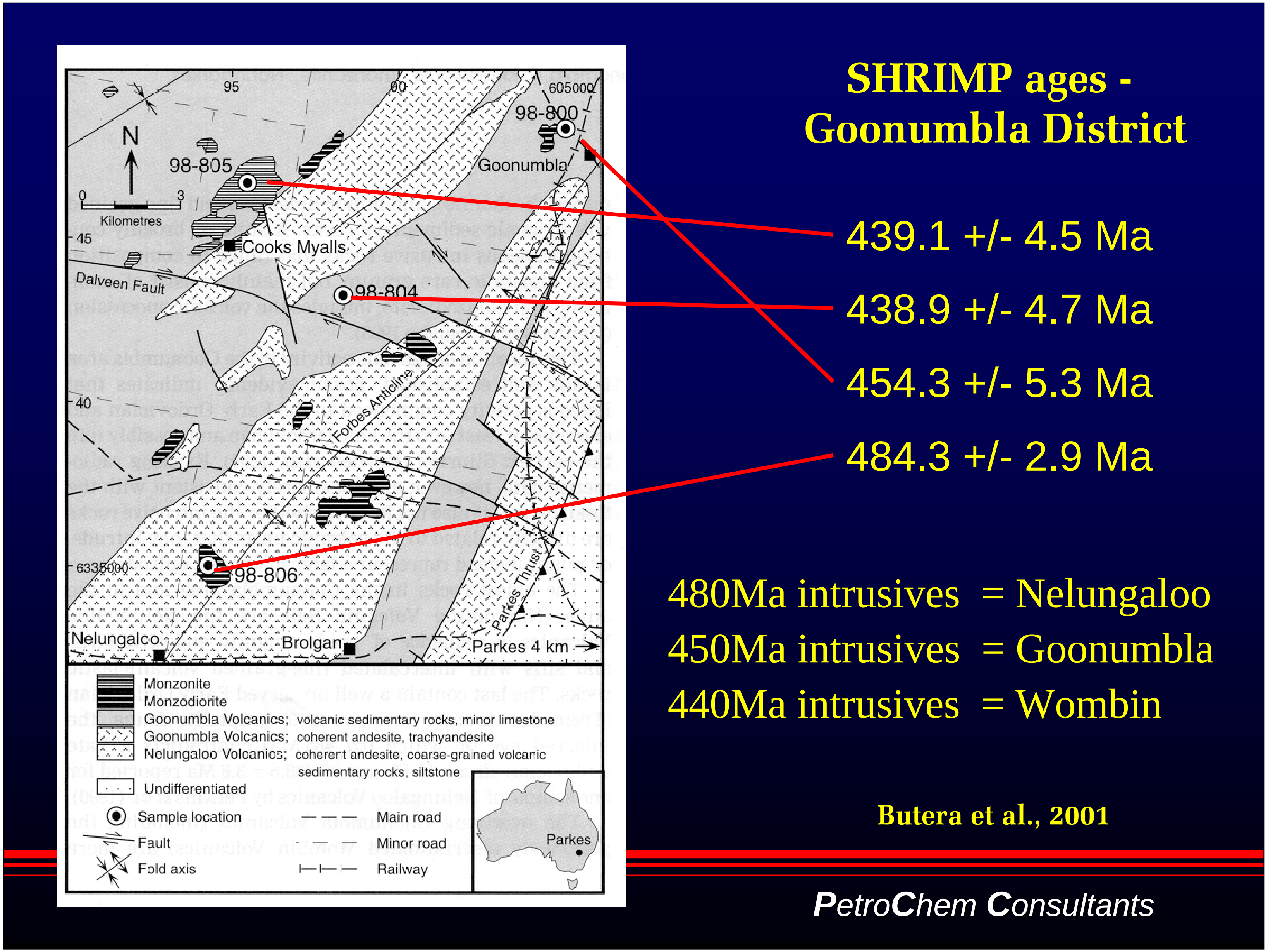

Cadia Intrusive Complex
0 cm 2
Cadia Intrusive Complex
0 cm 2
PetroChem Consultants



440 Ma
480 - 440Ma; 3 cycles
No change in relative enrichment over time!
Cargo
450 Ma
K2O wt%
SiO2 wt%
8
7
6
5
4
3
2
1
52
56
60
64
68
72
76
CADIA
COPPER HILL
GOONUMBLA
PetroChem Consultants


SHRIMP ages -
Goonumbla District
439.1 +/- 4.5 Ma
438.9 +/- 4.7 Ma
454.3 +/- 5.3 Ma
484.3 +/- 2.9 Ma
480Ma intrusives = Nelungaloo
450Ma intrusives = Goonumbla
440Ma intrusives = Wombin
Butera et al., 2001
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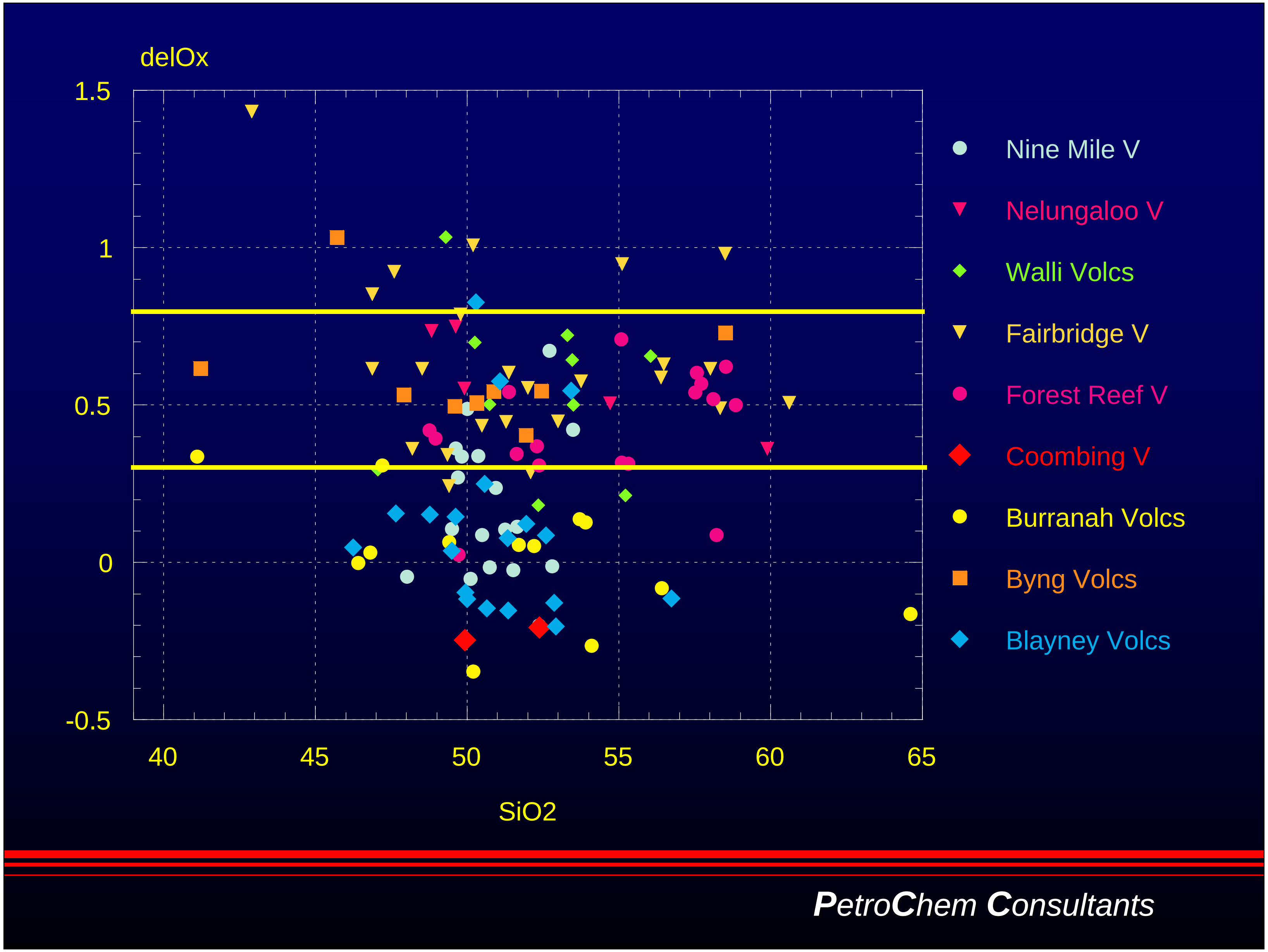
N
0 3
Kilometres
95
00
605000
45
40
6335000
98-805
98-800
98-804
98-806
Goonumbla
Cooks Myalls
Dalveen Fault
Forbes Anticline
Parkes Thrust
Nelungaloo
Brolgan
Parkes 4 km
Monzonite
Monzodiorite
Goonumbla Volcanics; volcanic sedimentary rocks, minor limestone
Goonumbla Volcanics; coherent andesite, trachyandesite
Nelungaloo Volcanics; coherent andesite, coarse-grained volcanic sedimentary rocks, siltstone
Undifferentiated
Sample location
Fault
Fold axis
Main road
Minor road
Railway
Parkes


delOx
1.5
1
0.5
0
-0.5
40
45
50
55
60
65
SiO2
Nine Mile V
Nelungaloo V
Walli Volcs
Fairbridge V
Forest Reef V
Coombing V
Burranah Volcs
Byng Volcs
Blayney Volcs
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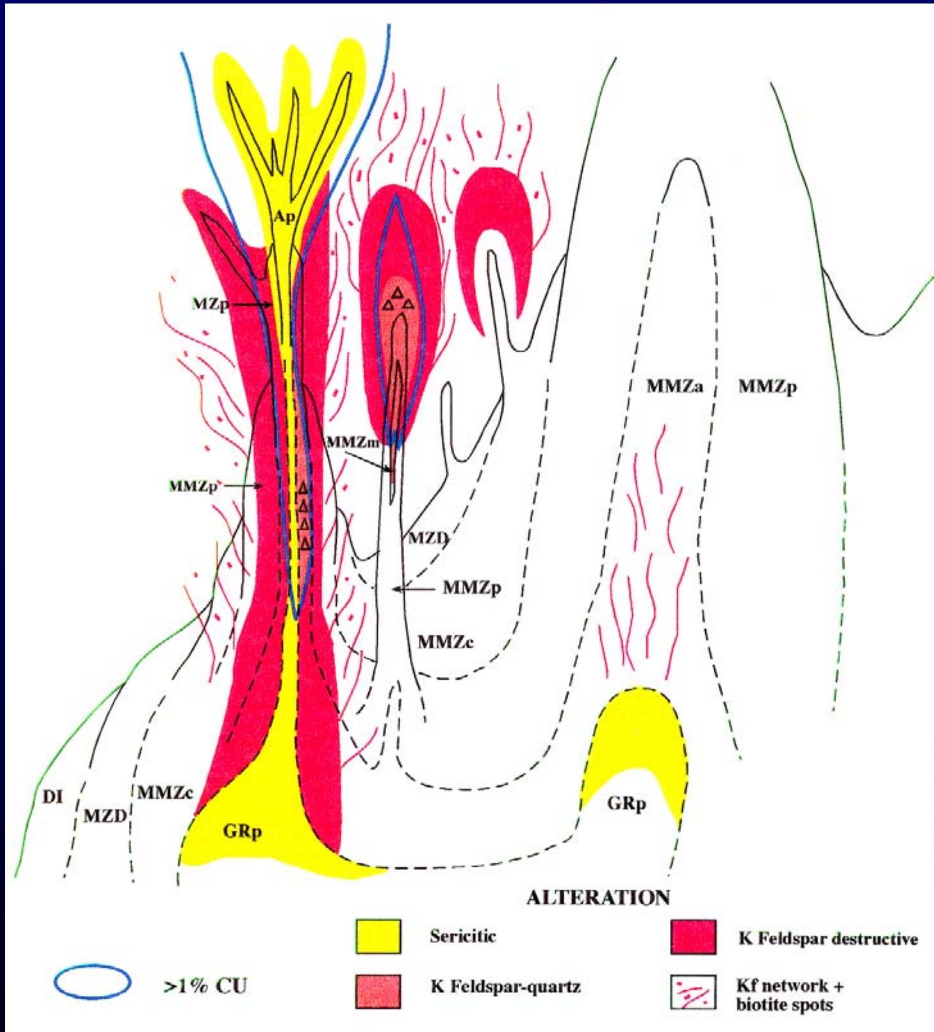
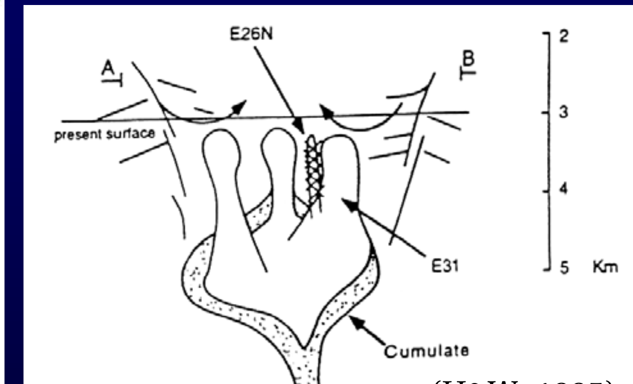
Intrusion - Alteration - Mineralisation Relationships

North Parkes





(H&W, 1995)

AP	=	aplite
GRp	=	granite porphyry
MZp	=	monzonite porphyry
MMZm	=	mosaic textured mafic monzonite
MMZp	=	mafic monzonite porphyry
MMZc	=	coarse mafic monzonite
MMZa	=	mafic monzonite aphanitic
MZD	=	monzodiorite
DI	=	diorite

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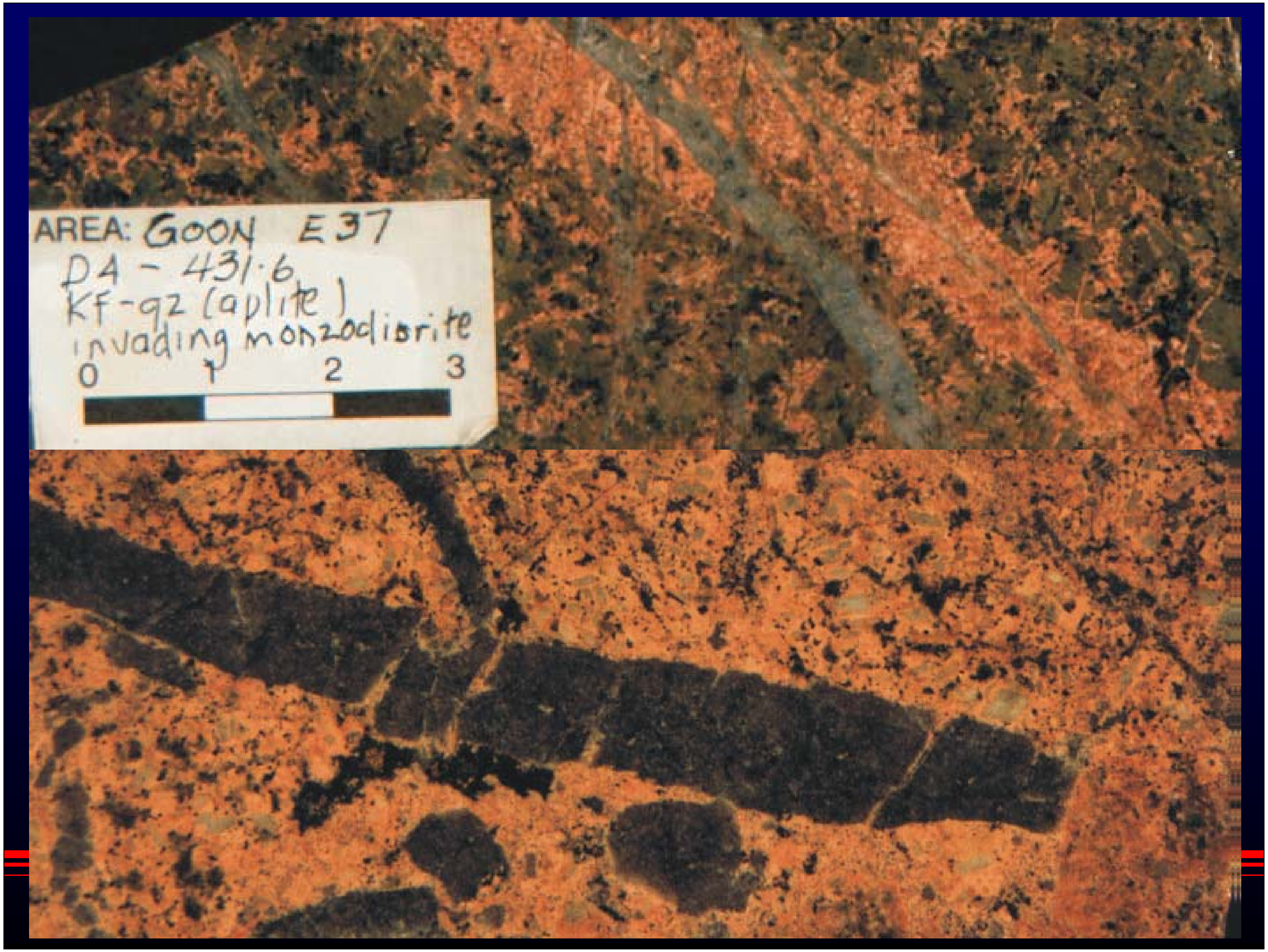
AREA: GOON E37
DA - 431.6
Kf-qz (aplite)
invading monzodiorite
0 1 2 3

Why is the Ordovician so prospective?

- The Ordovician has all the parameters considered conducive to porphyry Cu-Au mineralization.
- Appear to be volatile rich systems at least at the felsic stage.
- Degree of preservation has allowed mineralized upper portions to be preserved.

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LFB S-D/Carb Igneous Metallogeny

- Igneous Metallogeny of the LFB is a simple function of:
  - Granite type
  - Compositional evolution
  - Presence of fractional crystallisation
  - Oxidation State
- Ordovician chemistries, oxidation states are not present in younger rocks

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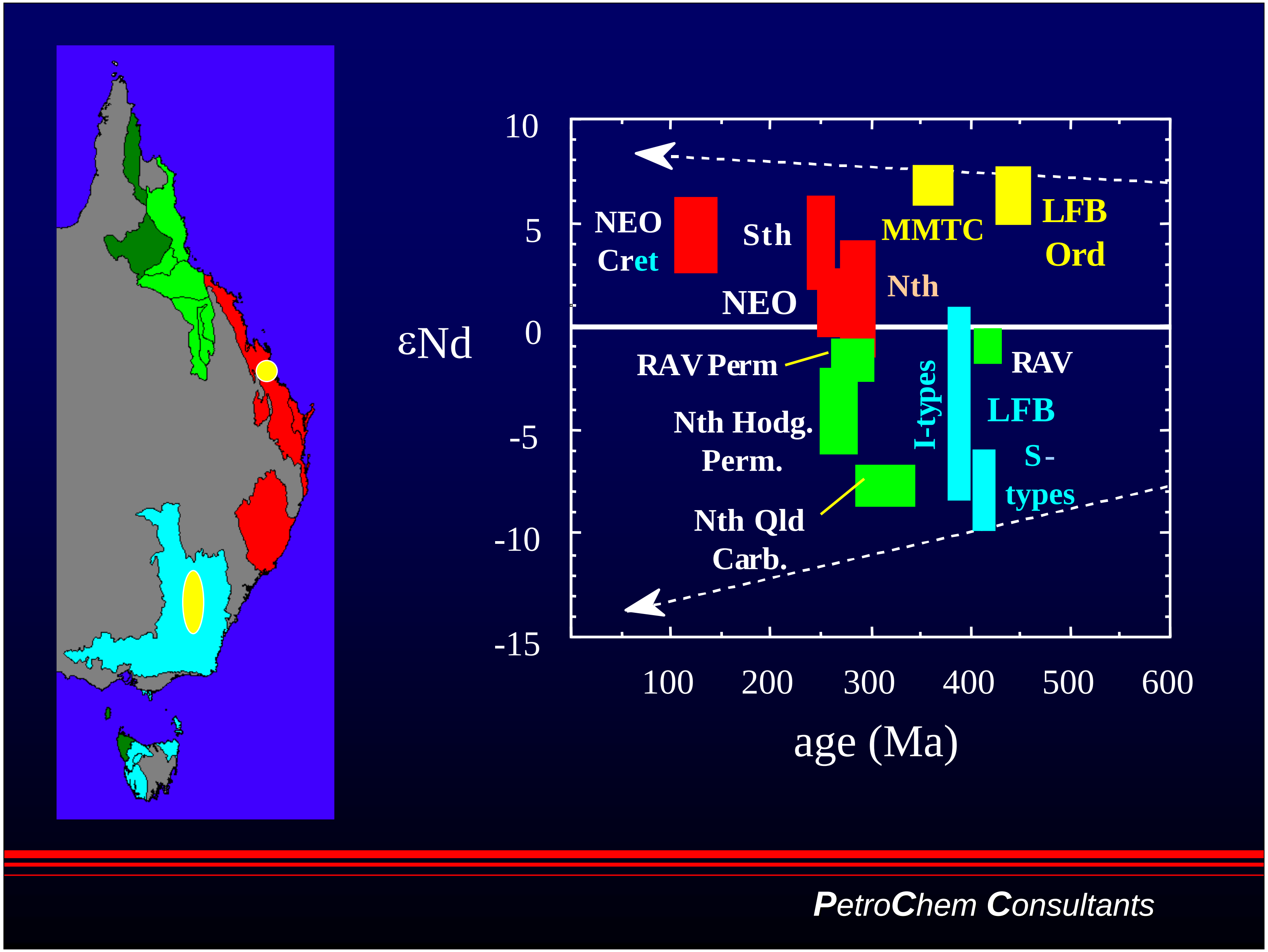
10
5
0
-5
-10
-15
εNd
100
200
300
400
500
600
age (Ma)
NEO
Cret
Sth
NEO
MMTC
Nth
LFB
Ord
RAV Perm
Nth Hodg.
Perm.
Nth Qld
Carb.
I-types
RAV
LFB
S-
types
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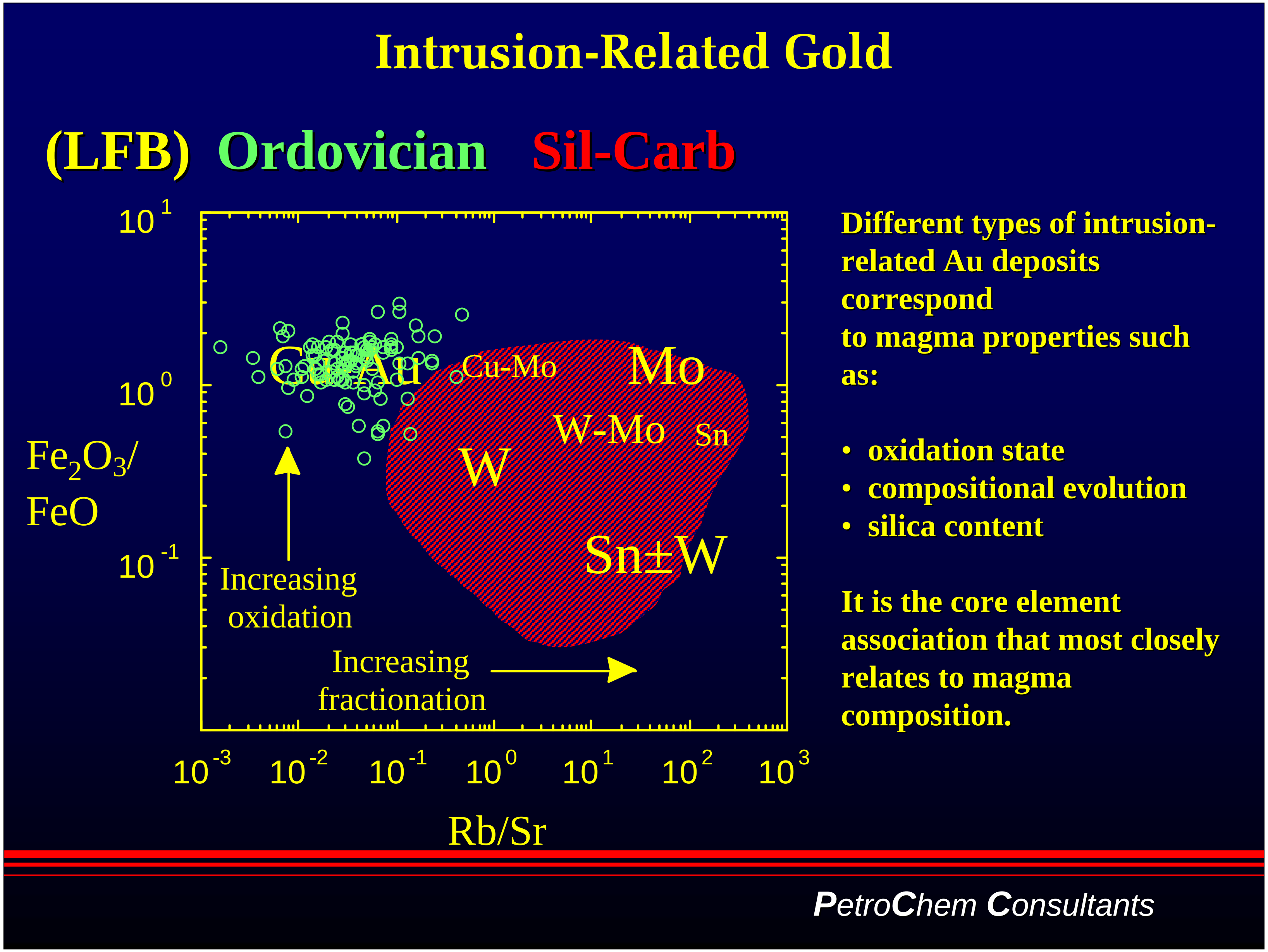
Intrusion-Related Gold
(LFB) Ordovician Sil-Carb
10^1
10^0
10^{-1}
Fe_2O_3/ FeO
Cu-Au
Cu-Mo
Mo
W-Mo
Sn
W
Sn±W
Increasing oxidation
Increasing fractionation
10^{-3} 10^{-2} 10^{-1} 10^0 10^1 10^2 10^3
Rb/Sr
Different types of intrusion-related Au deposits correspond to magma properties such as:
• oxidation state
• compositional evolution
• silica content
It is the core element association that most closely relates to magma composition.
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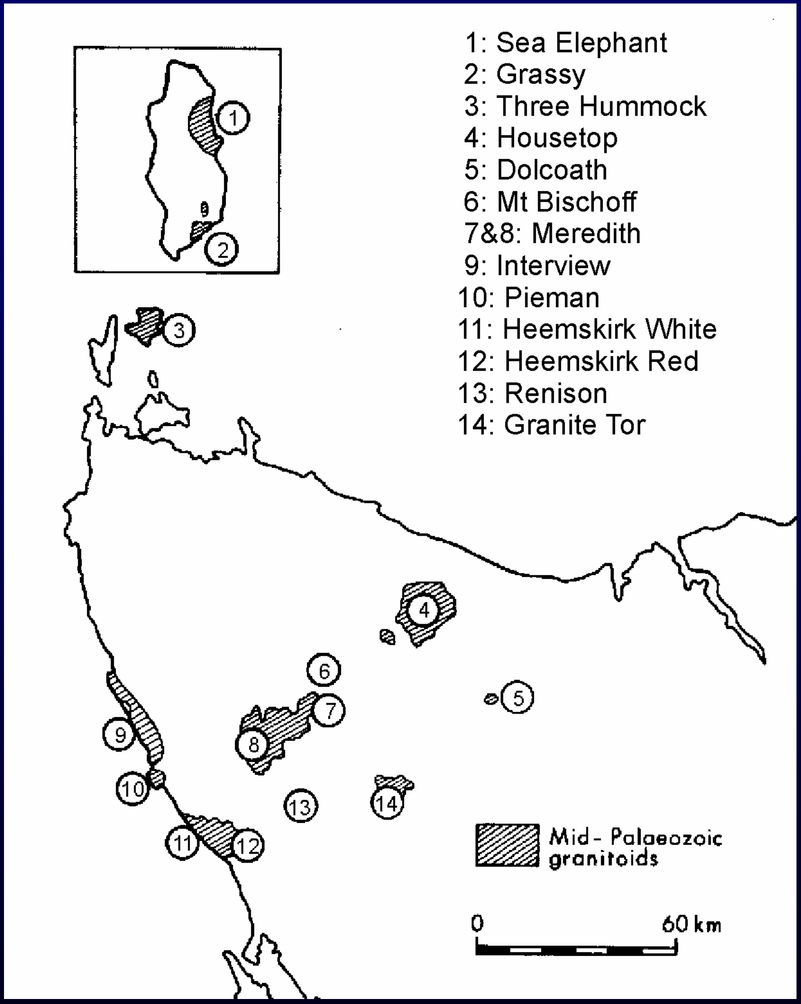
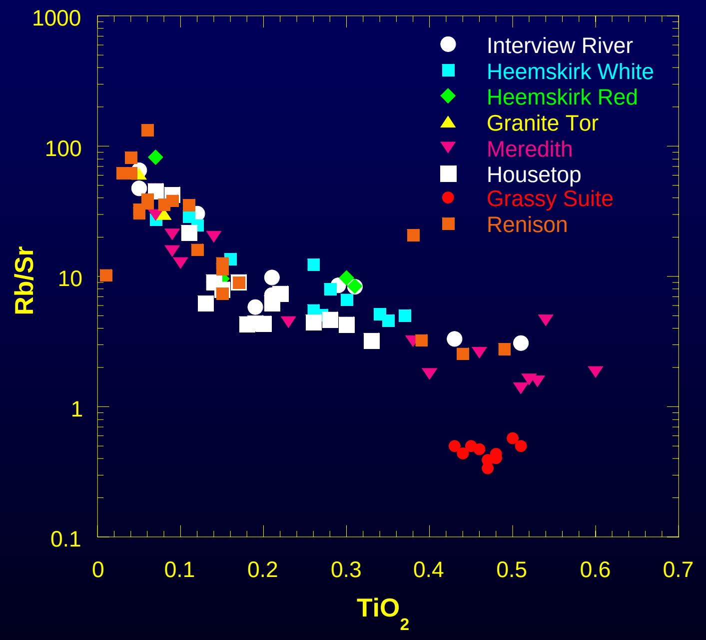


Western Tasmania - Why is it so highly productive?



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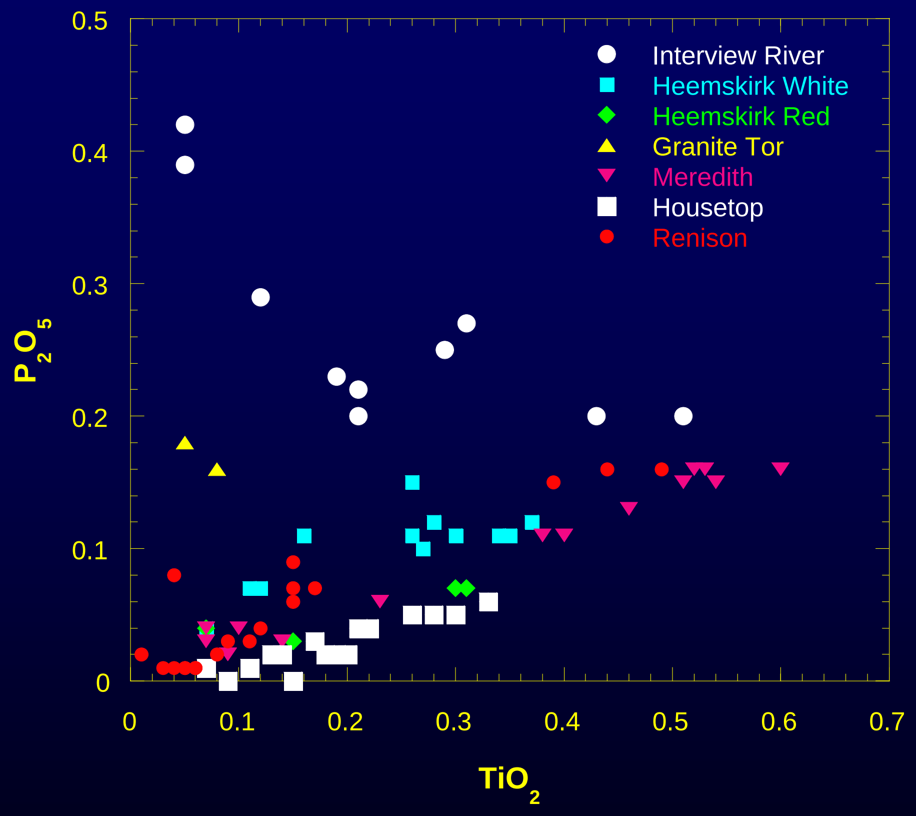
Western Tasmania - Why is it so highly productive?



Most suites, including the Sn mineralised ones, are I-types. Most Sn production in eastern Australia has been sourced from I-types

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Some gold-igneous associations in the post Ordovician LFB

- Au polymetallic (Cu Mo Pb Zn..) associations with moderately oxidised and fractionated granite systems.
- Au (+/- As, Te, Bi) with weakly oxidised to neutral granites and more mafic rocks.
- Au with reduced granites of central Vic - granite derived or remobilised?

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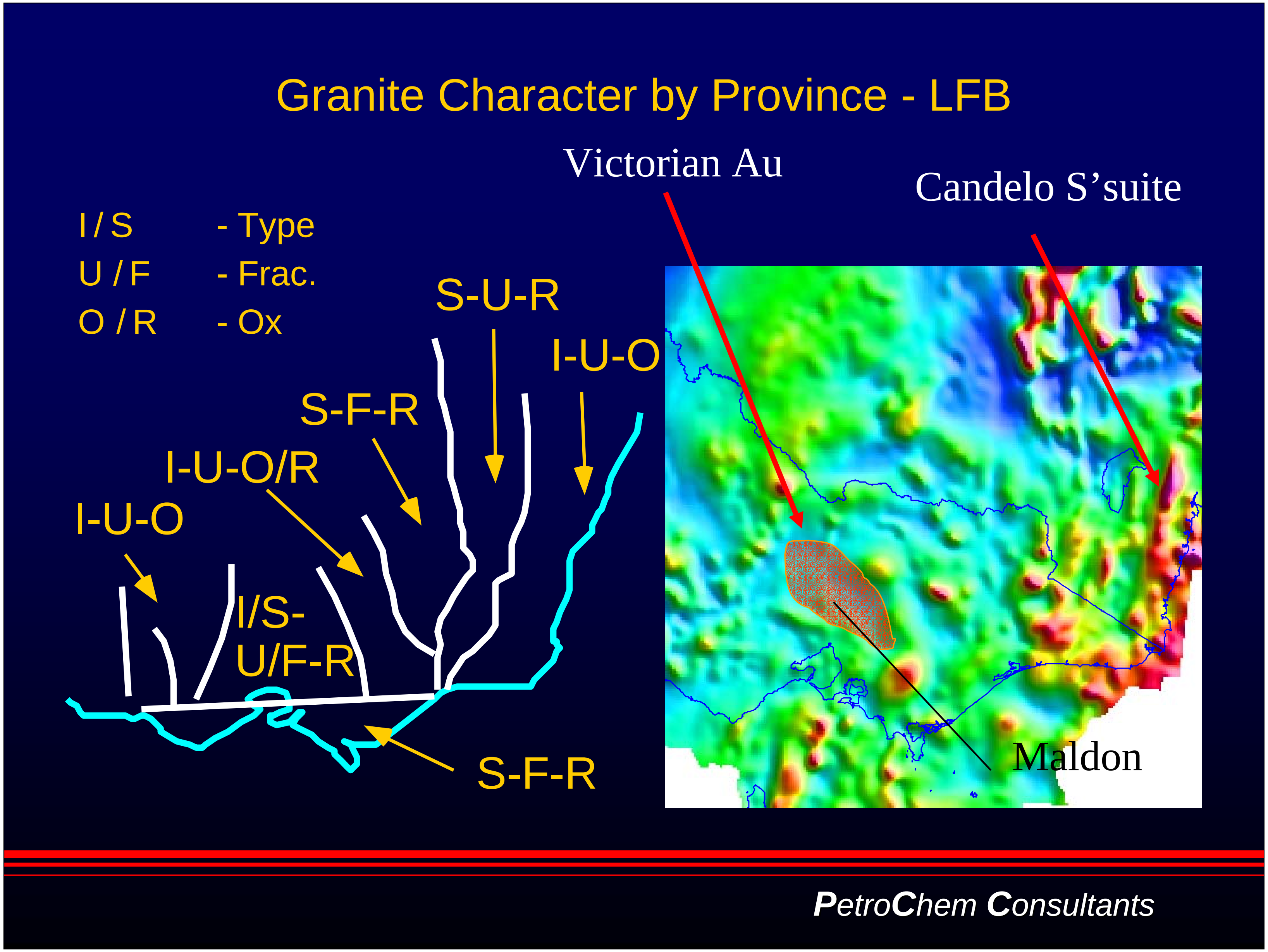
Granite Character by Province - LFB
Victorian Au
Candelo S'suite
I / S - Type
U / F - Frac.
O / R - Ox
S-U-R
I-U-O
S-F-R
I-U-O/R
I-U-O
I/S-
U/F-R
S-F-R
Maldon
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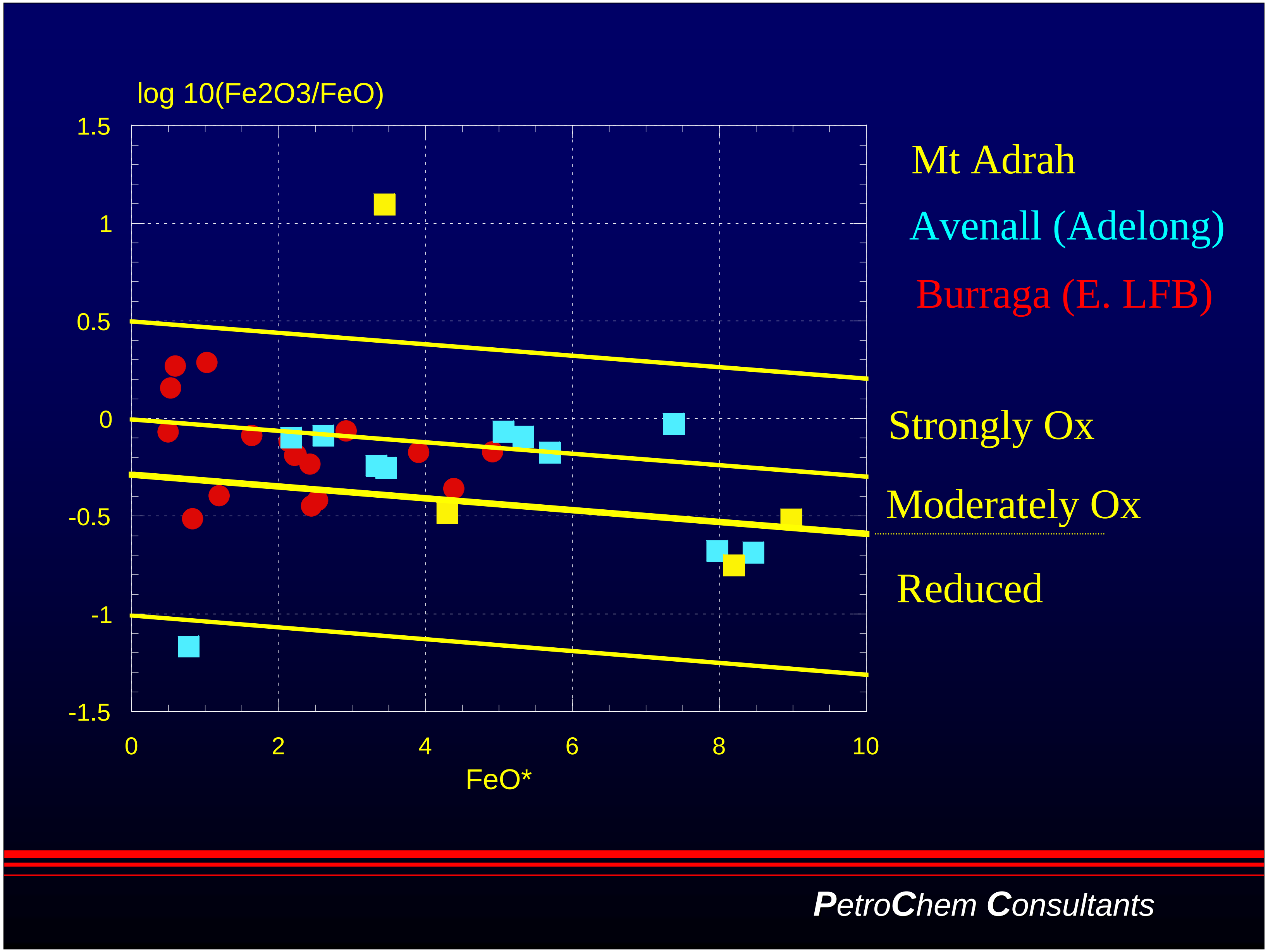
log 10(Fe2O3/FeO)
1.5
1
0.5
0
-0.5
-1
-1.5
0
2
4
6
8
10
FeO*
Mt Adrah
Avenall (Adelong)
Burraga (E. LFB)
Strongly Ox
Moderately Ox
Reduced
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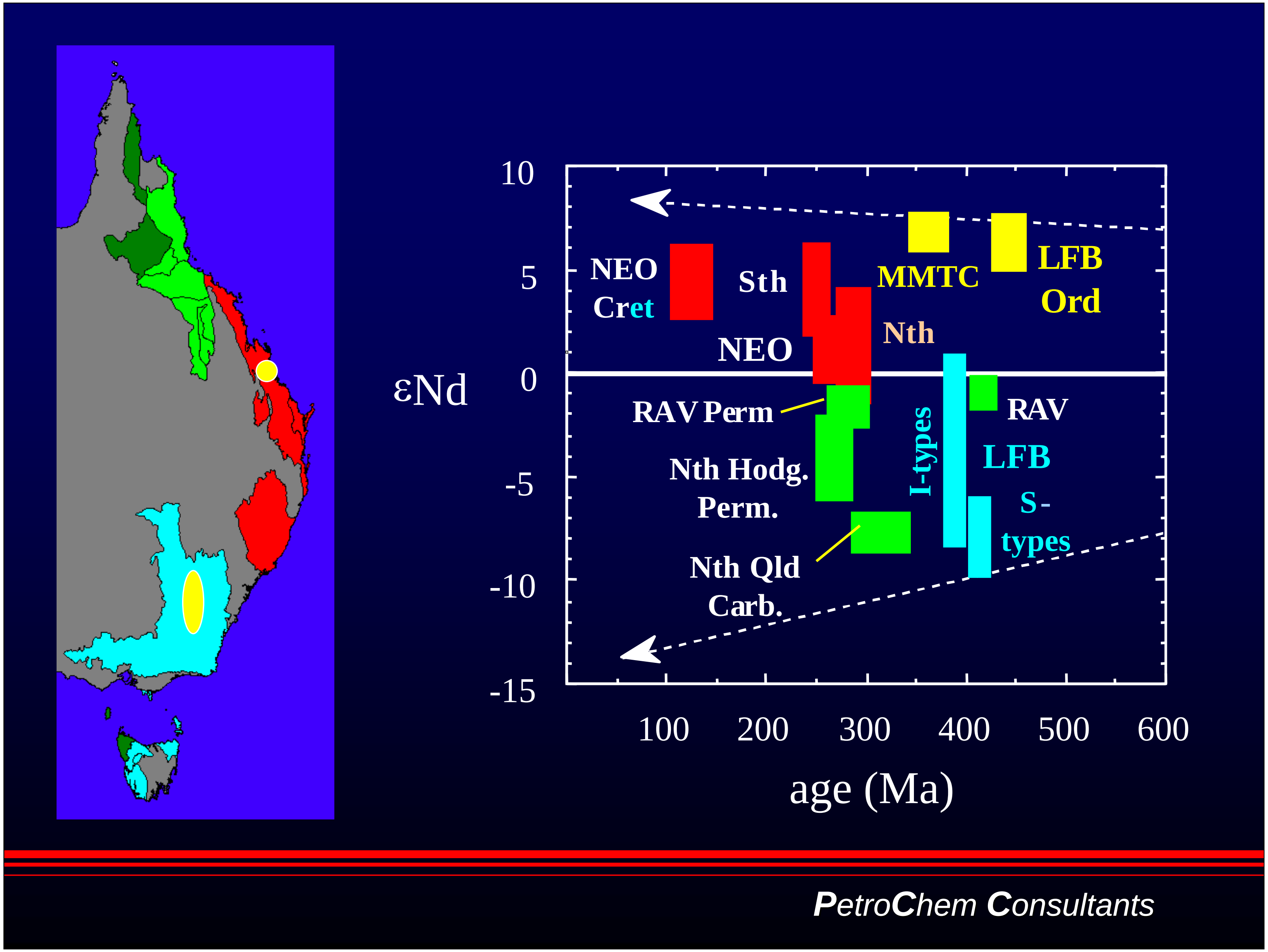
10
5
0
-5
-10
-15
εNd
NEO
Cret
Sth
NEO
MMTC
Nth
LFB
Ord
RAV Perm
Nth Hodg.
Perm.
Nth Qld
Carb.
I-types
RAV
LFB
S-
types
100
200
300
400
500
600
age (Ma)
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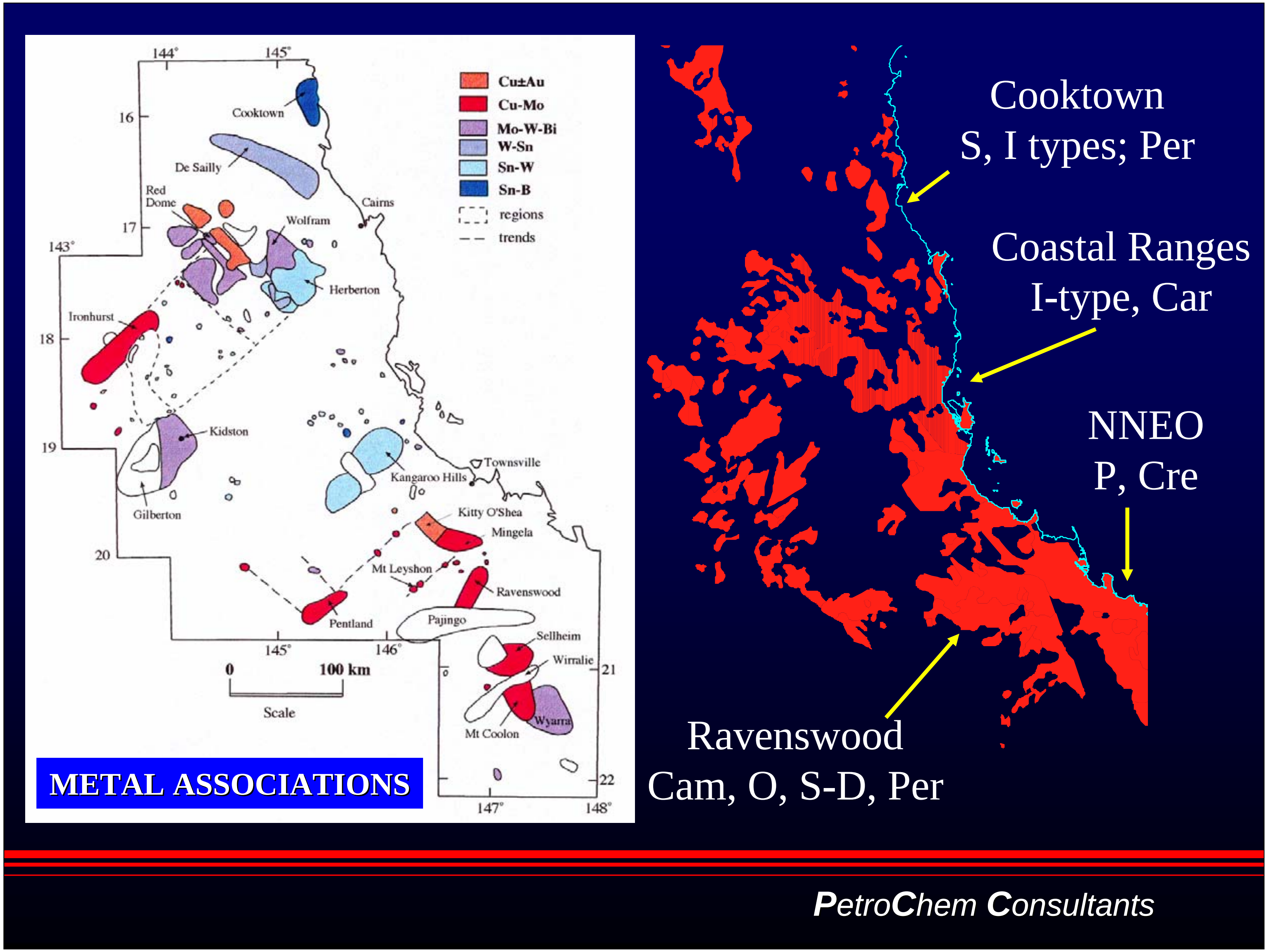
METAL ASSOCIATIONS
Cu±Au
Cu-Mo
Mo-W-Bi
W-Sn
Sn-W
Sn-B
regions
trends
Cooktown
De Sailly
Red Dome
Wolfram
Cairns
Herberton
Ironhurst
Kidston
Gilberton
Townsville
Kangaroo Hills
Kitty O'Shea
Mingela
Mt Leyshon
Ravenswood
Pentland
Pajingo
Sellheim
Wirralie
Wyarra
Mt Coolon
0 100 km
Scale
Cooktown
S, I types; Per
Coastal Ranges
I-type, Car
NNEO
P, Cre
Ravenswood
Cam, O, S-D, Per
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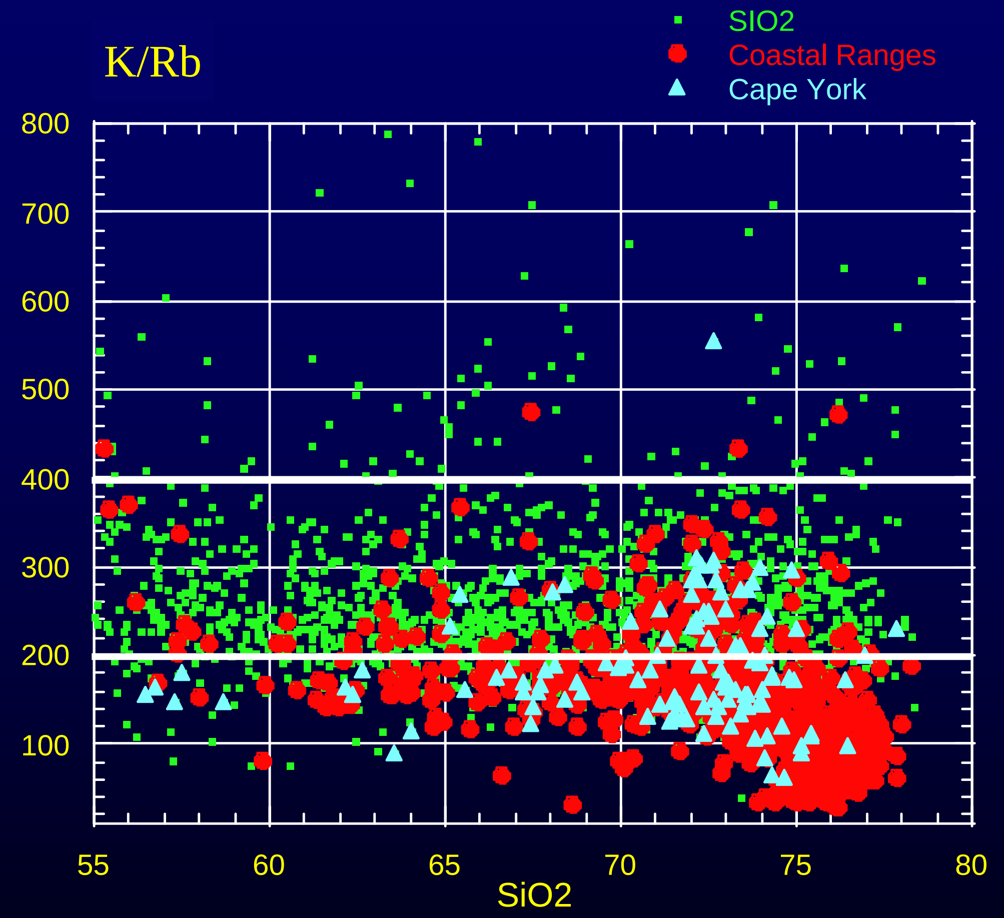

Cape York and coastal ranges Provinces are compositionally evolved - CYG much like the LFB Sil-Dev while CRG are more fractionated

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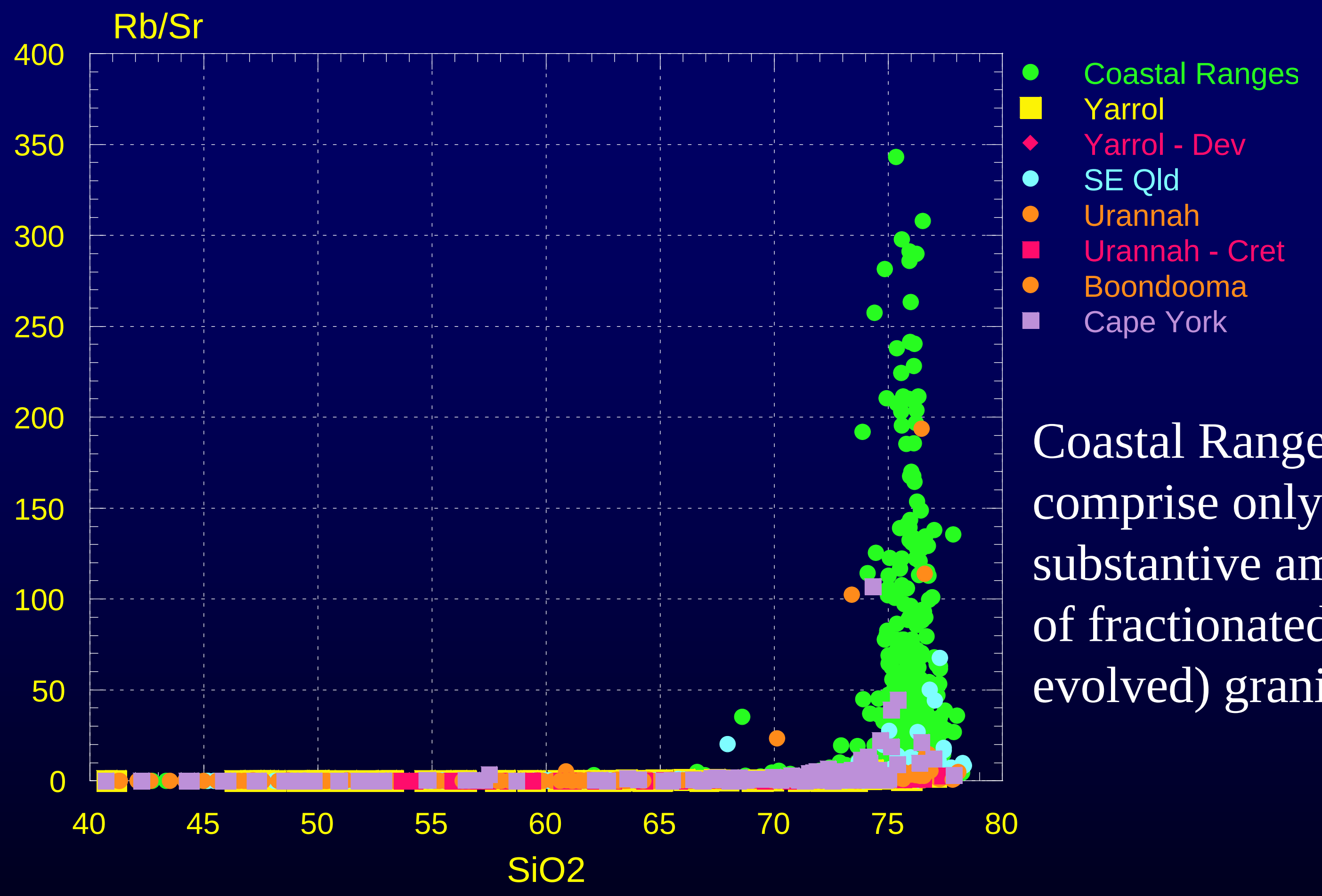

Coastal Ranges comprise only substantive amounts of fractionated (and evolved) granites.

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Au in W-Mo Association

Timbarra, Kidston, Red Dome Type

- Mo and W-Mo-Bi associations (granitophile)
- High-K calc-alkaline, evolved and fractionated suites in NEO and NQ.
- Au in paragenetically "distal" parts of systems
  - Au-basemetal; Au-As; Au-Bi-Te.
- Kidston is breccia hosted, Timbarra is disseminated, Red Dome is skarn; but magmas and metallogenic associations are similar.

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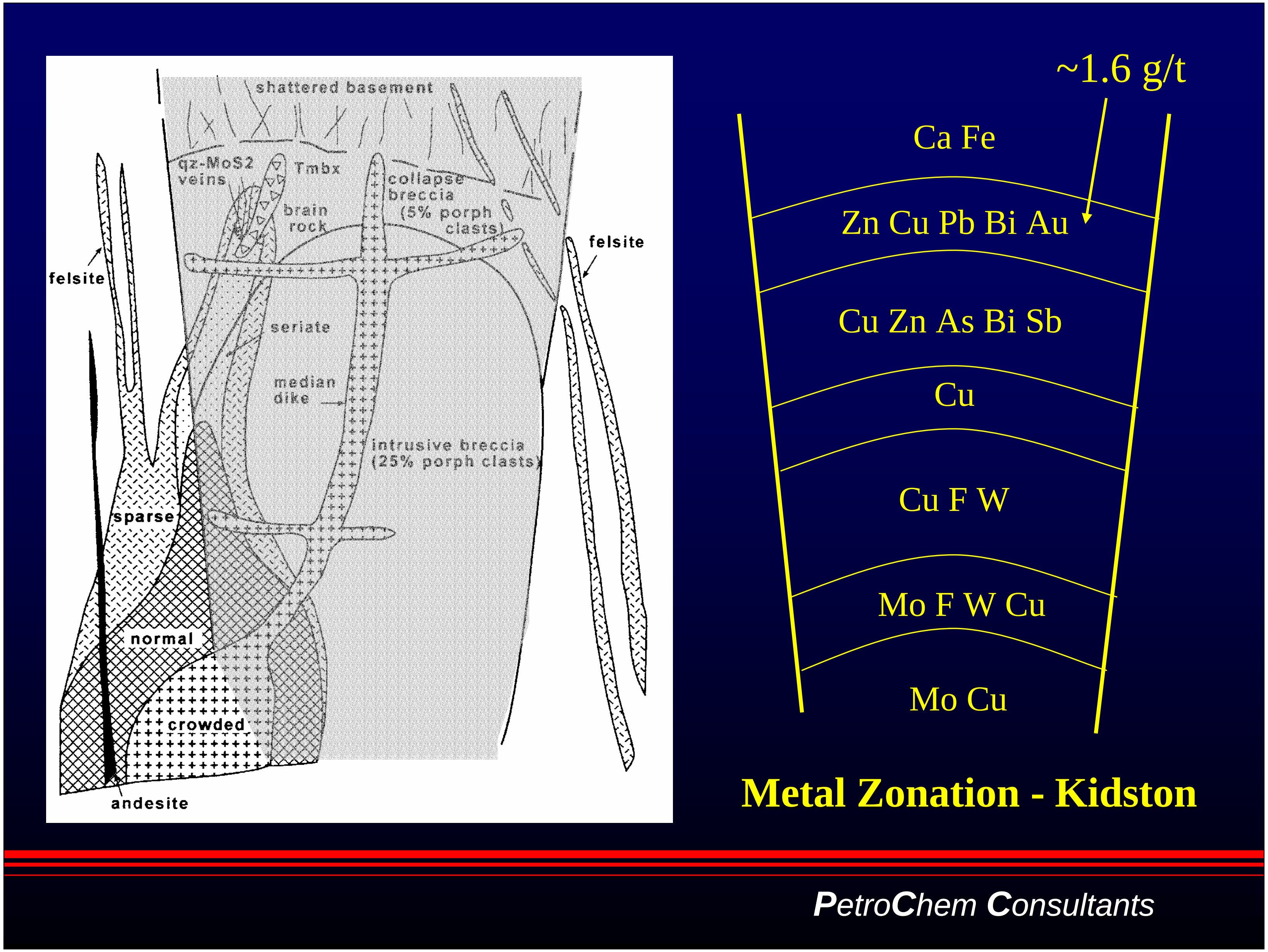
shattered basement
qz-MoS2 veins
Tmbx
collapse breccia (5% porph clasts)
brain rock
felsite
felsite
seriate
median dike
intrusive breccia (25% porph clasts)
sparse
normal
crowded
andesite
~1.6 g/t
Ca Fe
Zn Cu Pb Bi Au
Cu Zn As Bi Sb
Cu
Cu F W
Mo F W Cu
Mo Cu
Metal Zonation - Kidston
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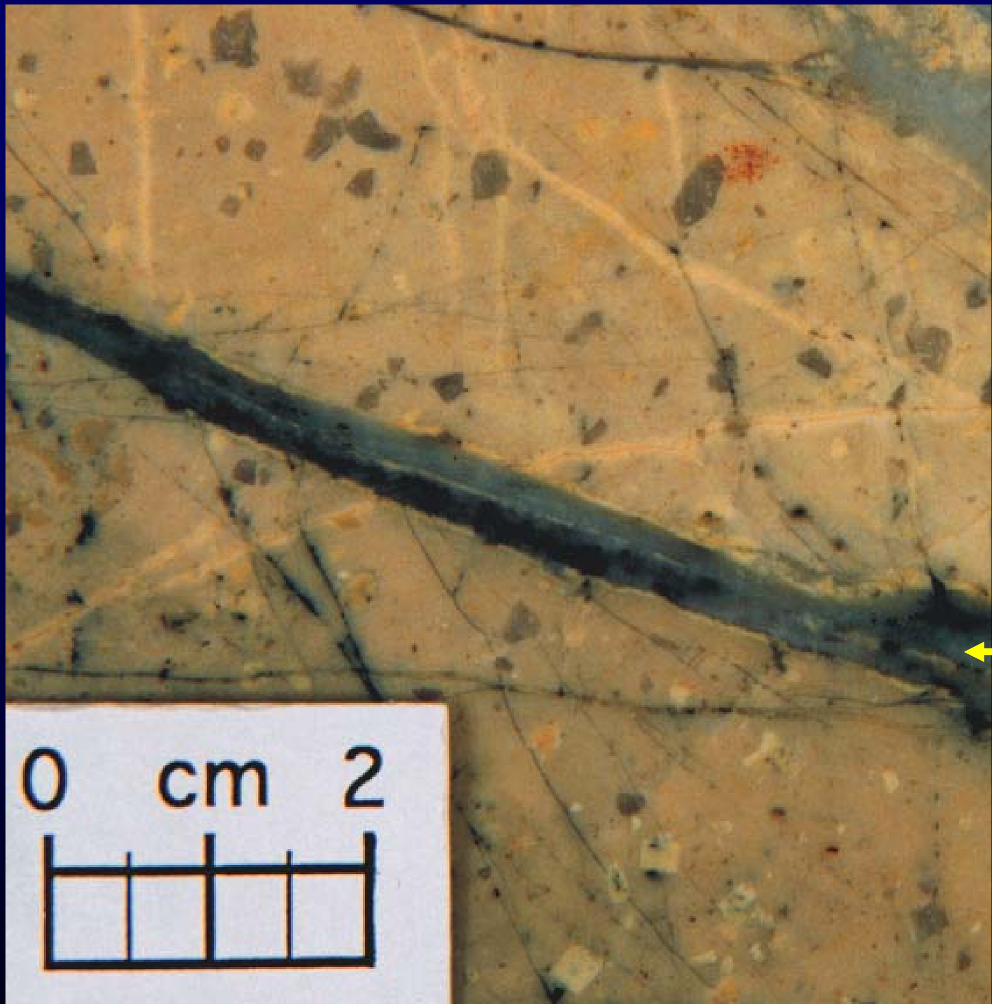
Kidston

Porphyry with high T. mineralisation



Qtz-MoS_2 vein

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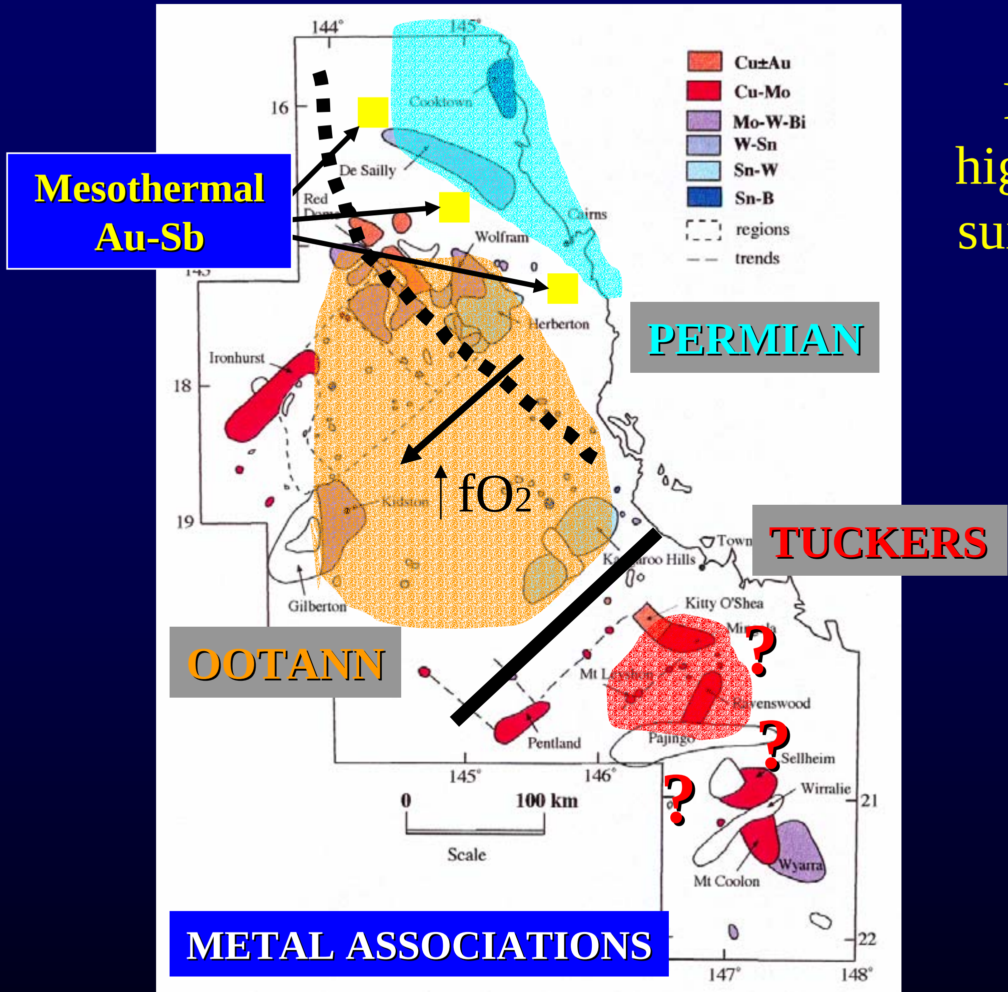

Relationships between highly prospective igneous suites and their boundaries

Ootann - Kidston and Red Dome, hot for Timbarra type

Tuckers - Mt Leyshon, hot for others at mafic and felsic end.

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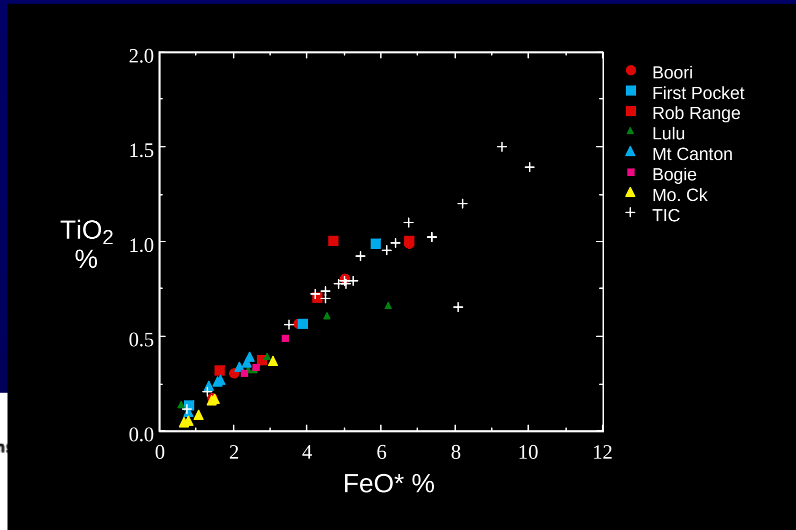
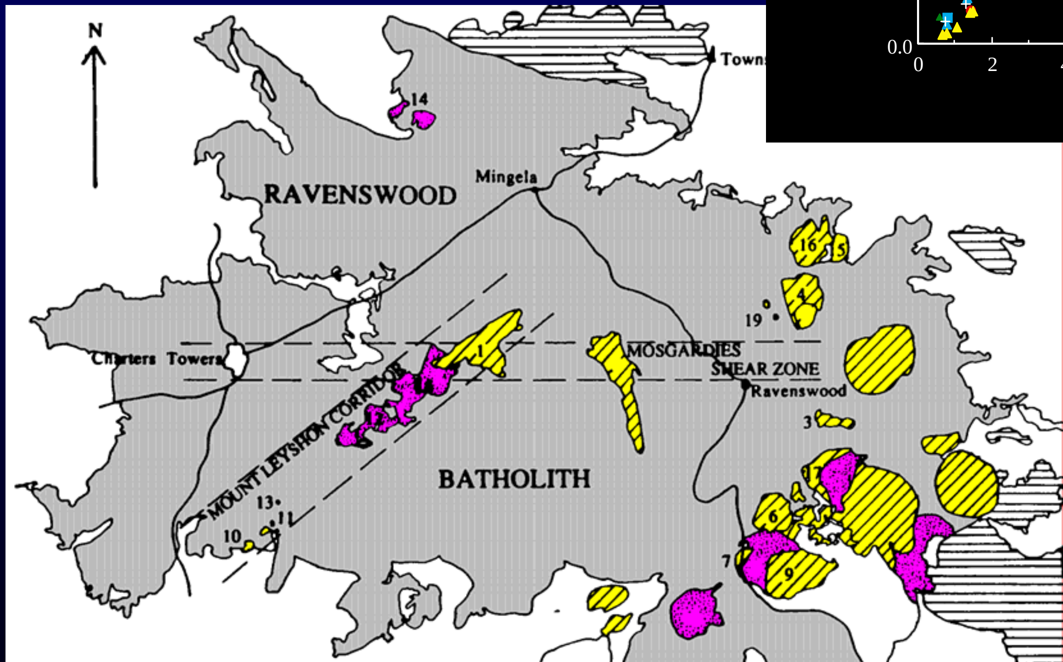
Permian Complexes - Ravenswood Batholith





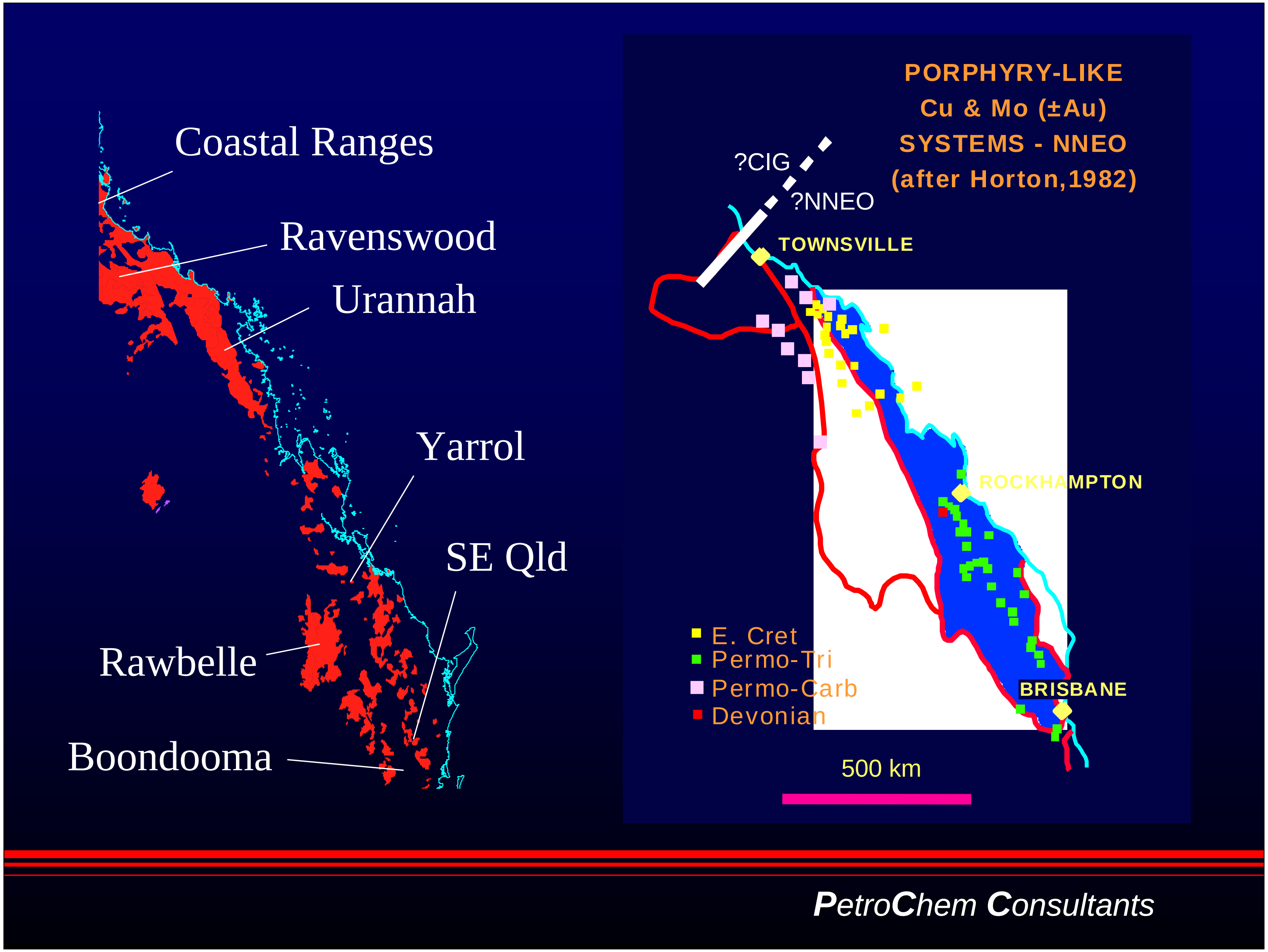
Intrusives

Volcanics

40 km

***P**etro**C**hem **C**onsultants*


Mount Leyshon 4/01
PetroChem Consultants


Coastal Ranges
Ravenswood
Urannah
Yarrol
SE Qld
Rawbelle
Boondooma
PORPHYRY-LIKE
Cu & Mo (±Au)
SYSTEMS - NNEO
(after Horton,1982)
?CIG
?NNEO
TOWNSVILLE
ROCKHAMPTON
BRISBANE
E. Cret
Permo-Tri
Permo-Carb
Devonian
500 km
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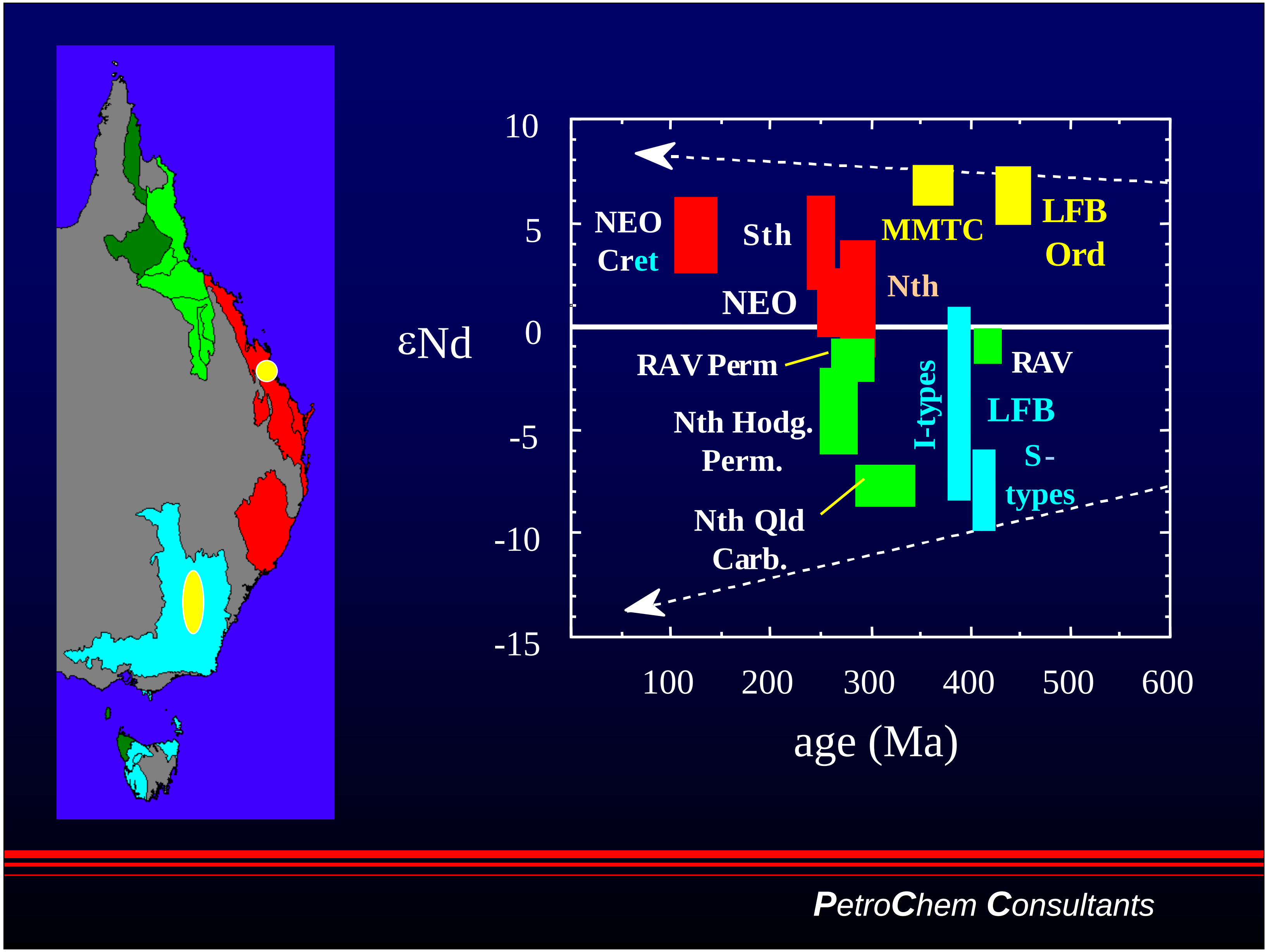
10
5
0
-5
-10
-15
εNd
100
200
300
400
500
600
age (Ma)
NEO
Cret
Sth
NEO
MMTC
Nth
LFB
Ord
RAV Perm
Nth Hodg.
Perm.
Nth Qld
Carb.
I-types
RAV
LFB
S-
types
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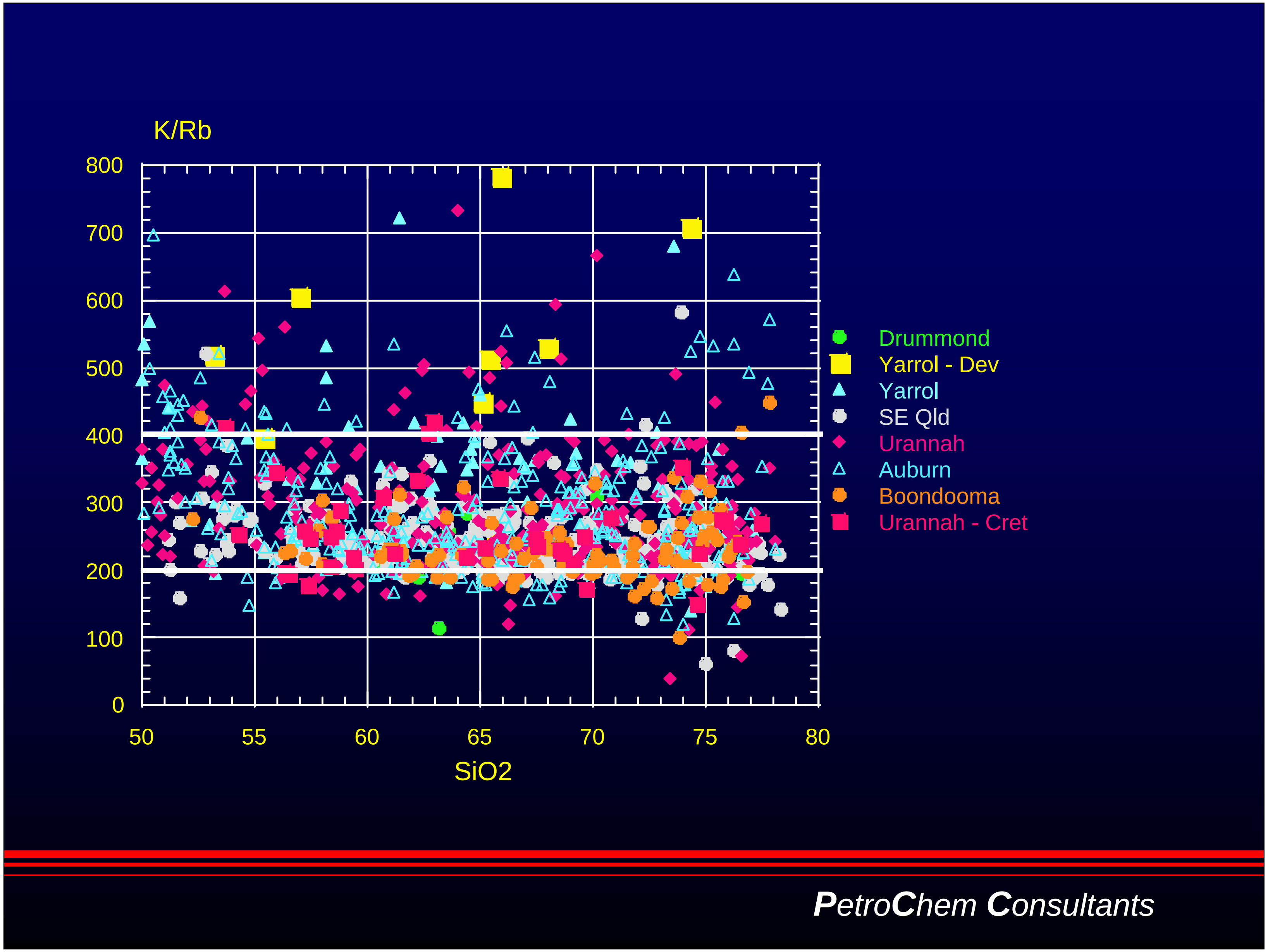
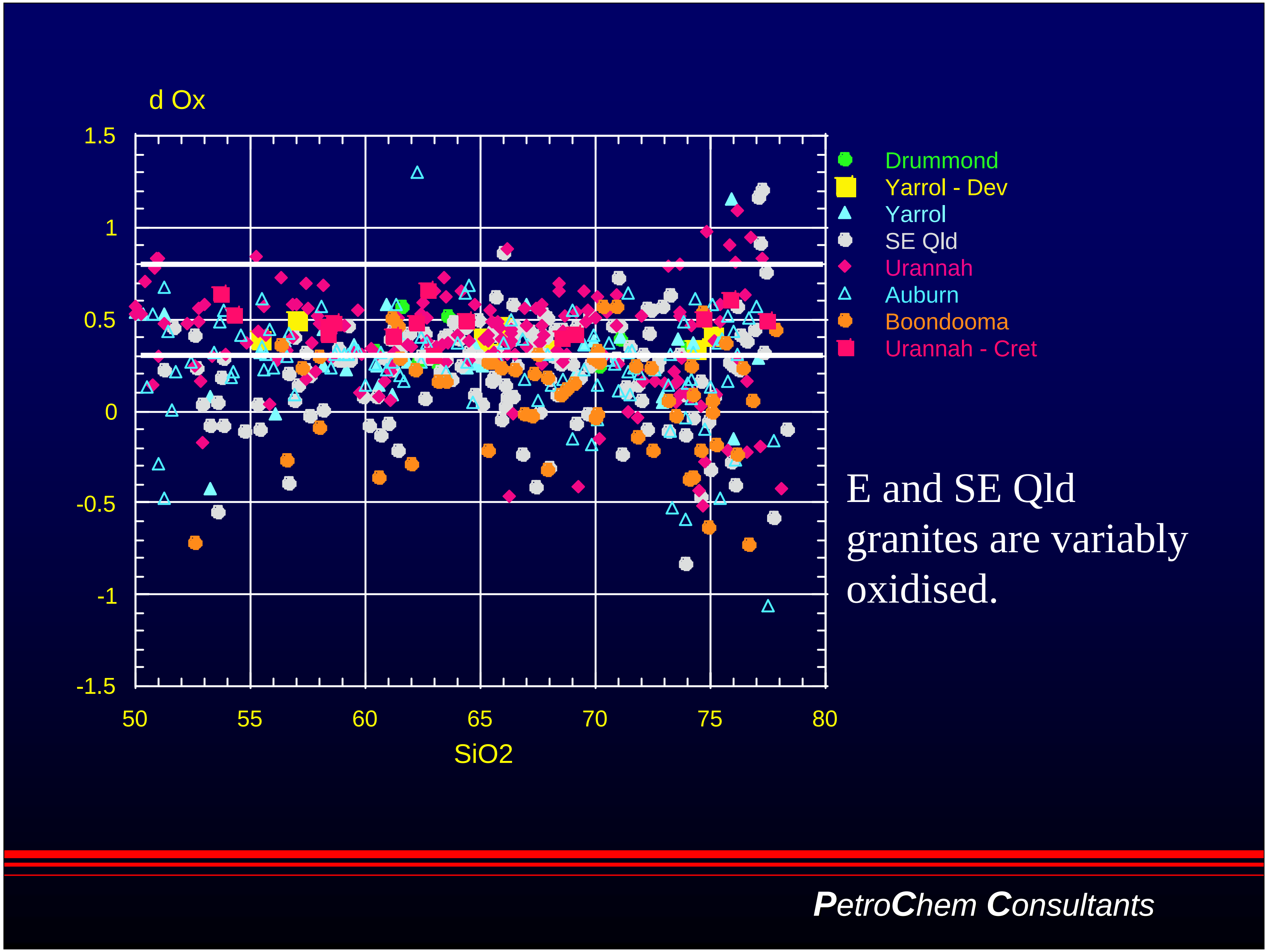

K/Rb
800
700
600
500
400
300
200
100
0
50
55
60
65
70
75
80
SiO2
Drummond
Yarrol - Dev
Yarrol
SE Qld
Urannah
Auburn
Boondooma
Urannah - Cret
PetroChem Consultants


d Ox
1.5
1
0.5
0
-0.5
-1
-1.5
50
55
60
65
70
75
80
SiO2
Drummond
Yarrol - Dev
Yarrol
SE Qld
Urannah
Auburn
Boondooma
Urannah - Cret
E and SE Qld granites are variably oxidised.
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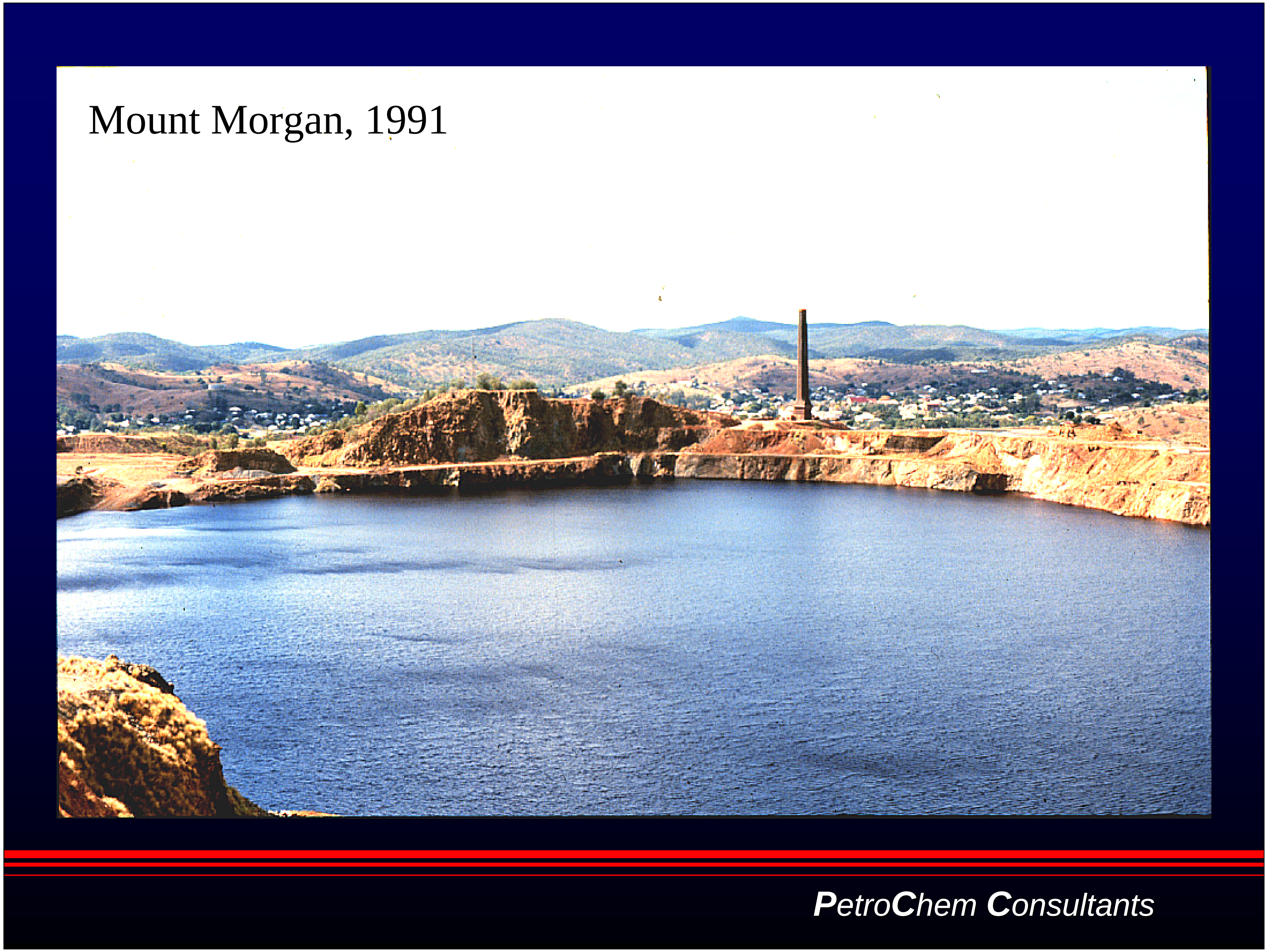
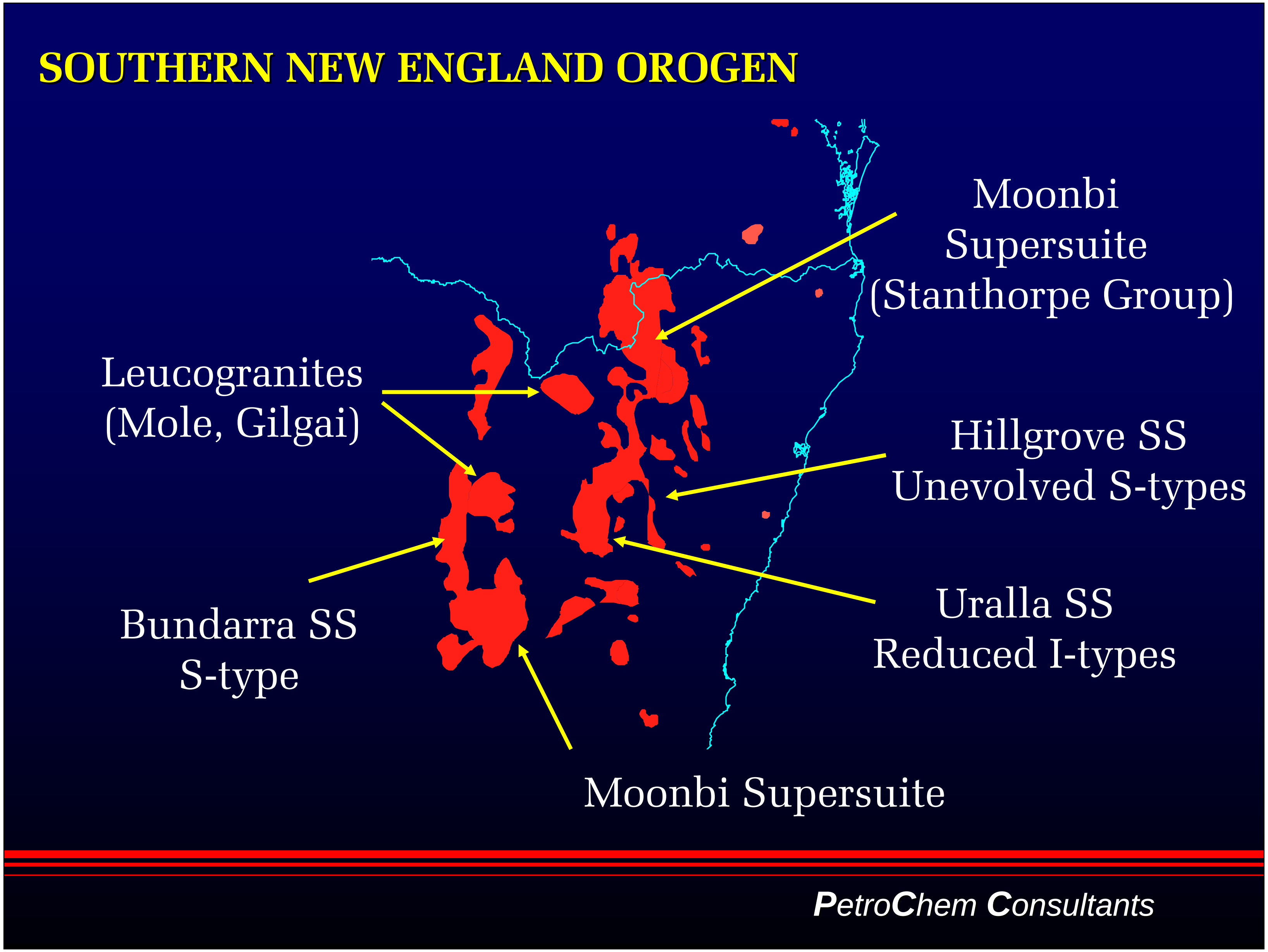
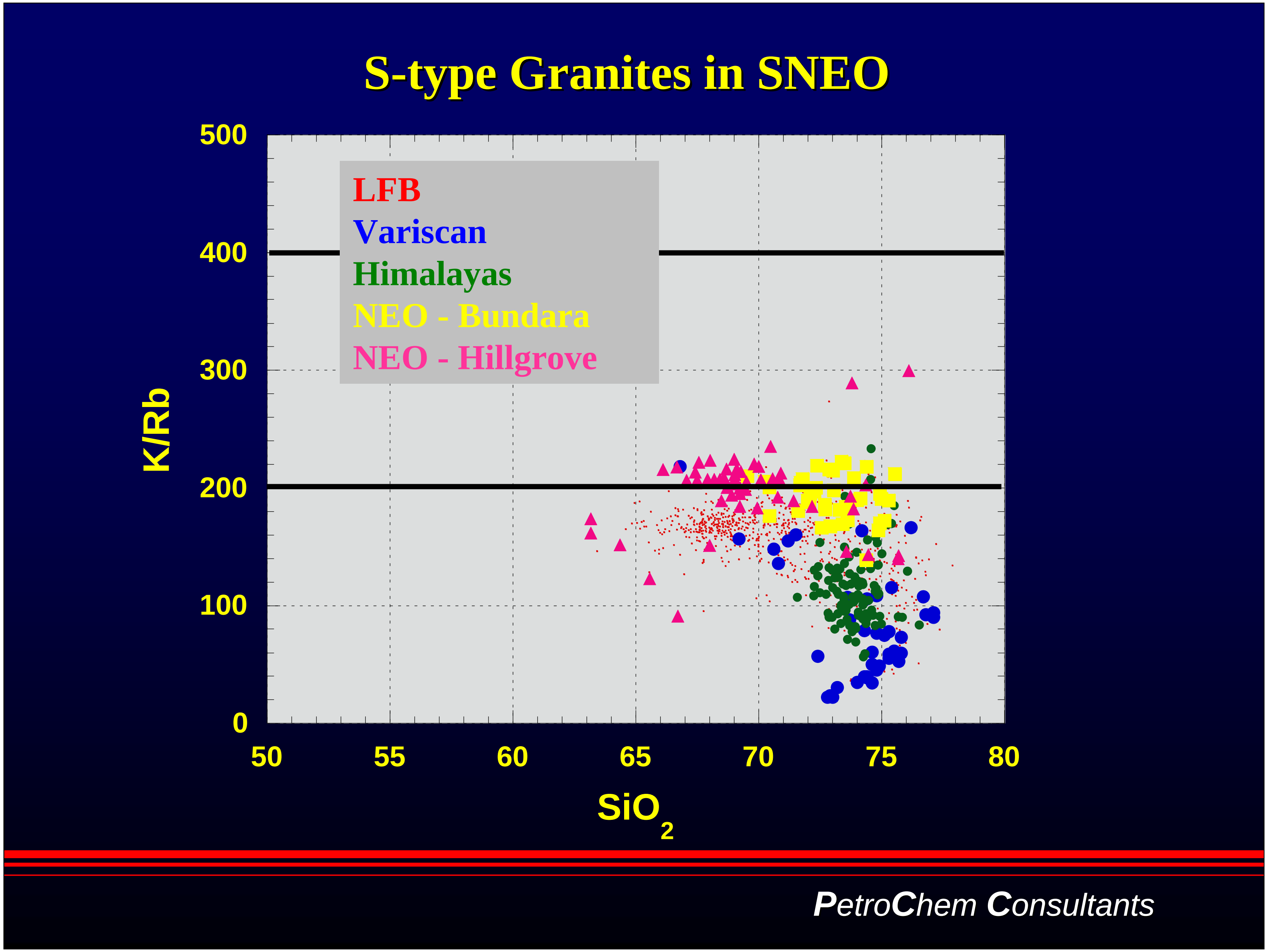
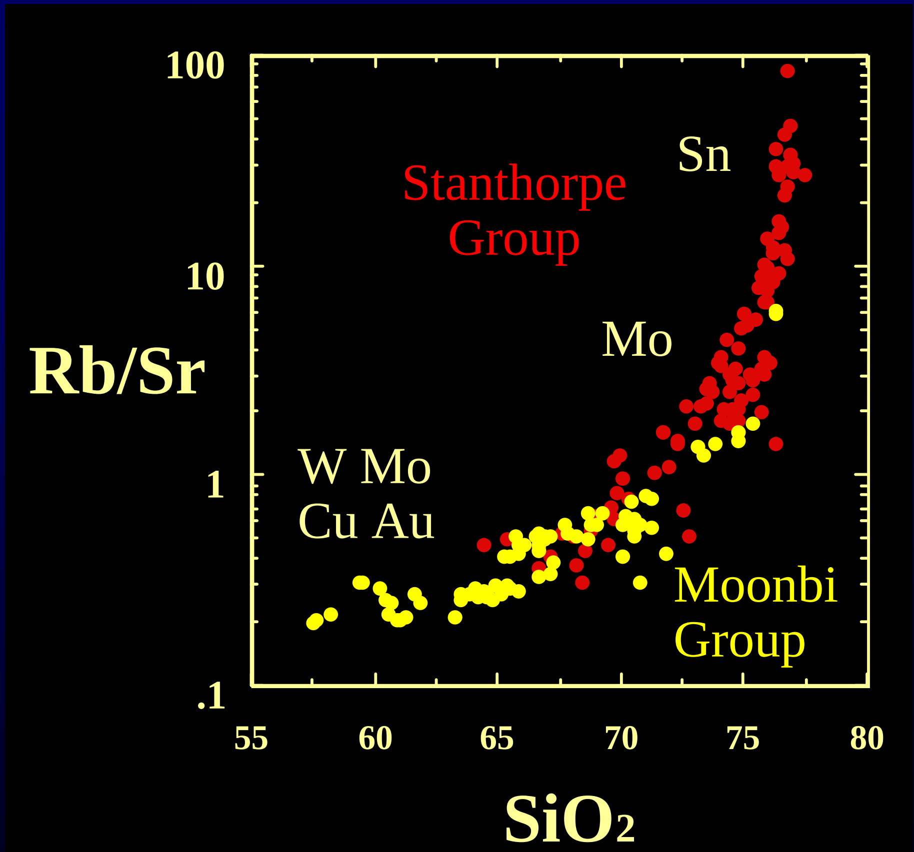

Mount Morgan, 1991
PetroChem Consultants


SOUTHERN NEW ENGLAND OROGEN
Moonbi Supersuite (Stanthorpe Group)
Leucogranites (Mole, Gilgai)
Hillgrove SS Unevolved S-types
Uralla SS Reduced I-types
Bundarra SS S-type
Moonbi Supersuite
PetroChem Consultants


S-type Granites in SNEO
LFB
Variscan
Himalayas
NEO - Bundara
NEO - Hillgrove
K/Rb
0
100
200
300
400
500
50
55
60
65
70
75
80
SiO2
PetroChem Consultants

Moonbi Supersuite



- High-K
- Strongly fractionated
- Relatively oxidised
- Sth'n Group associated with W-Mo, Nth'n Group with polymetallic Mo, Sn, Au associations

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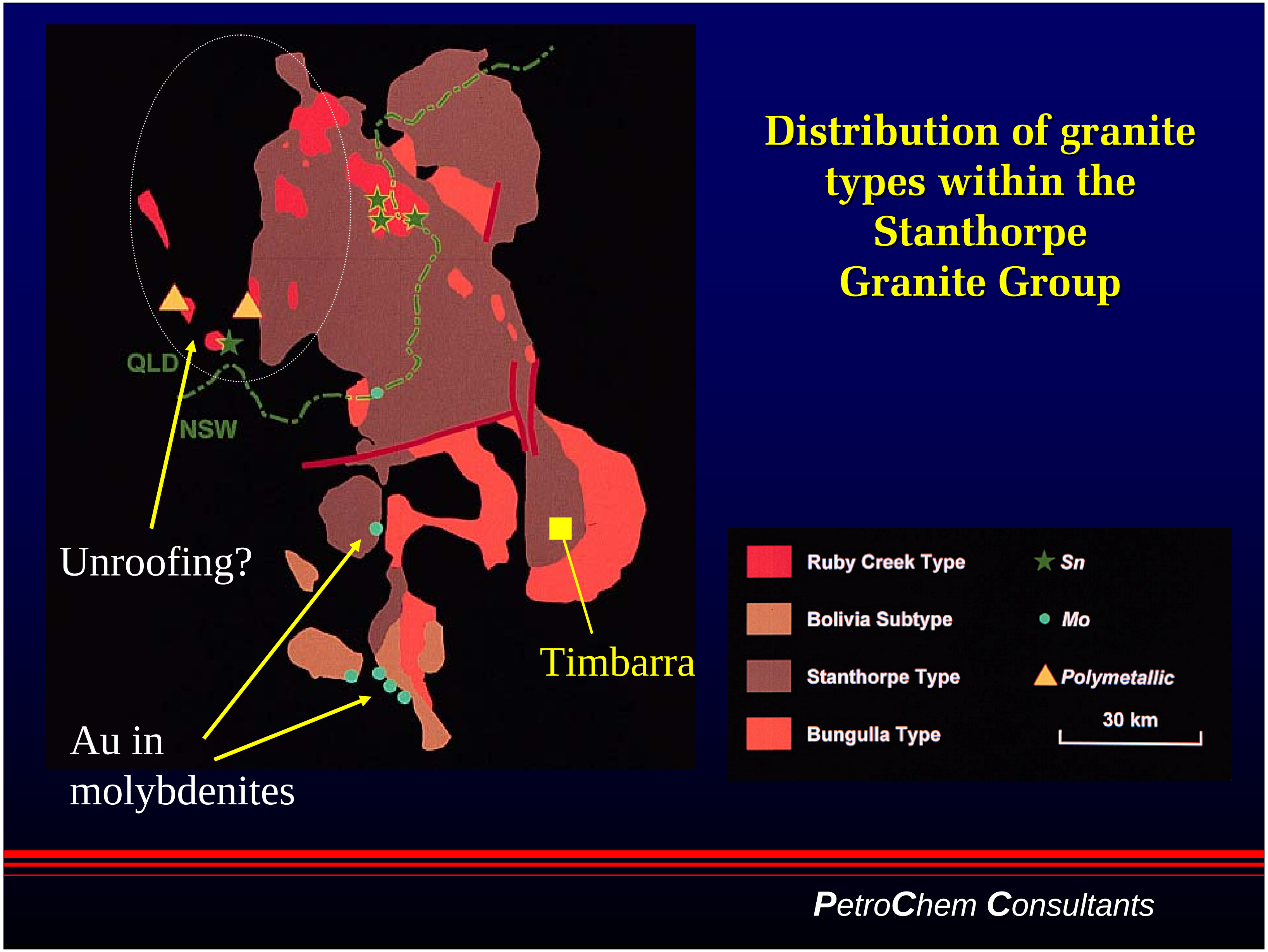
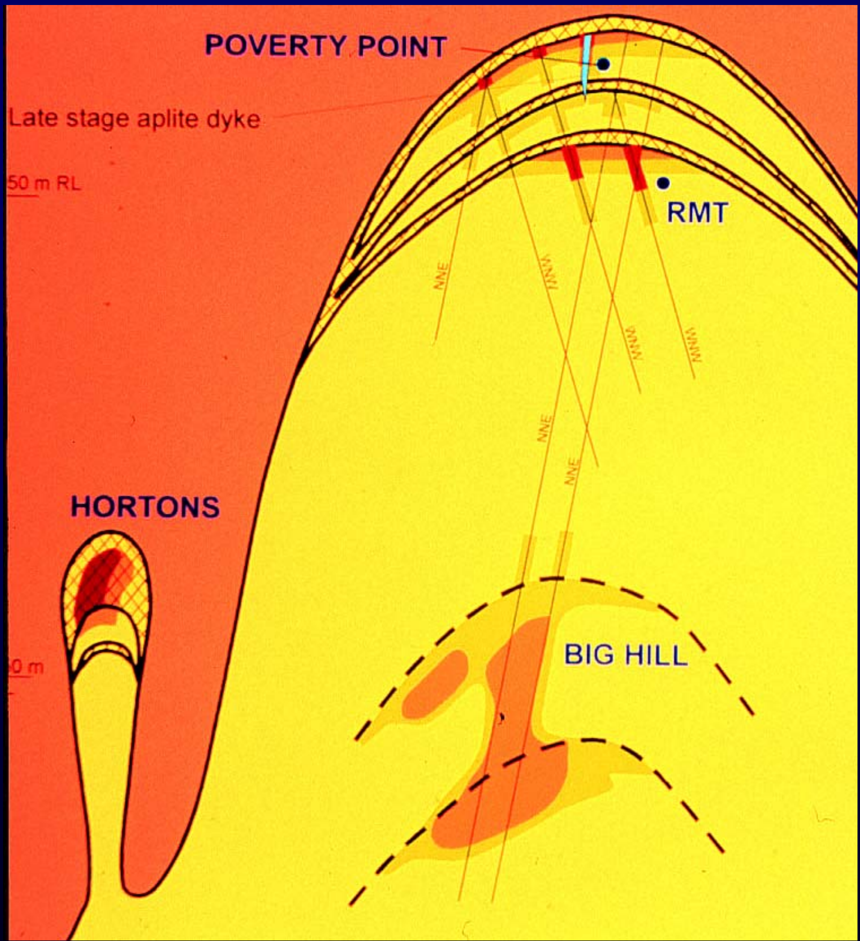

Distribution of granite types within the Stanthorpe Granite Group
QLD
NSW
Unroofing?
Au in molybdenites
Timbarra
Ruby Creek Type
Bolivia Subtype
Stanthorpe Type
Bungulla Type
Sn
Mo
Polymetallic
30 km
PetroChem Consultants



Timbarra Type

- Au is disseminated in apical portions of granite cupolas, often beneath internal contacts.
- Miarolitic cavities, pegmatites, aplites.
- Greisen, early Mo veins also present

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