ARCHAEAN GRANITES

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Archaean cratons that formed throughout some 40% of the earth's history (>2500 Ma), now comprise <10% of the continents, but contribute significantly to the world's mineral wealth. Remnant Archaean terrains vary in age from fragments as old as 3.6 to 4.0 Ga (e.g., Isua - Greenland, Acasta – Slave Province), to more common younger cratons (3.6 to 2.5 Ga) of various sizes, the largest being the Superior Province (1,570,000 km^2), which alone constitutes greater than 20% of the total exposed Archaean (Thurston, 1991). Better known Australian examples include the small, but well exposed (<3.6 Ga) Pilbara Craton (45,000 km^2), and the significantly larger, but poorly outcropping Yilgarn Craton (>600,000 km^2), both in Western Australia. Granitic rocks form the main component of most Archaean Cratons (e.g., ~70% of the Yilgarn). They occur as syn-volcanic and younger intrusive units within volcano-sedimentary assemblages (greenstone belts), as intrusive components of batholiths, and as components of high-grade gneissic terrains. Their compositional range is extensive and reflects both short-lived or local tectonic processes as well as longer-term process that relate to regional or global evolution.

Tonalite-Trondhjemite-Granodiorite (TTG) suite

Although ranging from diorite to syenogranite, a large number of Archaean granites are of tonalite, trondhjemite or granodiorite composition, a feature which led early workers to introduce the TTG-suite terminology (Jahn et al., 1981; also called TTD: tonalite-trondhjemite-dacite by some workers). This closely coincided with the recognition, perhaps best encapsulated in a series of papers published within the Trondhjemite volume edited by Barker (1979), that the majority of such rocks are unified by a distinctive geochemistry - they are intermediate to felsic (mostly >65% SiO_2), with high Na_2O/K_2O >1.5), low to moderate LILE contents and with no potassium-enrichment with increasing differentiation (e.g., Barker & Arth, 1976). A result is that TTG-suite nomenclature has become largely synonymous with these geochemical features, with one important modification. Arth, Barker and co-workers (e.g., Barker & Arth, 1976), amongst others, recognised that the sodic rock series can be further subdivided into what they termed high-Al and low-Al subgroups (or end-members), discriminated by the contrary behaviour of elements controlled largely by either plagioclase, garnet and/or hornblende. High-Al types, largely interpreted to reflect melting in the presence of garnet and amphibole, but not plagioclase (or via hornblende/garnet fractionation), are characterised by elevated Sr (Sr-undepleted) and Eu, fractionated REEs, with low HREE (Y- and HREE-depleted), and high Sr/Y ratios. In contrast, low-Al members are characterised by lower Sr (Sr-depleted) and Eu, less fractionated REEs, with higher HREE (Y- and HREE-undepleted), and lower Sr/Y ratios, and reflect control by feldspar (either by residual feldspar during partial melting, or via feldspar fractionation). Many studies have shown that most Archaean TTGs fall into the high-Al subgroup (see review by Martin, 1994), and so, unfortunately, a high-pressure origin has become implicit in the term 'Archaean TTG'. Like Drummond et al. (1996), we prefer to follow the original definition of TTGs, i.e., simply restricted to sodic and felsic igneous rock compositions, with high-Al and low-Al qualifiers used as required. In Australia, true TTGs are largely confined to the Pilbara (Table 1), being poorly represented in the Yilgarn. Pilbara TTGs include both low-Al and high-Al types.

Origins of TTGs

Many early studies (best summarised by Barker & Arth, 1976, Barker, 1979) showed that TTGs were ultimately derived from a source with a broadly (low-K) basaltic composition, either by partial melting or fractional crystallisation at a variety of pressures, consistent with numerous experimental data (e.g., Rapp et al., 1991). The lack of mafic end-members in Archaean TTGs suggest that partial melting was the dominant process. Further, the predominance of high-Al TTGs, in conjunction with the inferred hotter mantle in the Archaean, led a number of authors (e.g., Martin, 1986) to propose that most Archaean TTGs were produced by partial melting of subducting slabs. Supporting evidence for this mechanism was provided by the recognition that mg numbers (45-50 and above), and MgO, Ni and Cr contents, of Archaean TTGs are significantly higher than would be expected by simple partial melting of basaltic material alone, the inference being that an additional component such as interaction with the mantle wedge was required. This appears to be the case for younger TTGs (<3.1 Ga), in particular (Smithies, 2000).

Possible modern analogues? - the adakite connection

Arc magmatism in modern convergent plate margins is thought to be largely derived via partial melting of the mantle wedge in response to volatile fluxing from the slab. In rare circumstances, however, typically in regions undergoing low-angle or flat subduction, silica-enriched (>57% SiO_2) magmas with elevated Al_2O_3, Na_2O, Na_2O/K_2O, LILEs, Sr and HREE/LREE and low HREE are found. These magmas, called adakites (Drummond & Defant, 1990), are inferred to be derived by partial melting of the subducting slab (Kay, 1978). They have many close chemical similarities to high-Al TTGs, including trends to elevated mg#, Ni and Cr, leading workers (Drummond & Defant, 1990; Martin, 1999) to suggest that adakites represent modern-day analogues of what is inferred to have been a much more common process in a hotter Archaean mantle. This analogue best fits with late Archaean (post 3.1 Ga) TTGs; older TTGs do not show high mg numbers, Cr and Ni and appear to either require extreme flat subduction with minimal, or no, mantle wedge interaction (Smithies et al., in press), or perhaps a more non-uniformitarian model.

Transitional ‘TTGs’

Our work (e.g., Champion & Smithies, 2001), shows that within many Archaean terranes there exists a subclass of sodic granites (which we call transitional TTGs), largely comprising trondhjemites, granodiorites and granites, that when compared to ‘true” TTGs have higher LILE contents, show strong enrichment in LILEs (e.g., K_2O) with increasing differentiation, and tend towards more siliceous compositions (68-77% SiO_2), but still possess a similar characteristic high-Al (more rarely low-Al) signature. Typically, such transitional TTGs are either contemporaneous with, or postdate true TTGs, but may also grade to more mafic compositions that overlap with true TTGs. These transitional TTGs dominate some cratons, the best example being the Yilgarn Craton where they comprise some 60% of the granites (Table 1). Although differences between the two may in part reflect smaller degrees of partial melting coupled with fractionation, Sm-Nd isotopic and inherited zircon data indicate that the petrogenesis of most transitional TTGs requires the involvement of pre-existing crust. The extent to which this crustal component represents input via the subduction process (e.g., subducted sediments) is unclear, however, this process does not explain the presence of inherited zircons. Alternative explanations include a response to thicker pre-existing crust (assimilation-fractional crystallisation processes), or pure crustal melts in thickened Archaean crust.

High-Mg andesites/diorites

The intermediate to felsic (55->62% SiO_2), high-Mg andesites/diorites series, (also called sanukitoids), are characterised by high mg# (typically 60 and above), Cr and Ni, requiring a mantle component, and elevated LILEs (medium- to high-K). These rocks are typically ascribed to subduction-modification of the mantle source with or without some later crustal interaction (e.g., Shirey & Hanson, 1984; Smithies & Champion, 2000). First recognised in Canada (Shirey & Hanson, 1984), they appear to form only a minor component (<5%), of Archaean cratons. They are commonly late in the magmatic cycle and appear to be confined to the late Archaean. High-Mg diorites occur within both the Yilgarn and the Pilbara (Table 1), though are best documented in the central Pilbara (Smithies & Champion, 2000), where they form a ca 2.95 Ga suite inferred to have been derived by partial melting of mantle previously modified by slab-melts. Although compositions of high-Mg diorites tend to converge with TTGs at more felsic compositions, they can commonly be discriminated by a number of factors including their elevated LILEs. Like TTGs, high-Mg diorites have inferred modern analogues, i.e., high-Mg andesites.

Other Archaean granite types

Although TTGs are typically considered the main Archaean granite suite, it is increasingly apparent that a great variety of granite types occur within the Archaean (e.g., Sylvester, 1994). More importantly, it is clear that there is a pronounced secularity with increasing granite diversity through time, particularly within Archaean terranes younger than 3.2 Ga (Champion & Smithies, 2001; Smithies et al., in press; Table 1). The range in granite types, especially the secularity, can be largely attributed to three, clearly interrelated, processes (Champion & Smithies, 2001; Martin & Moyen, 2002; Smithies et al., in press): a) increasing felsic component (and perhaps thickness) of crust, leading to both greater crustal interaction and crustal reworking; b) an increasing variety of crustal diversity, in particular in felsic (TTG) and sedimentary protoliths; and c) increasing operation of convergent margin tectonic processes akin to modern-day subduction environments, with associated mantle metasomatism. By the late Archaean equivalents to all modern day granite types can be found. Non-TTG granites include fractionated (and variously contaminated) tholeiites and plagiogranites, intrusive equivalents of basalt-andesite-dacite-rhyolite series, crustal melts of TTGs, S-type granites, alkaline granites and syenites, and lamprophyres. With the exception of S-type granites, all are found within the Pilbara and Yilgarn cratons (Table 1). The most voluminous of these are those interpreted to result from partial melting of TTGs. These include the Low-Ca granites of Champion & Sheraton (1997), which form ~20% of the Yilgarn Craton, and were emplaced throughout the whole craton almost totally within a 25 Ma period (ca 2.655-2.63 Ga).

Mineralisation

The Late Archaean, especially 2.75 Ga and younger, is a period of extensive mineralisation comprising lode gold and other commodities (e.g., Hagemann & Cassidy, 2000). Although, it is tempting to suggest there is some relationship between this mineralisation and the evidence for convergent margin tectonic processes and associated mantle metasomatism operating in the late Archaean, there is no clear direct link. In contrast, most of the Late Archaean gold not only appears to be late, postdating both greenstone formation and TTG and related magmatism, but as pointed out by Hagemann and Cassidy (2000), is often contemporaneous with late crustal magmatism. This certainly appears to be the case for the Yilgarn Craton, where emplacement of the Low-Ca granites overlap with that of the commonly accepted ages (ca 2.64-2.63 Ga) of the inferred Yilgarn-wide gold mineralisation.

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	East Pilbara	**Central Pilbara**	**Eastern Yilgarn**
1. TTG high-Al and low-Al; ± crustal contribution	3.45 Ga high-Al; some isotopic evidence for crustal contribution	3.26-2.95 Ga low-Al	3.3 to 2.8 Ga?? Inferred as the source protolith for Low-Ca group granites
2. "Transitional TTG" LILE-enriched sodic magmatism, includes some TTG magmatism; high-Al and low-Al; chemical (± isotopic) evidence for crustal contribution	3.3-3.25 Ga dominantly high-Al; subgroup of low-Al; isotopic & chemical evidence for crustal contribution	3.26-2.95 Ga Low-Al	(2.76 &) 2.71-2.655 Ga High-Ca group; dominantly high-Al; minor low-Al; strong isotopic signature of crustal input
3. Fe-rich medium- to high-K magmatism characterised by strong low-pressure signature; Fe-rich; often elevated HFSE; clear evidence of crustal component	3.3-3.25 Ga		2.74 to 2.66 Ga High-HFSE group.
4. High-Mg diorite LILE-enriched intermediate to felsic magmatism; clear mantle-derived component. LILE-enrichment interpreted as mantle-wedge subduction enrichment (± crustal contribution).		2.95 Ga	2.67 to 2.65 Ga variable LILE & LREE enrichment
5. Alkaline to sub-alkaline (syenitic) intermediate to felsic; variable LILE contents; elevated HFSE		2.95 Ga Portree Complex	2.665 to 2.64 Ga Syenitic group
6. High-K silicic magmatism often with strongly fractionated end-members; chemical and isotopic signatures indicate dominant crustal component (reworking of TTGs?)	2.93 Ga & 2.85 Ga	2.93 Ga & 2.85 Ga	2.655 to 2.63 Ga Low-Ca group. Across whole Yigarn.

Table 1. Archaean granite types of the central and eastern Pilbara and eastern Yilgarn Craton. Data sources in Champion & Sheraton (1997) and Champion & Smithies (2001).

ARCHAEAN GRANITES

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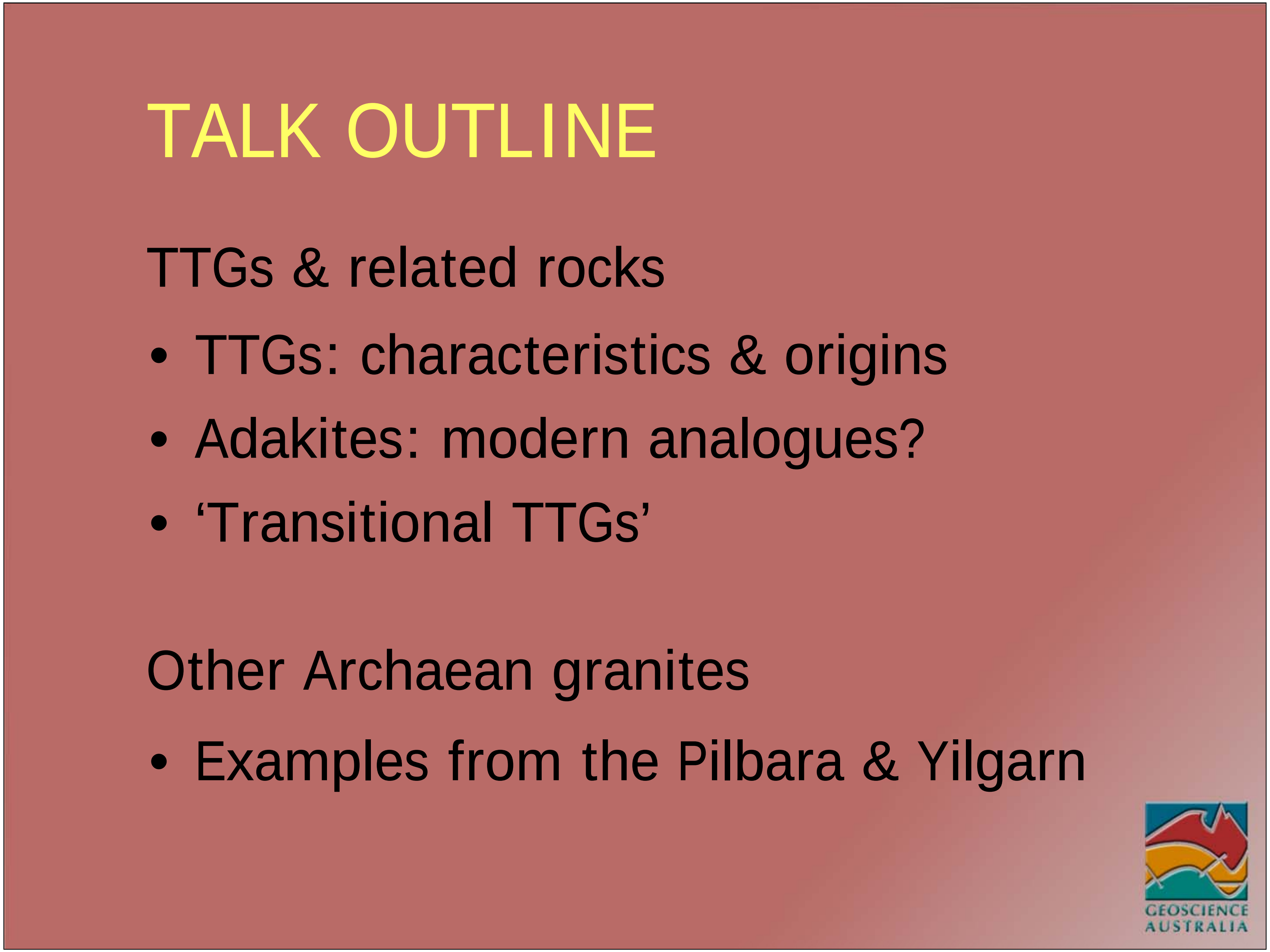


TALK OUTLINE

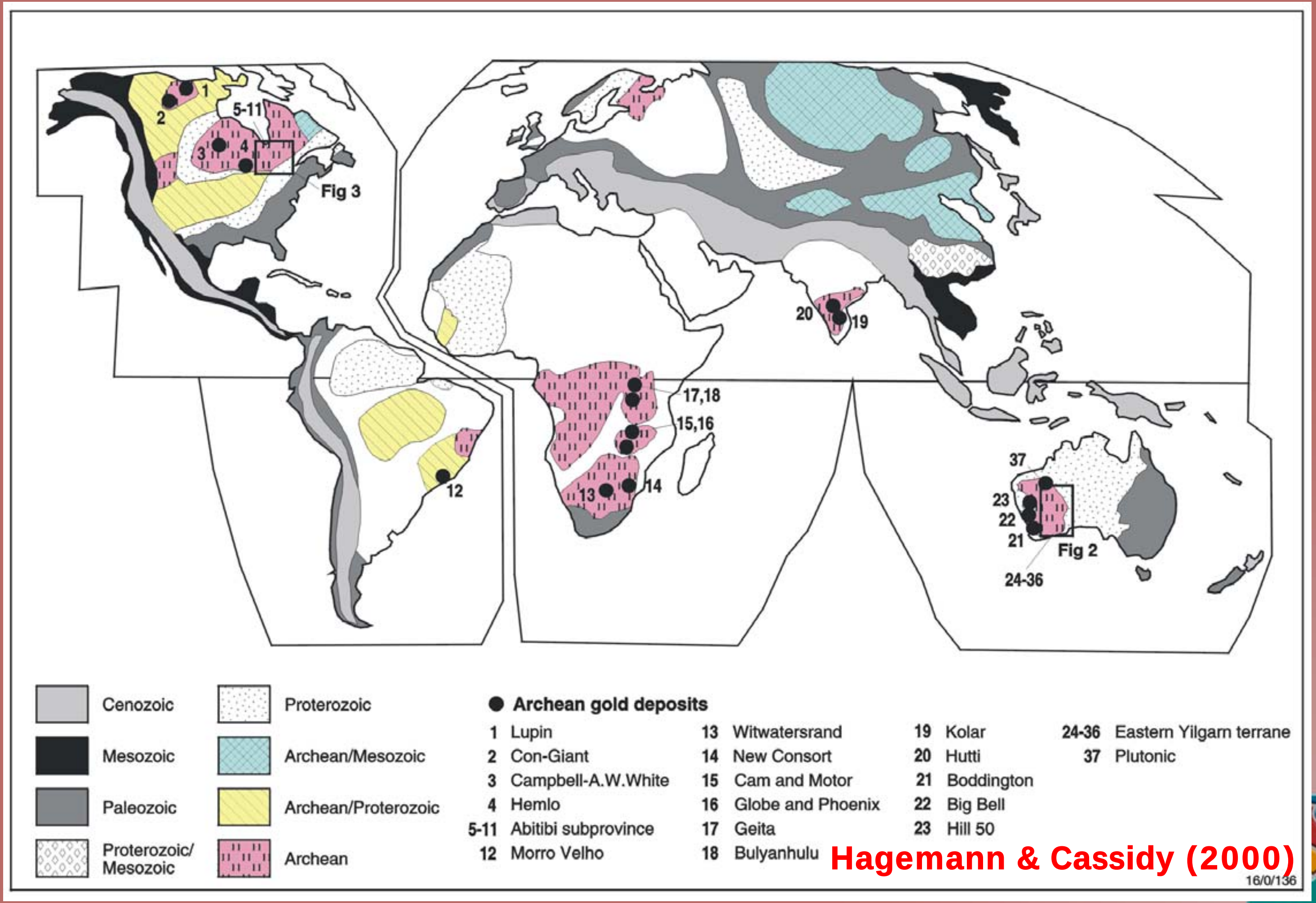
TTGs & related rocks

- TTGs: characteristics & origins
- Adakites: modern analogues?
- ‘Transitional TTGs’

Other Archaean granites

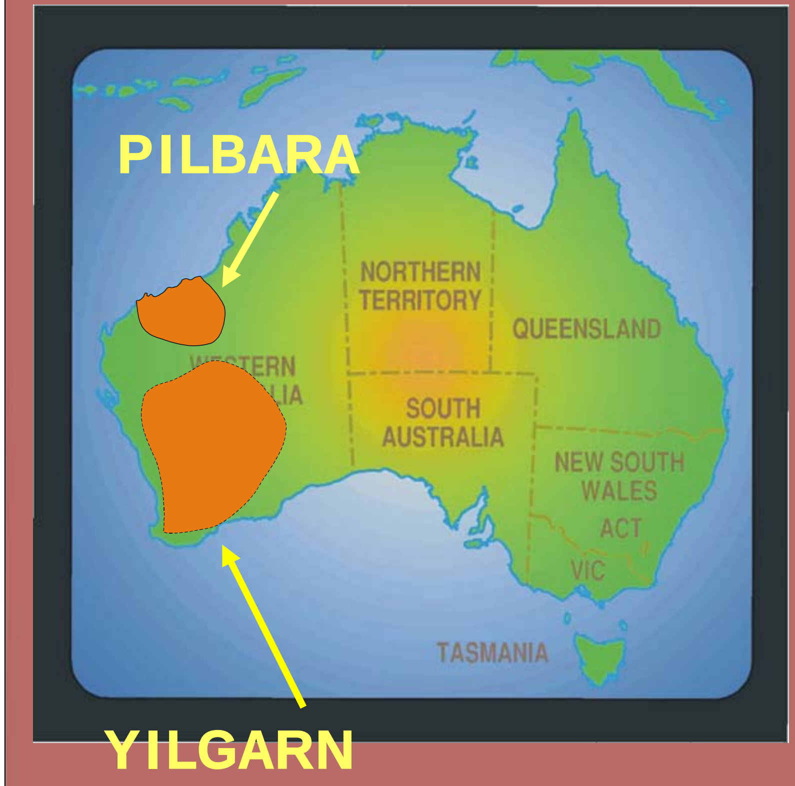
- Examples from the Pilbara & Yilgarn

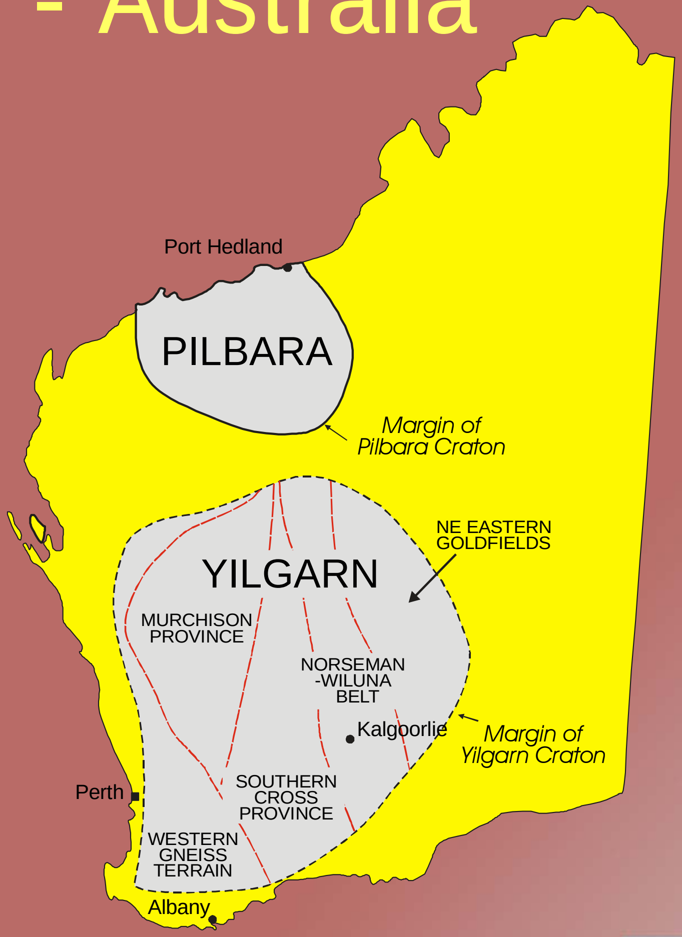
Archaean - worldwide



Hagemann & Cassidy (2000)

Archaean cratons - Australia





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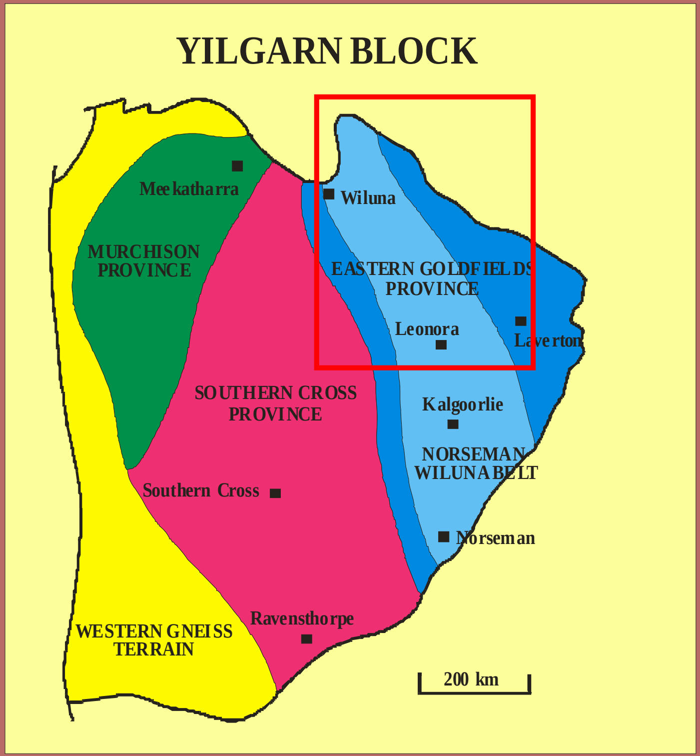
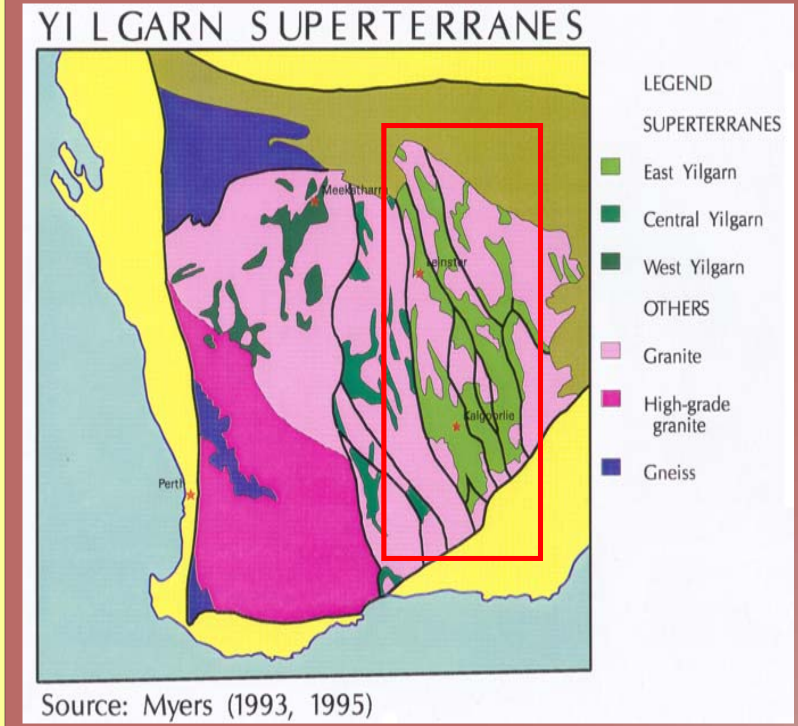
Yilgarn Craton

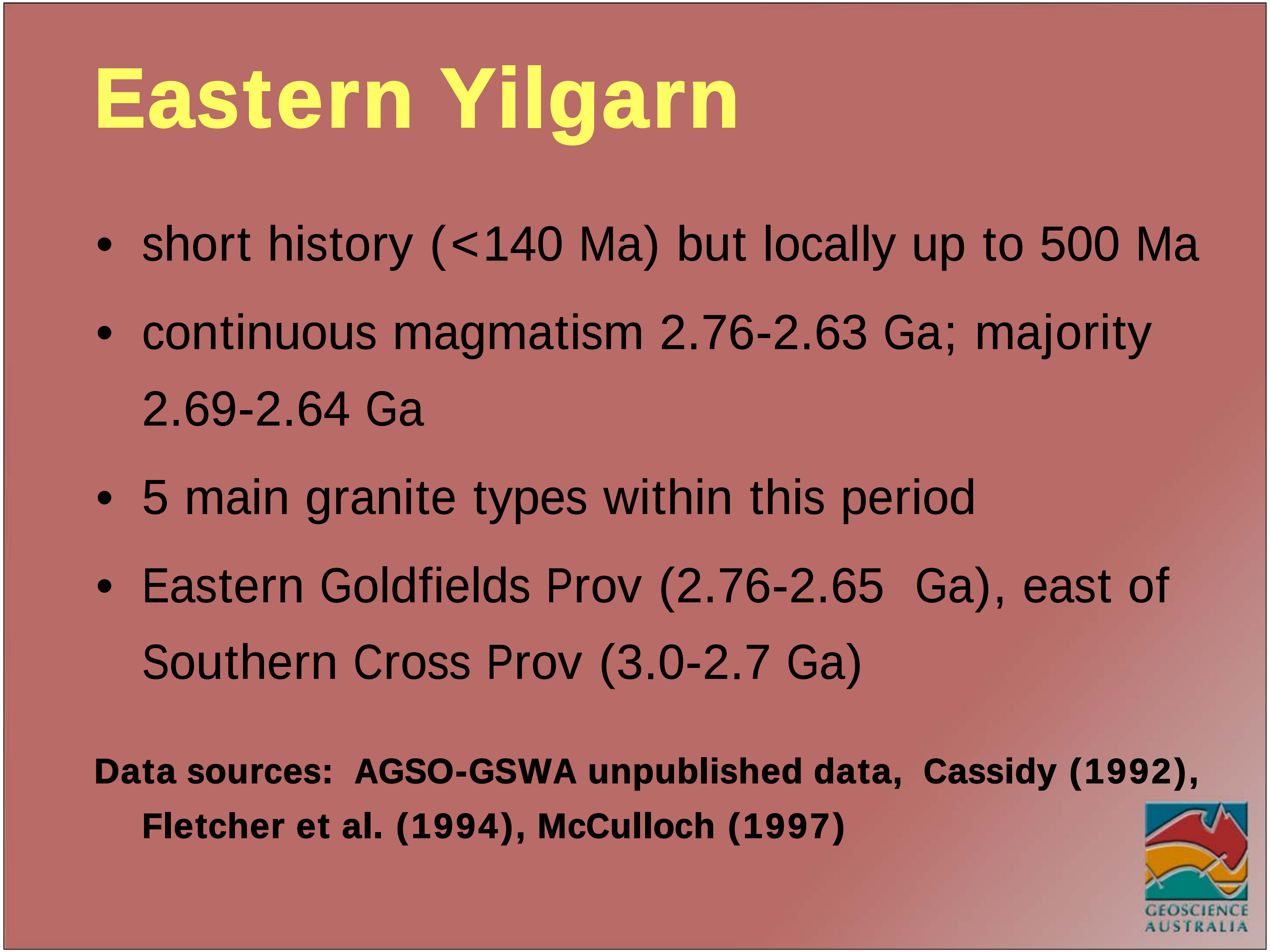


Gee et al. (1981)



Source: Myers (1993, 1995)

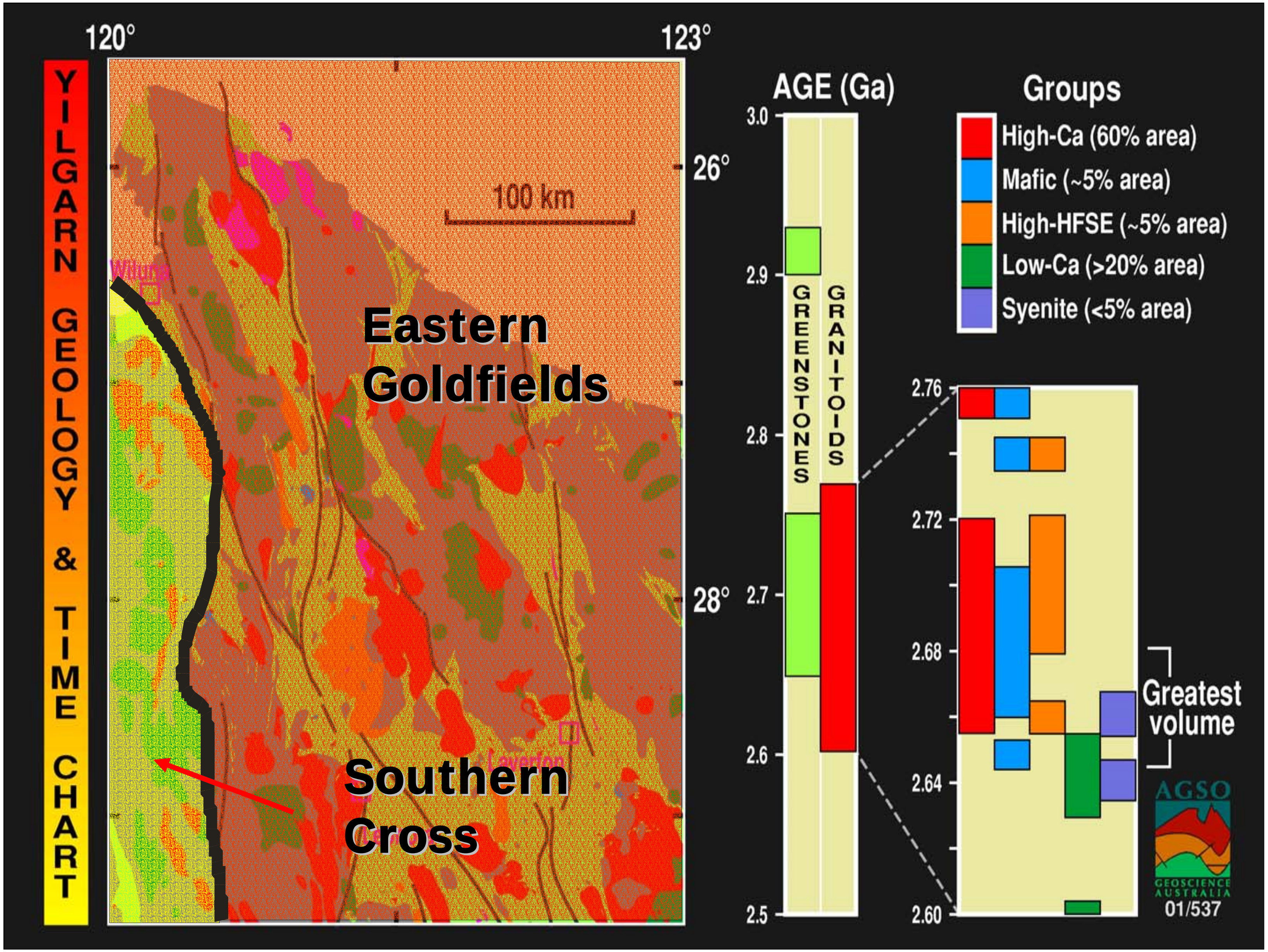
Myers (1993, 1995)



Eastern Yilgarn

- short history (<140 Ma) but locally up to 500 Ma
- continuous magmatism 2.76-2.63 Ga; majority 2.69-2.64 Ga
- 5 main granite types within this period
- Eastern Goldfields Prov (2.76-2.65 Ga), east of Southern Cross Prov (3.0-2.7 Ga)

Data sources: AGSO-GSWA unpublished data, Cassidy (1992), Fletcher et al. (1994), McCulloch (1997)


YILGARN GEOLOGY & TIME CHART
120°
123°
26°
28°
100 km
Wiluna
Eastern Goldfields
Southern Cross
Laverton
AGE (Ga)
3.0
2.9
2.8
2.7
2.6
2.5
GREENSTONES
GRANITOIDS
Groups
High-Ca (60% area)
Mafic (~5% area)
High-HFSE (~5% area)
Low-Ca (>20% area)
Syenite (<5% area)
2.76
2.72
2.68
2.64
2.60
Greatest volume
AGSO
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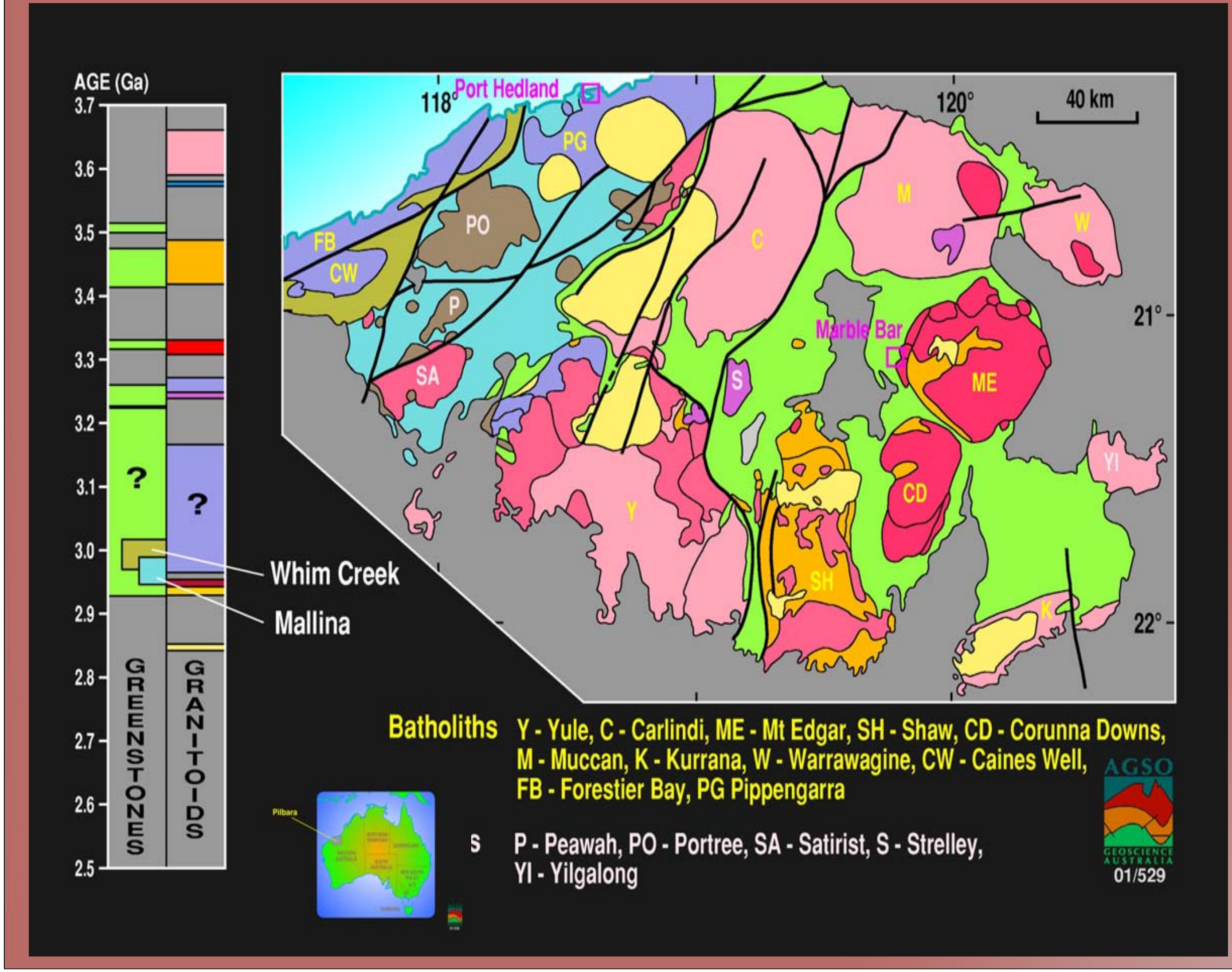
Pilbara Craton



Batholiths Y - Yule, C - Carlindi, ME - Mt Edgar, SH - Shaw, CD - Corunna Downs,
M - Muccan, K - Kurrana, W - Warrawagine, CW - Caines Well,
FB - Forestier Bay, PG Pippengarra

s P - Peawah, PO - Portree, SA - Satirist, S - Strelley,
YI - Yilgalong

East Pilbara

- long history (>800 Ma)
- episodic granite events: >3.5, 3.45, 3.3, 3.24, 2.95, 2.85, 2.76 Ga
- domal granites (>60%) & enveloping greenstones
- relatively thin (<40 km) non-mafic crust

Data sources: Bickle et al. (1983, 1989, 1993), Brauhart & Morant (2000), Collins (1993), Davy (1988), McCulloch (1987), AGSO-GSWA unpublished data

Central Pilbara

- moderate-long history (<500 Ma mostly)
- episodic granite events: >3.42, 3.27-2.945?, 2.945, 2.93, 2.85, 2.76 Ga
- elongate Mallina Basin (rift) on edge of East Pilbara
- also affected by West Pilbara tectonics

Sources: AGSO-GSWA unpublished data

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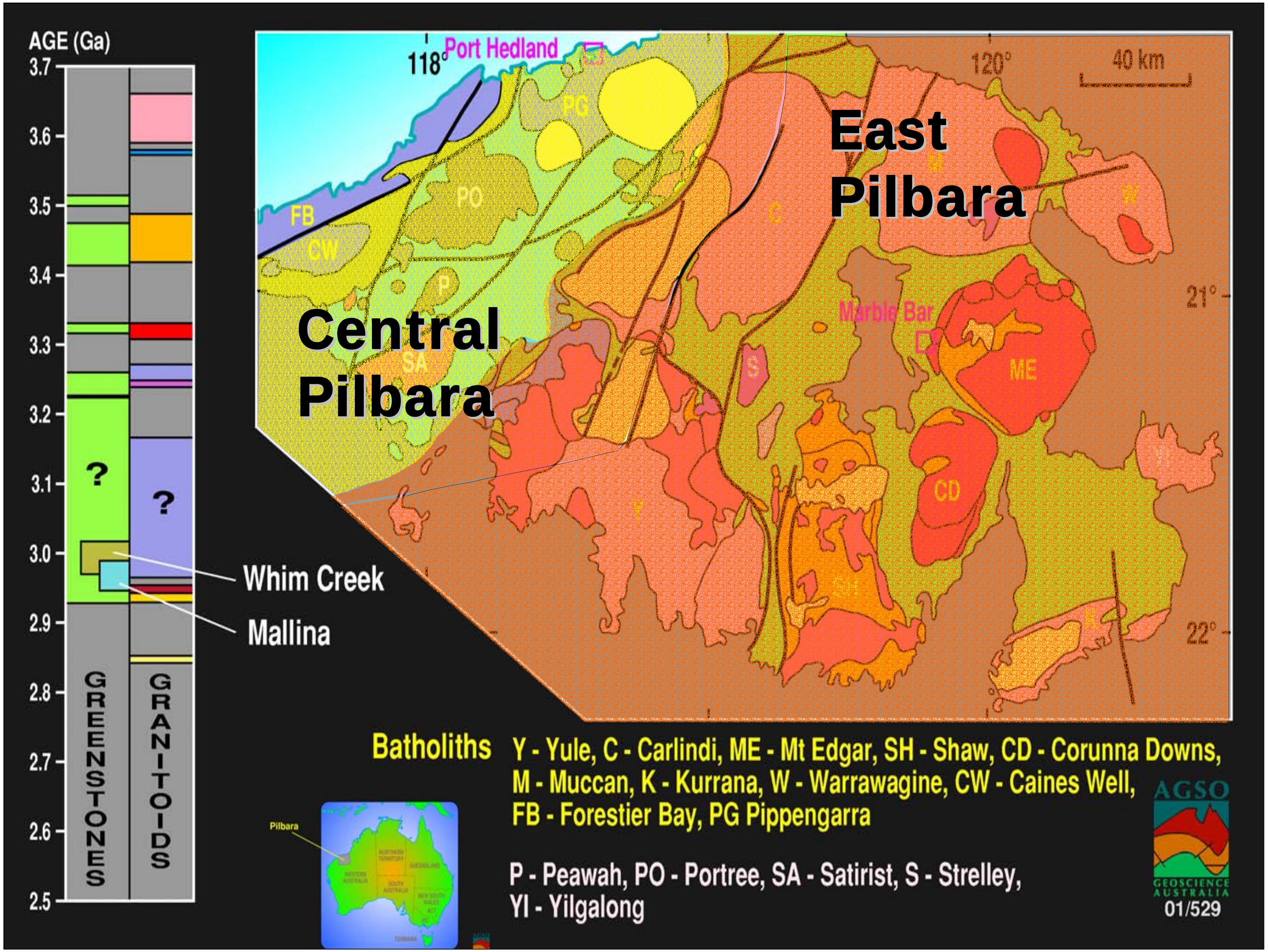

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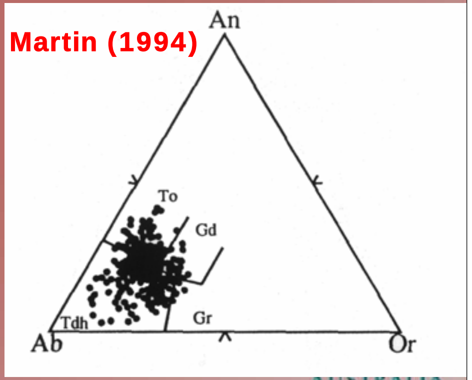
P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

TTGs - definition

Tonalites, Trondhjemites & Granodiorites

- term first used by Jahns et al. (1981), to describe and group the common lithologies of Archaean rocks in the Pilbara.
- clearly applicable to most Archaean terranes, where these lithologies dominant



Martin (1994)

TTGs - some key references

- Jahn et al. (1981) - first use of TTG term
- Barker (1979) - Trondhjemite volume
- Martin (1994, 1999)
- Martin & Moyen (2002)
- Smithies (2001)

TTGs - definition

Unified by distinctive geochemistry (e.g., Barker & Arth, 1976).

- intermediate to felsic (mostly >65% SiO_2)
- high Na_2O/K_2O, low- to medium-K, low to moderate LILE content
- no strong potassium enrichment evident in more siliceous members
- negative Nb, Ta anomalies

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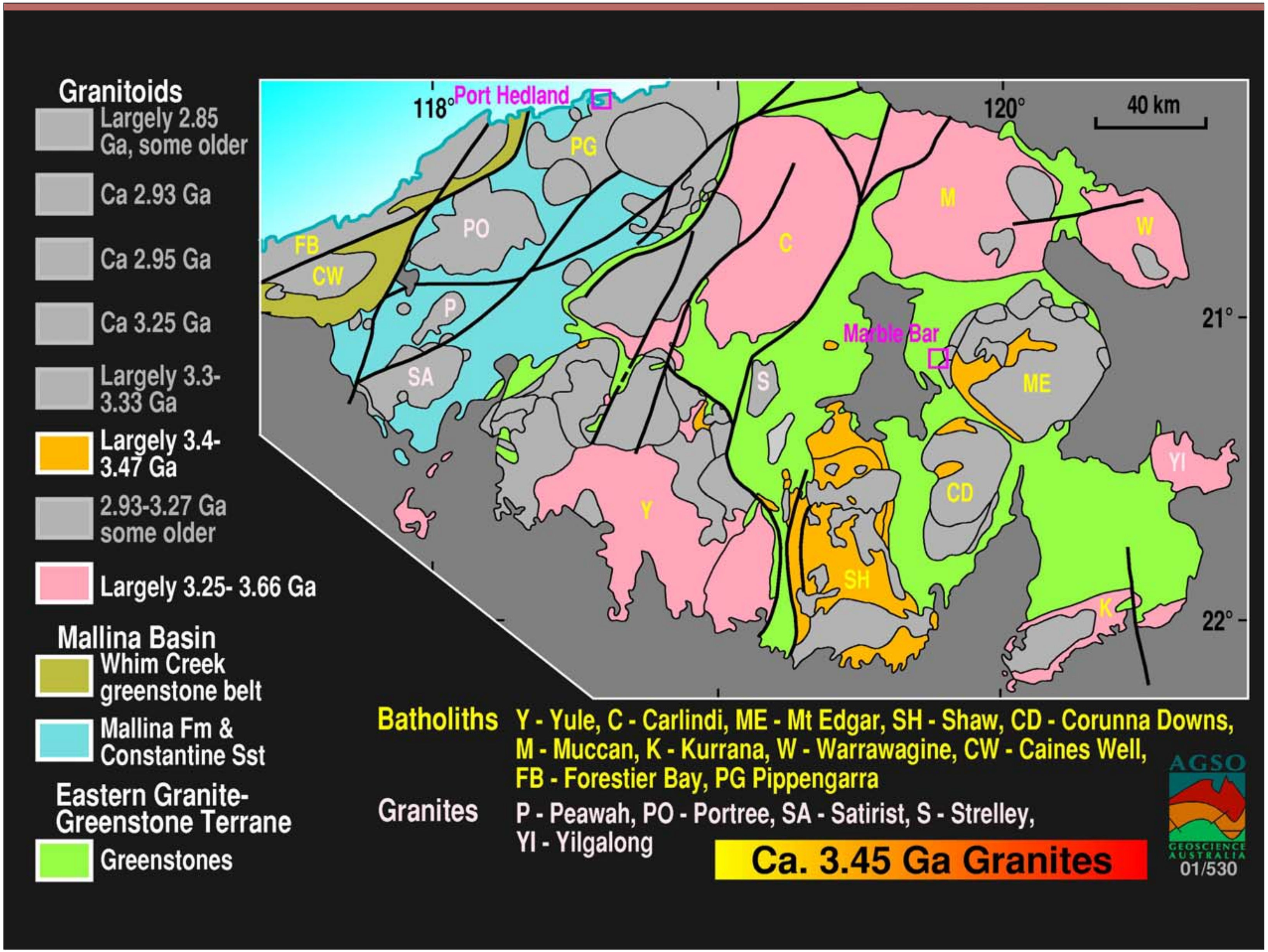

Ca. 3.45 Ga Granites

Granitoids

- ■ Largely 2.85 Ga, some older
- ■ Ca 2.93 Ga
- ■ Ca 2.95 Ga
- ■ Ca 3.25 Ga
- ■ Largely 3.3-3.33 Ga
- ■ Largely 3.4-3.47 Ga
- ■ 2.93-3.27 Ga some older
- ■ Largely 3.25- 3.66 Ga

Mallina Basin

- ■ Whim Creek greenstone belt
- ■ Mallina Fm & Constantine Sst

Eastern Granite-Greenstone Terrane

- ■ Greenstones

Batholiths Y - Yule, C - Carlindi, ME - Mt Edgar, SH - Shaw, CD - Corunna Downs, M - Muccan, K - Kurrana, W - Warrawagine, CW - Caines Well, FB - Forestier Bay, PG Pippengarra

Granites P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

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Ca. 2.95 Ga Granites

Granitoids

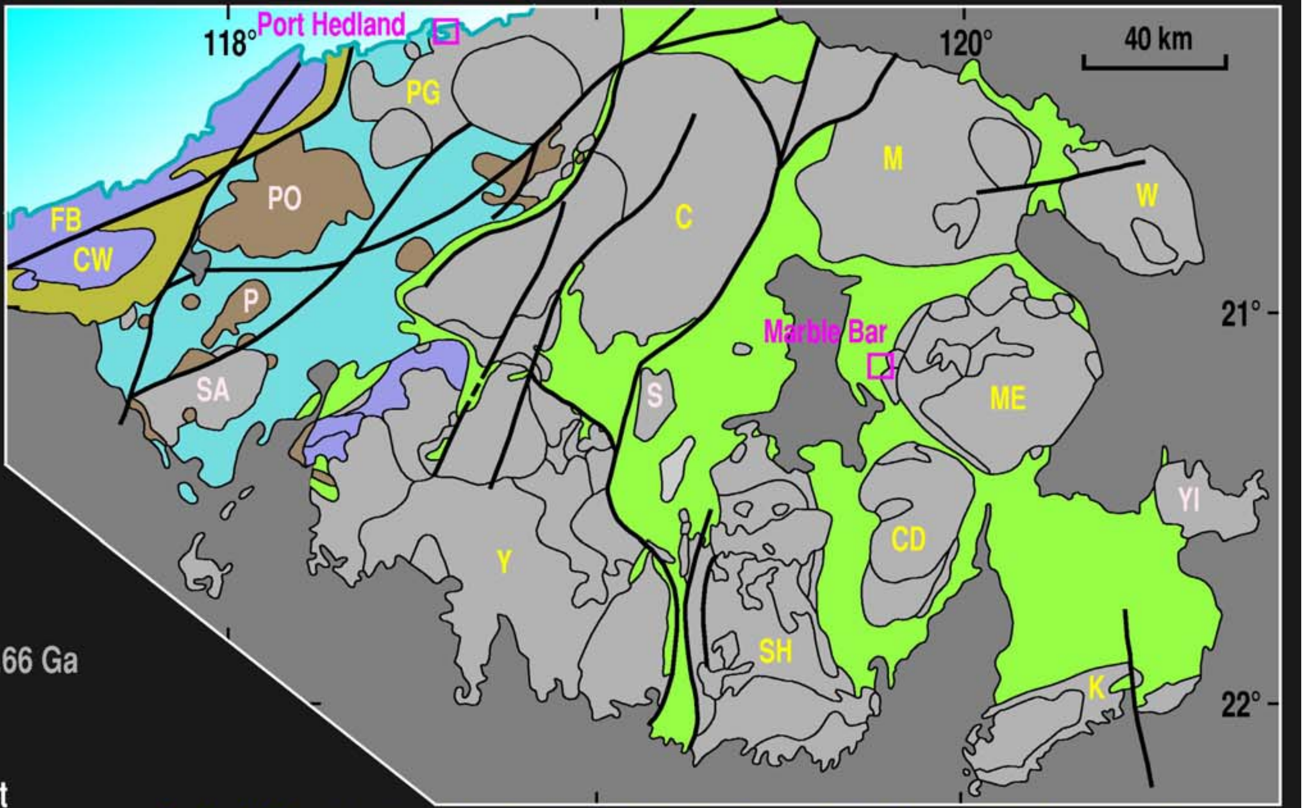
- ⬜ Largely 2.85 Ga, some older
- ⬜ Ca 2.93 Ga
- 🟫 **Ca 2.95 Ga**
- ⬜ Ca 3.25 Ga
- ⬜ Largely 3.3-3.33 Ga
- ⬜ Largely 3.4-3.47 Ga
- 🟪 2.93-3.27 Ga some older
- ⬜ Largely 3.25- 3.66 Ga

Mallina Basin

- 🟨 Whim Creek greenstone belt
- 🟦 Mallina Fm & Constantine Sst

Eastern Granite-Greenstone Terrane

- 🟩 Greenstones



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Granites P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

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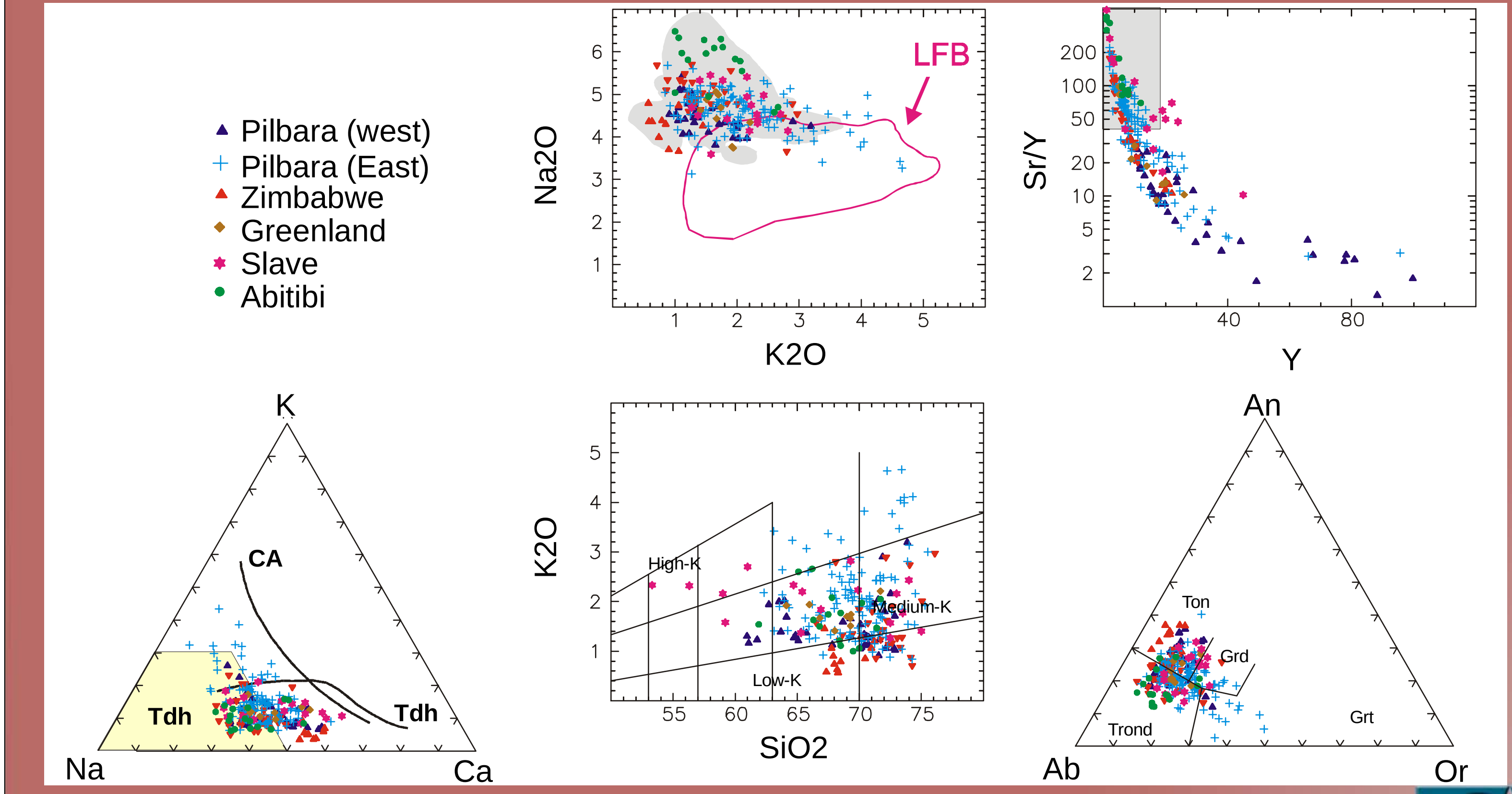
TTGs - Geochemistry

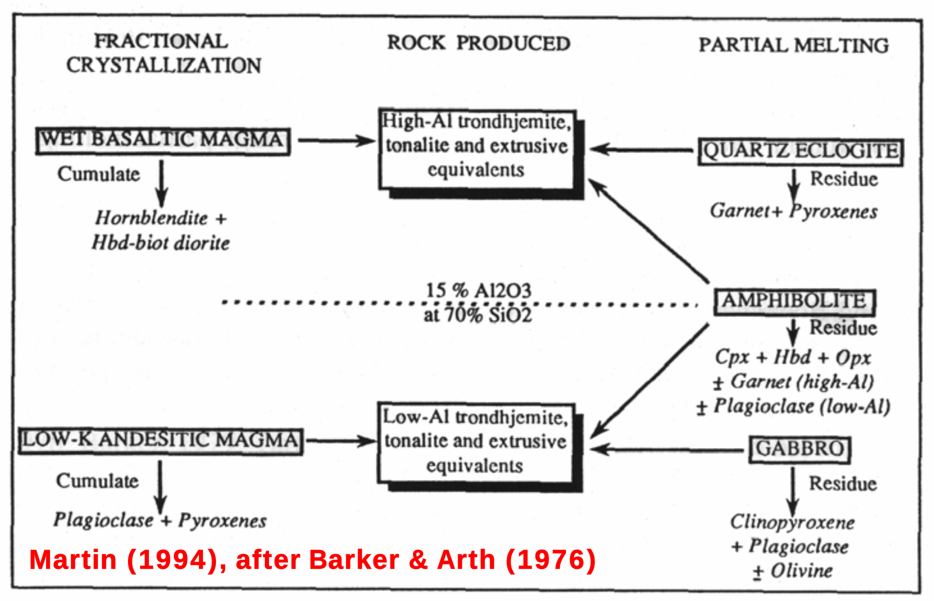


Data sources: GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Feng & Kerrich (1992); Luais & Hawkesworth (1994); Nutman & Bridgewater (1986); Davis et al. (1994)

TTGs - definition

Subgroups (really end-members)

- Arth, Barker and co-workers recognised high- and low-Al subgroups



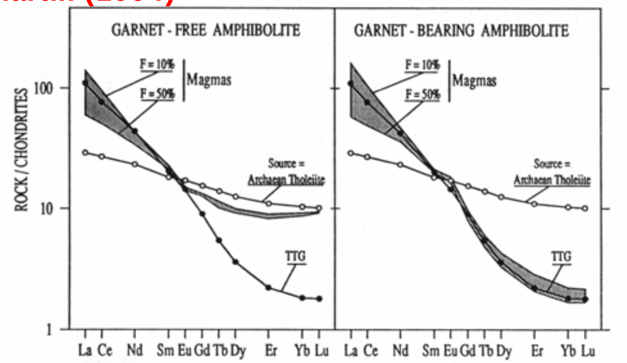
Martin (1994), after Barker & Arth (1976)

TTGs definition

Low-Al

- $Al_2O_3 < 15\%$ at 70% SiO_2
- Sr depleted, with negative Sr & Eu anomalies (evidence for plagioclase involvement)
- Y-undepleted (no major involvement of garnet and/or amphibole)

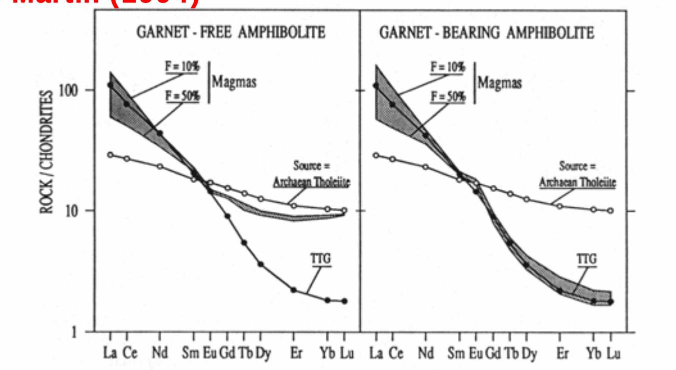
Martin (1994)



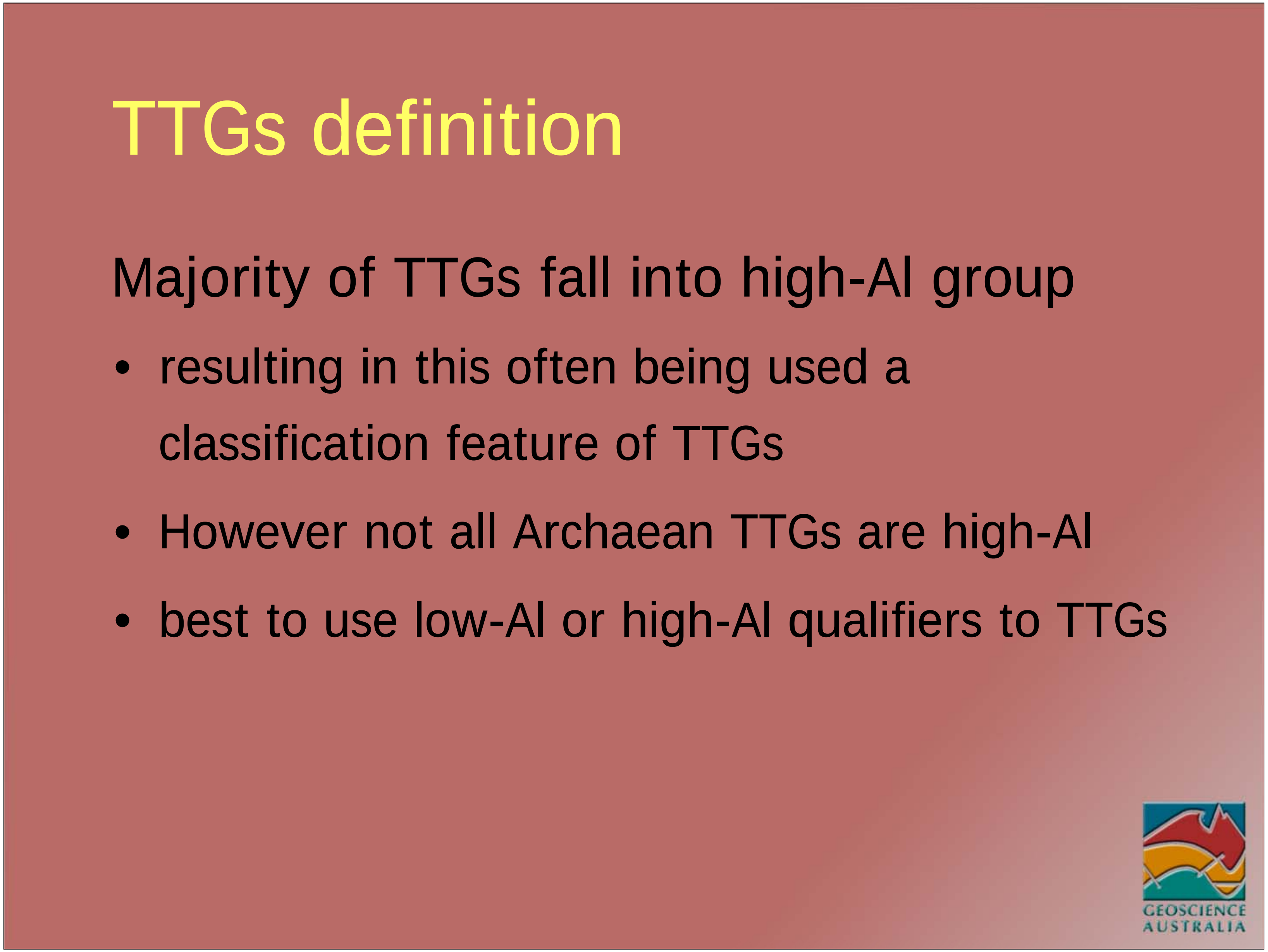
TTGs definition

High-Al

- Al_2O_3 > 15% at 70% SiO_2
- Sr undepleted; positive to small negative Sr & Eu anomalies (no major plagioclase involvement)
- Y-depleted (evidence for involvement of garnet and/or amphibole)



Martin (1994)



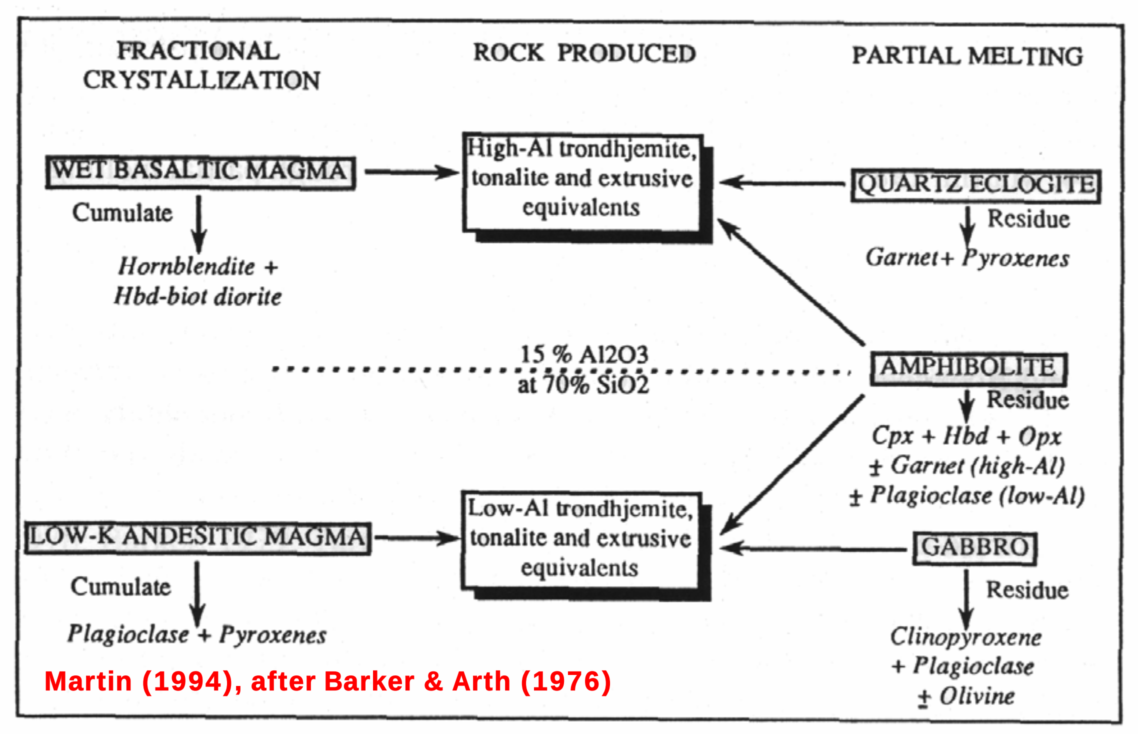
TTGs definition

Majority of TTGs fall into high-Al group

- resulting in this often being used a classification feature of TTGs
- However not all Archaean TTGs are high-Al
- best to use low-Al or high-Al qualifiers to TTGs

TTGs origins

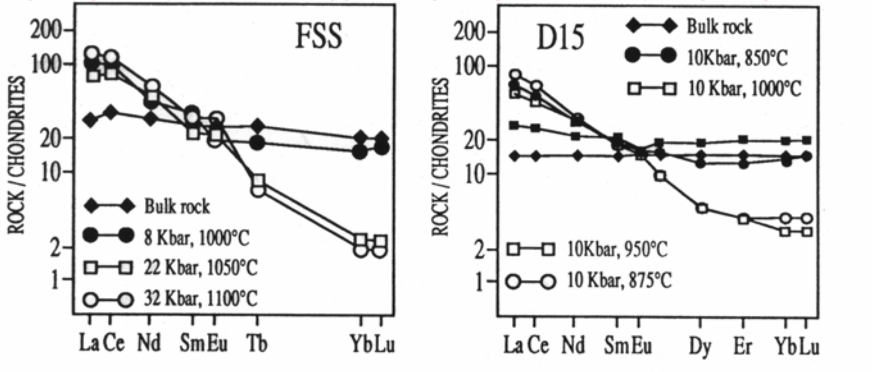
Barker & Arth (1976) scheme: Partial melting or fractionation from broadly basaltic sources at different pressures



Martin (1994), after Barker & Arth (1976)

TTGs origins

- majority support this viewpoint; consistent with trace element modelling and experimental evidence
- lack of mafic/intermediate members suggest partial melting important for the Archaean
- Either in thickened crust or via slab melting



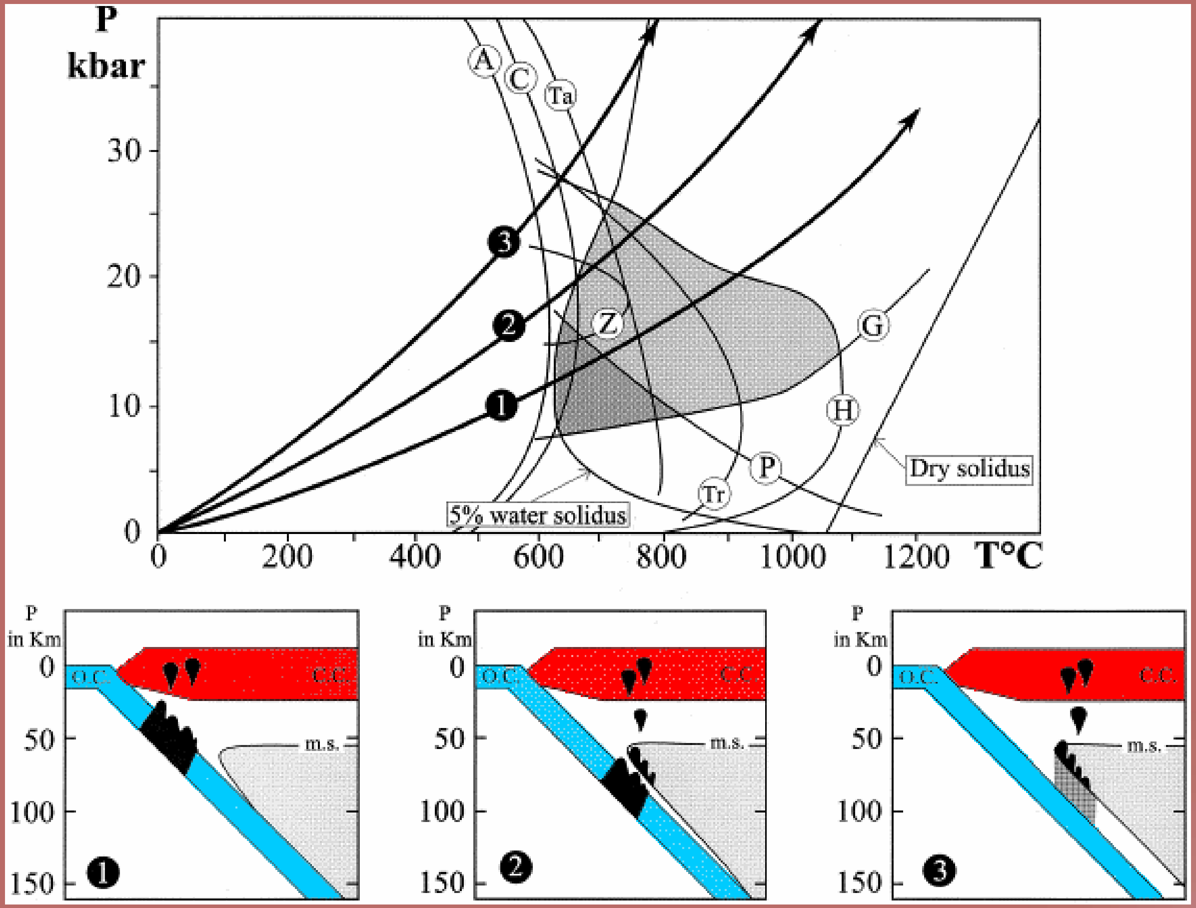
Martin (1994), using data from Rapp et al. (1991) & Wolf & Wyllie (1993)

TTGs origins

Slab melting

- proposed by number of authors, e.g., Martin (1986) to explain high pressure and basaltic source (high-Al TTGs)
- elegant model that can also account for other features, e.g., thermal requirements, continual supply of protolith, disposal of residues (given refraction evidence for felsic crust)

TTGs origins



Martin (1999). 1-Archaean; 2-adakite; 3-andesite

TTGs origins

However,

- experimental and other evidence also consistent with melting in thickened crust
- also not certain what form plate tectonics took in the Archaean, or even that plate tectonics were operative (e.g., Hamilton, 1998). More so for early- to mid-Archaean.

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Modern analogues?

One possible solution look at present. Are there examples of slab melting?

A class of magmas known as adakites, thought to represent slab melting, have been recognised: controversial though

Adakites - modern analogues?

Named after rocks from Adak Island & work of Kay (1978)

- what are they?
- where do they occur
- favourable tectonic regimes
- mode of formation

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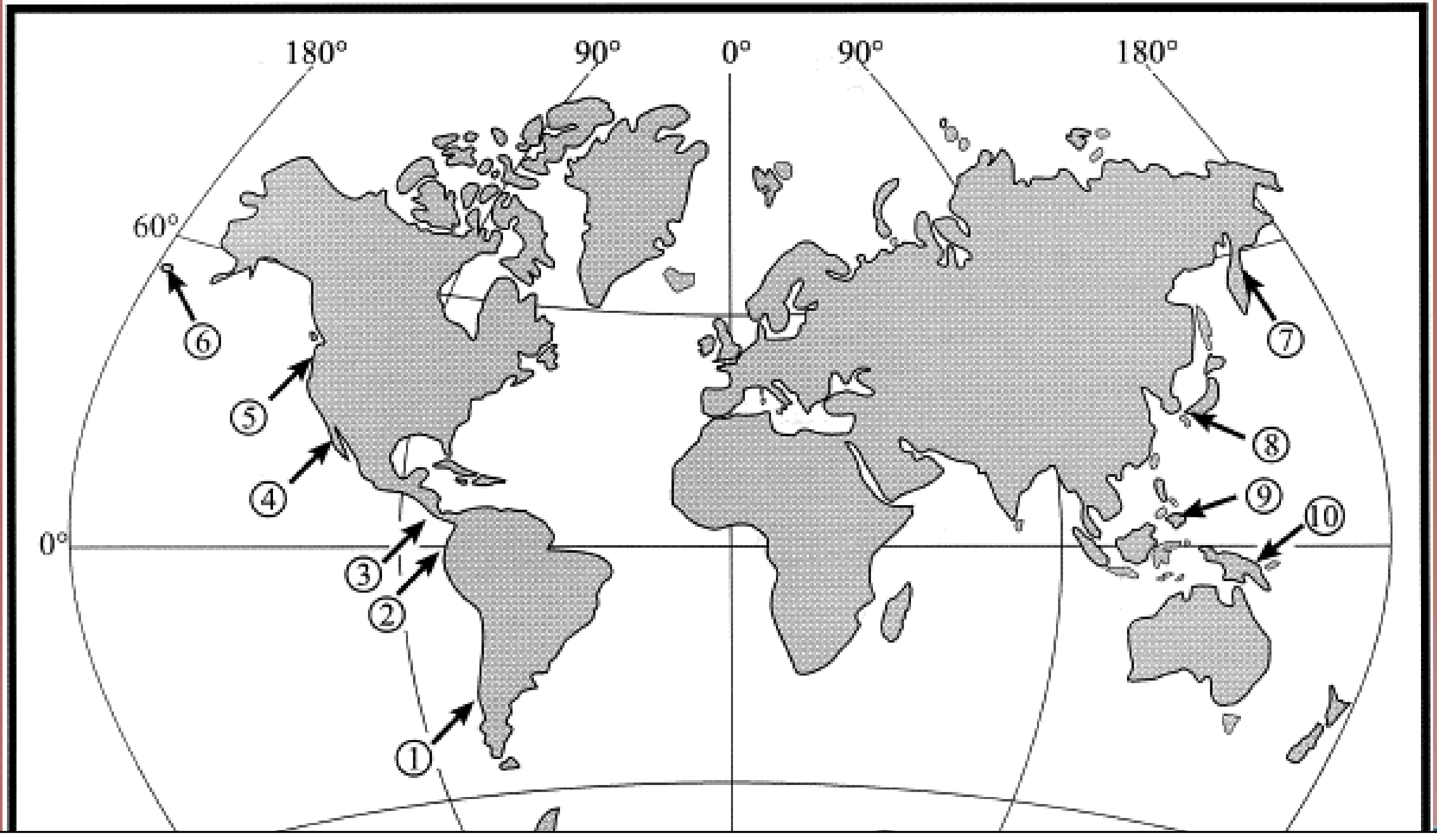
Adakites - distribution

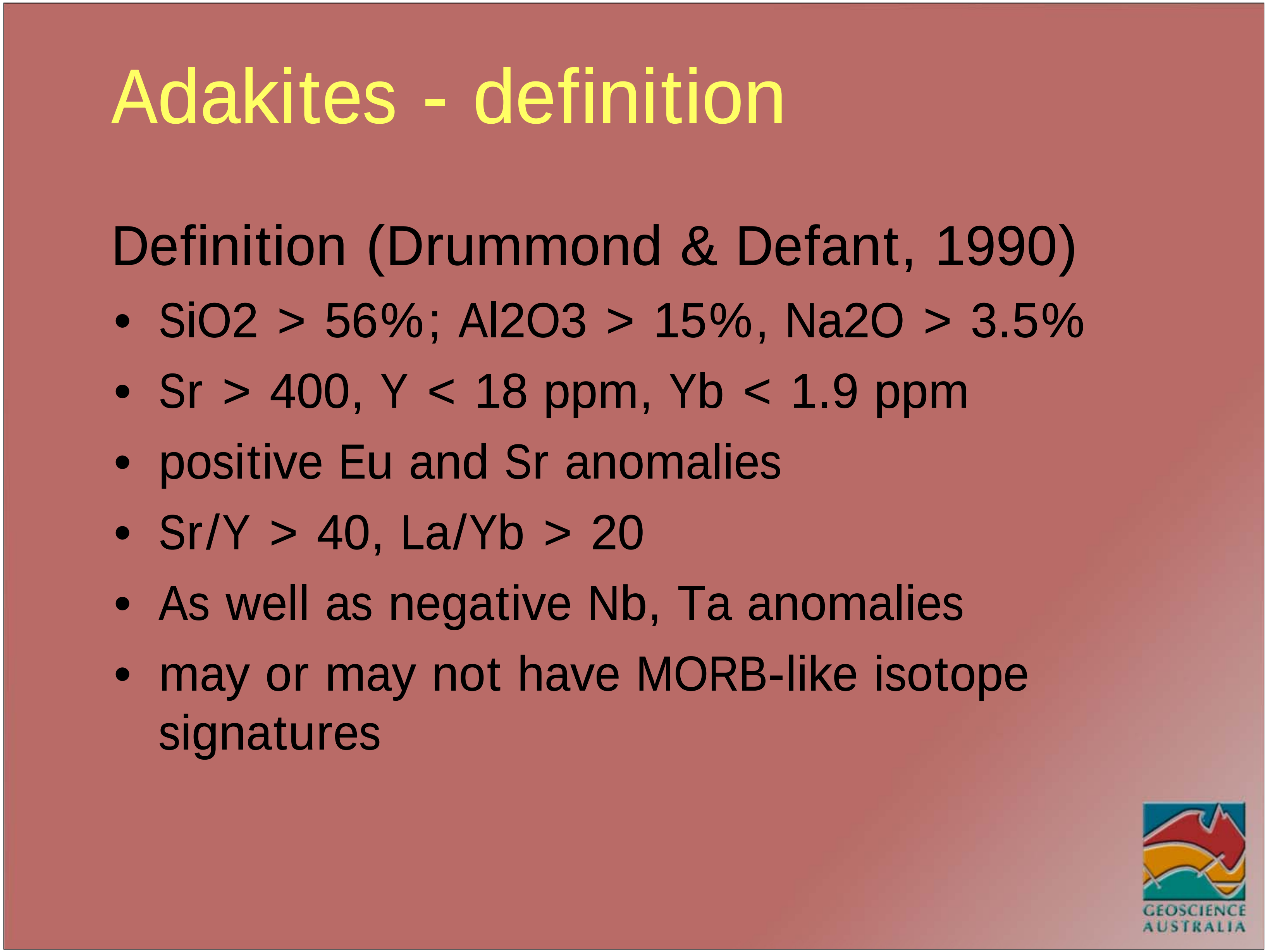


(1) Austral Chile; (2) Ecuador; (3) Panama and Costa Rica; (4) Mexico; (5) Baja California; (6) Aleutians; (7) Kamchatka; (8) Japan; (9) Philippines; (10) New Guinea. (references in Martin 1999). Figure from Martin (1999).

Adakites - key references

- Kay (1978)
- Drummond & Defant (1990) & companion papers
- Martin (1999)

- Data sources: Defant et al., 1992; Schiano et al., 1995; Kepezhinskas et al., 1996, 1997; Kay et al., 1993; Futa & Stern, 1988; Puig et al., 1984; Yogodzinski et al., 1994, 1995; Morris, 1995; Sajona et al., 1993; Beate et al., 2001; Smith & Leeman, 1987; Tatsumi & Ishizaka, 1982.

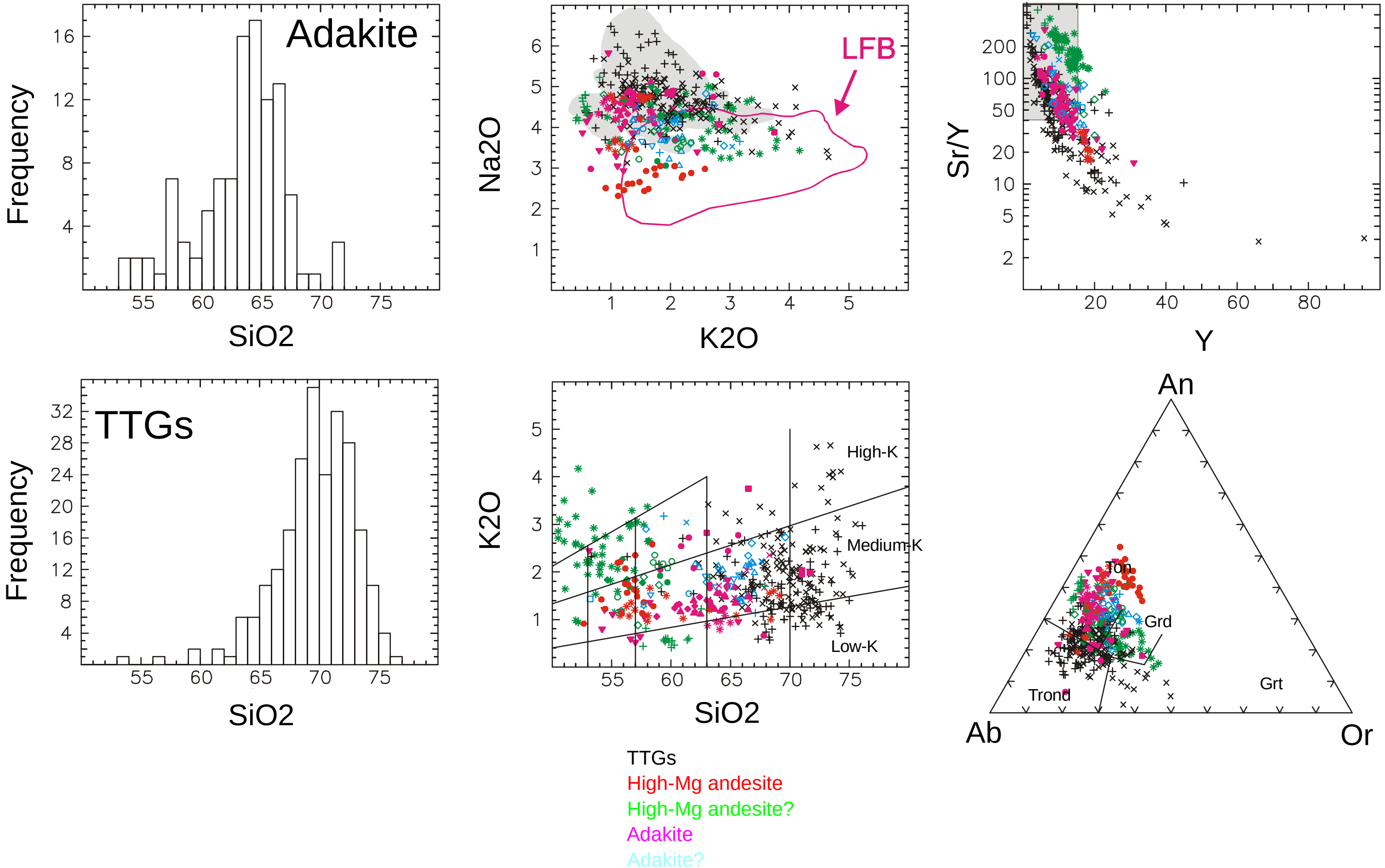


Adakites - definition

Definition (Drummond & Defant, 1990)

- SiO_2 > 56%; Al_2O_3 > 15%, Na_2O > 3.5%
- Sr > 400, Y < 18 ppm, Yb < 1.9 ppm
- positive Eu and Sr anomalies
- Sr/Y > 40, La/Yb > 20
- As well as negative Nb, Ta anomalies
- may or may not have MORB-like isotope signatures

Adakites - chemistry

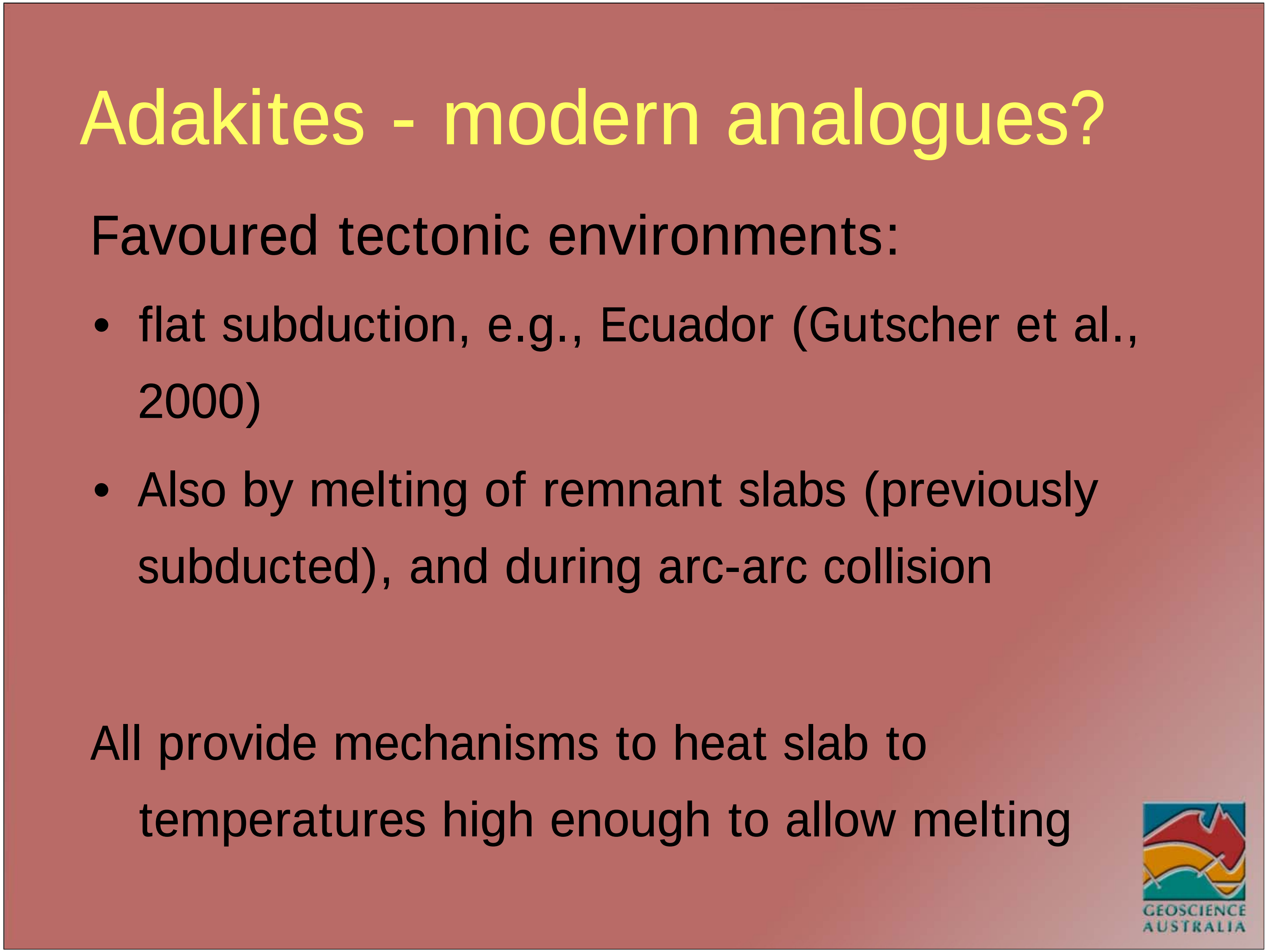


Data sources: Defant et al. (1992); Schiano et al. (1995); Kepezhinskas et al. (1996, 1997); Kay et al (1993); Futa & Stern (1988); Puig et al. (1984); Yogodzinski et al. (1994, 1995); Morris (1995); Sajona et al. (1993); Beate et al. (2001); Smith & Leeman (1987); Tatsumi & Ishizaka (1982); GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Feng & Kerrich (1992); Luais & Hawkesworth (1994); Nutman & Bridgewater (1986); Davis et al. (1994).

Adakites - modern analogues?

Favoured tectonic environments:

- subduction of young hot slabs - original & general model
- oblique or rapid subduction, e.g., Aleutians (Yogodzinski et al., 1995)
- slab tears/edges, e.g., Kamchatka (Yogodzinski et al., 2001); subduction initiation

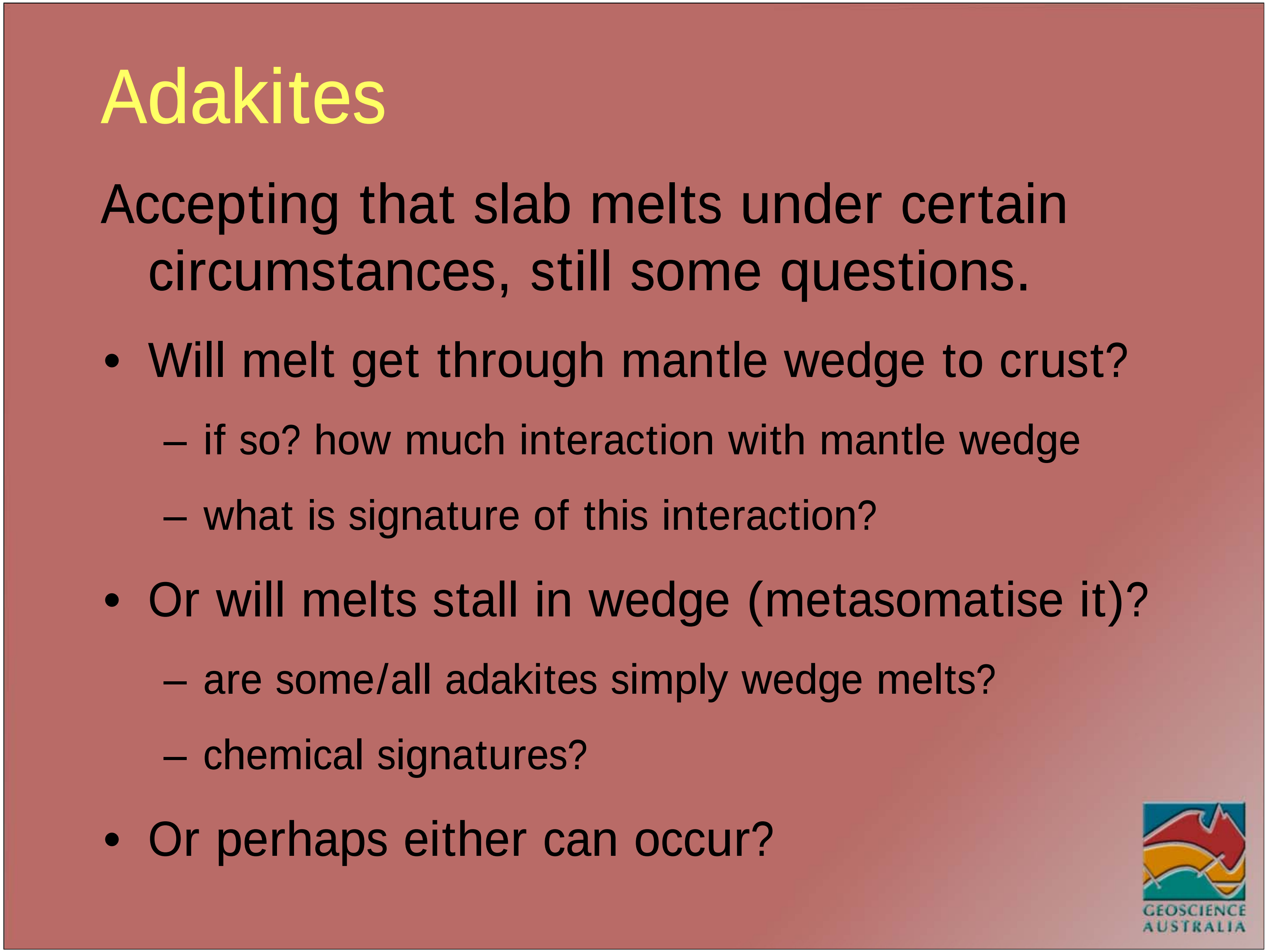


Adakites - modern analogues?

Favoured tectonic environments:

- flat subduction, e.g., Ecuador (Gutscher et al., 2000)
- Also by melting of remnant slabs (previously subducted), and during arc-arc collision

All provide mechanisms to heat slab to temperatures high enough to allow melting



Adakites

Accepting that slab melts under certain circumstances, still some questions.

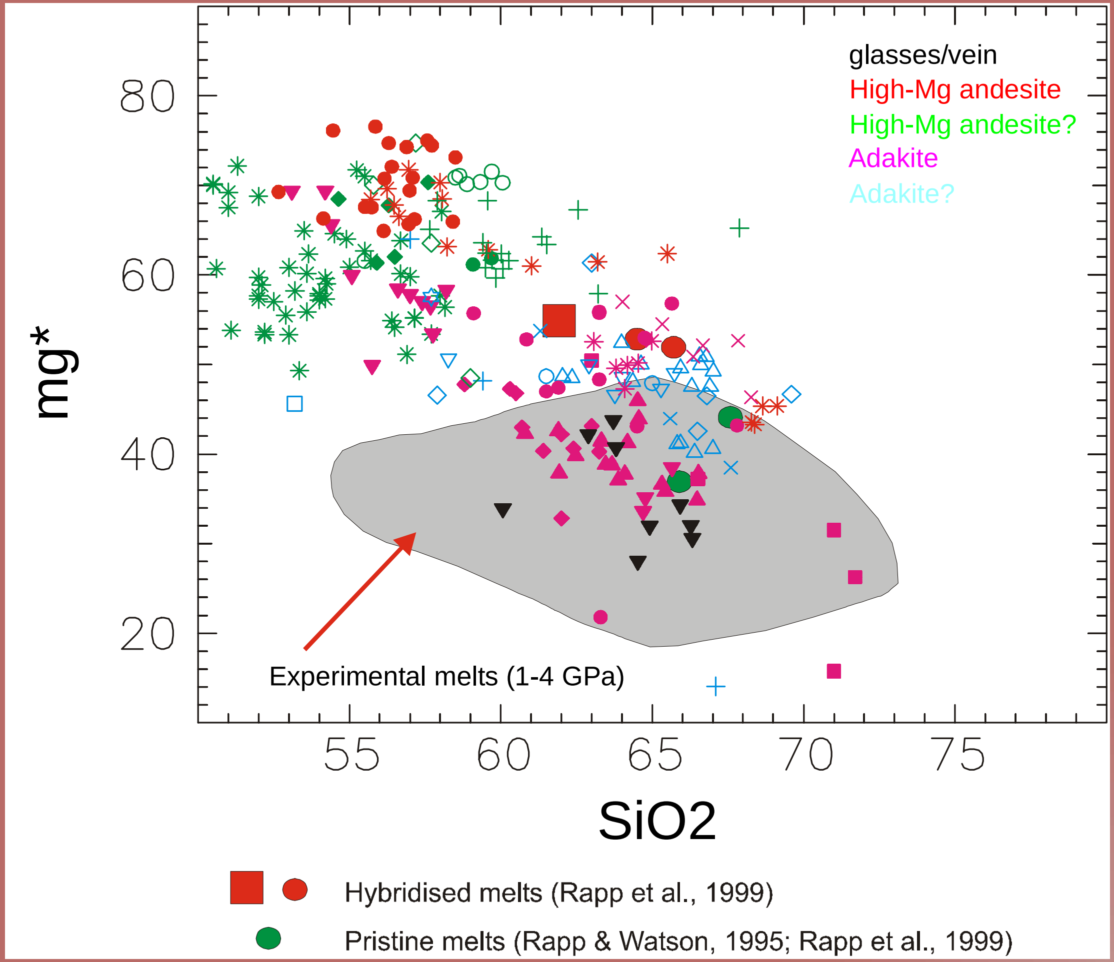
- Will melt get through mantle wedge to crust?
  - if so? how much interaction with mantle wedge
  - what is signature of this interaction?
- Or will melts stall in wedge (metasomatise it)?
  - are some/all adakites simply wedge melts?
  - chemical signatures?
- Or perhaps either can occur?

Adakites

Mantle wedge interaction

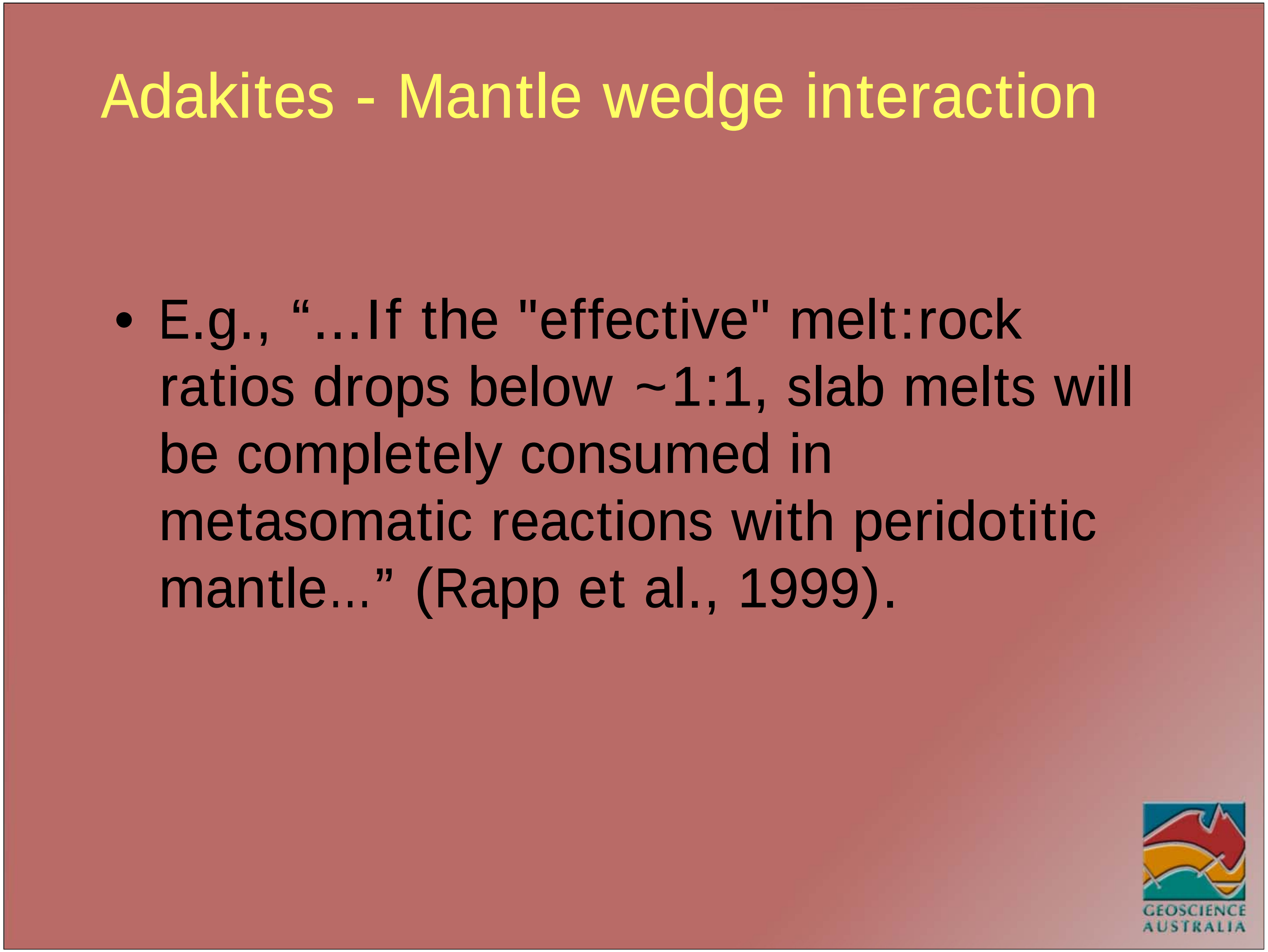
- Experimental data (e.g., Carroll & Wyllie, 1989; Rapp et al., 1999) suggests slab melts will be hybridised by mantle wedge (react with olivine)
  - – melt + peridotite = Mgo-, Ni-, Cr-enriched melt & pyroxene +/- garnet +/- residual peridotite

Adakites: wedge interaction



Adakites - Mantle wedge interaction

- Migration of slab melts through wedge and degree of interaction thought to depend on a number of factors, including:
    - slab melt flux
    - size of mantle wedge
    - localised pathways
- NB. Is mantle xenolith evidence for veins & glasses that resemble slab melts (e.g., Schiano et al. 1995)



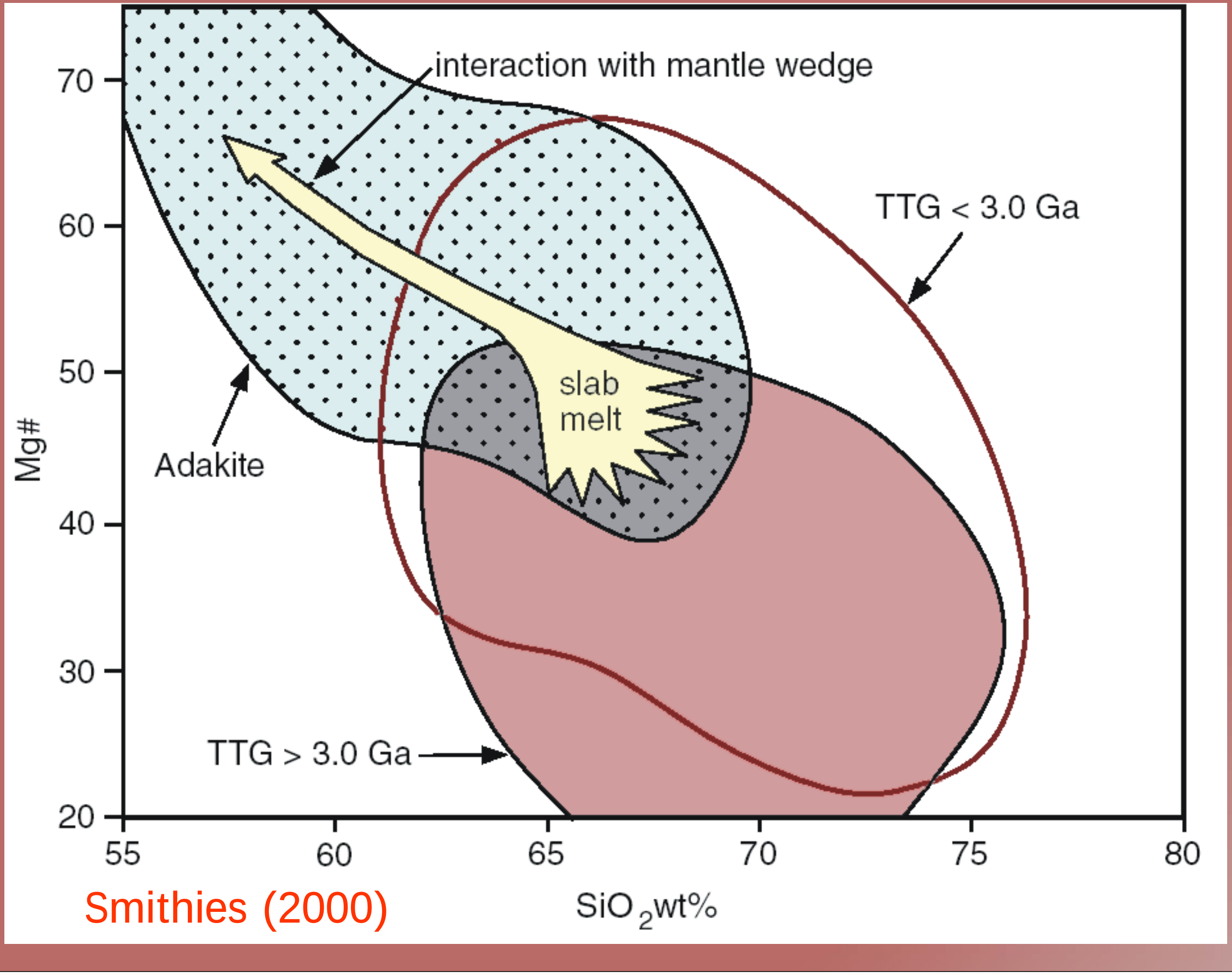
Adakites - Mantle wedge interaction

- E.g., “...If the "effective" melt:rock ratios drops below ~1:1, slab melts will be completely consumed in metasomatic reactions with peridotitic mantle...” (Rapp et al., 1999).

Adakites & TTGs

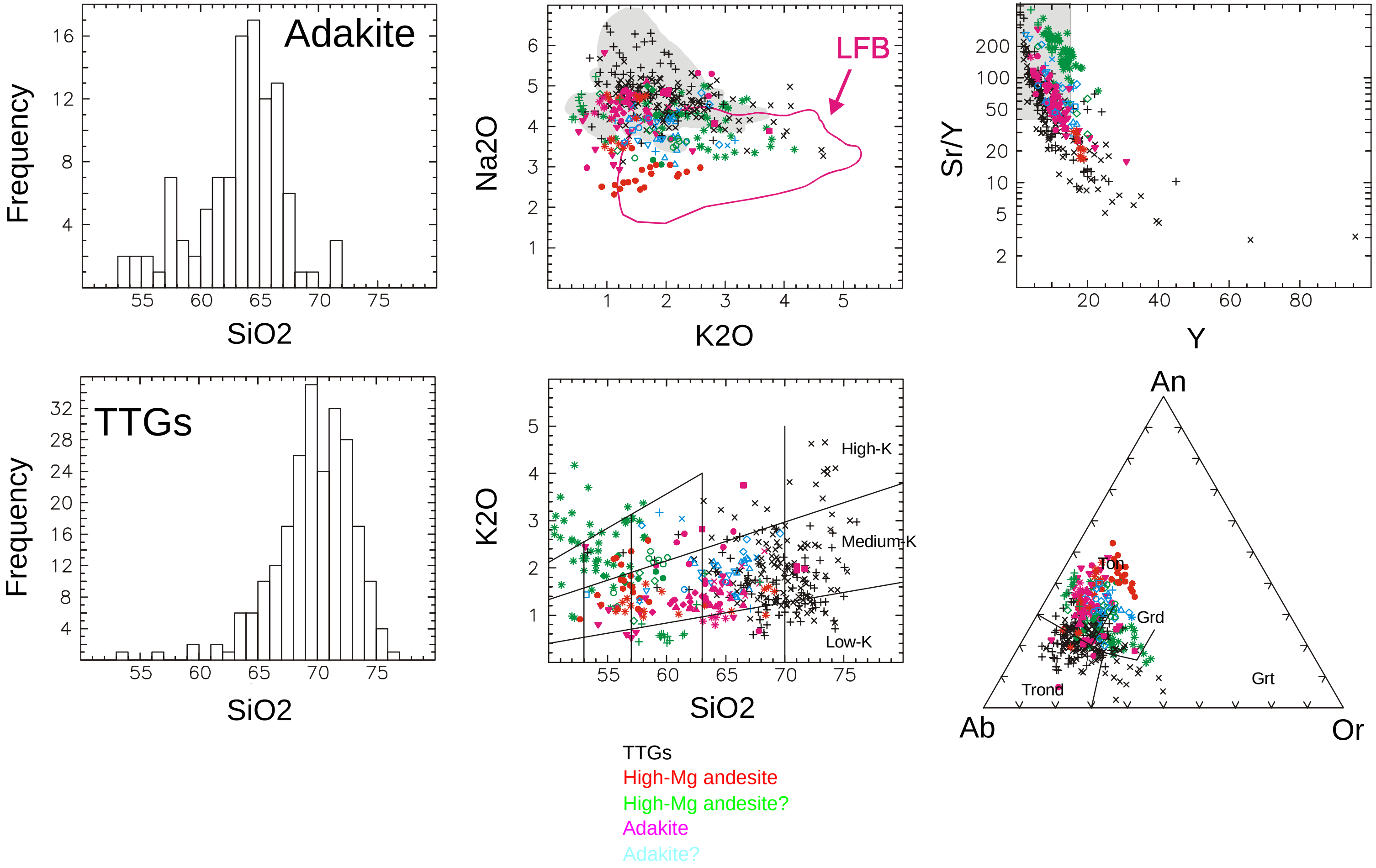
- adakites and TTGs clearly have broadly overlapping geochemistry with many similarities
- Archaean TTGs also have evidence for elevated mg*, Ni, Cr, like that seen in adakites, though appears to be most prevalent only in late Archaean (post 3.2 Ga) TTGs (Smithies, 2000)

Adakites & TTGs

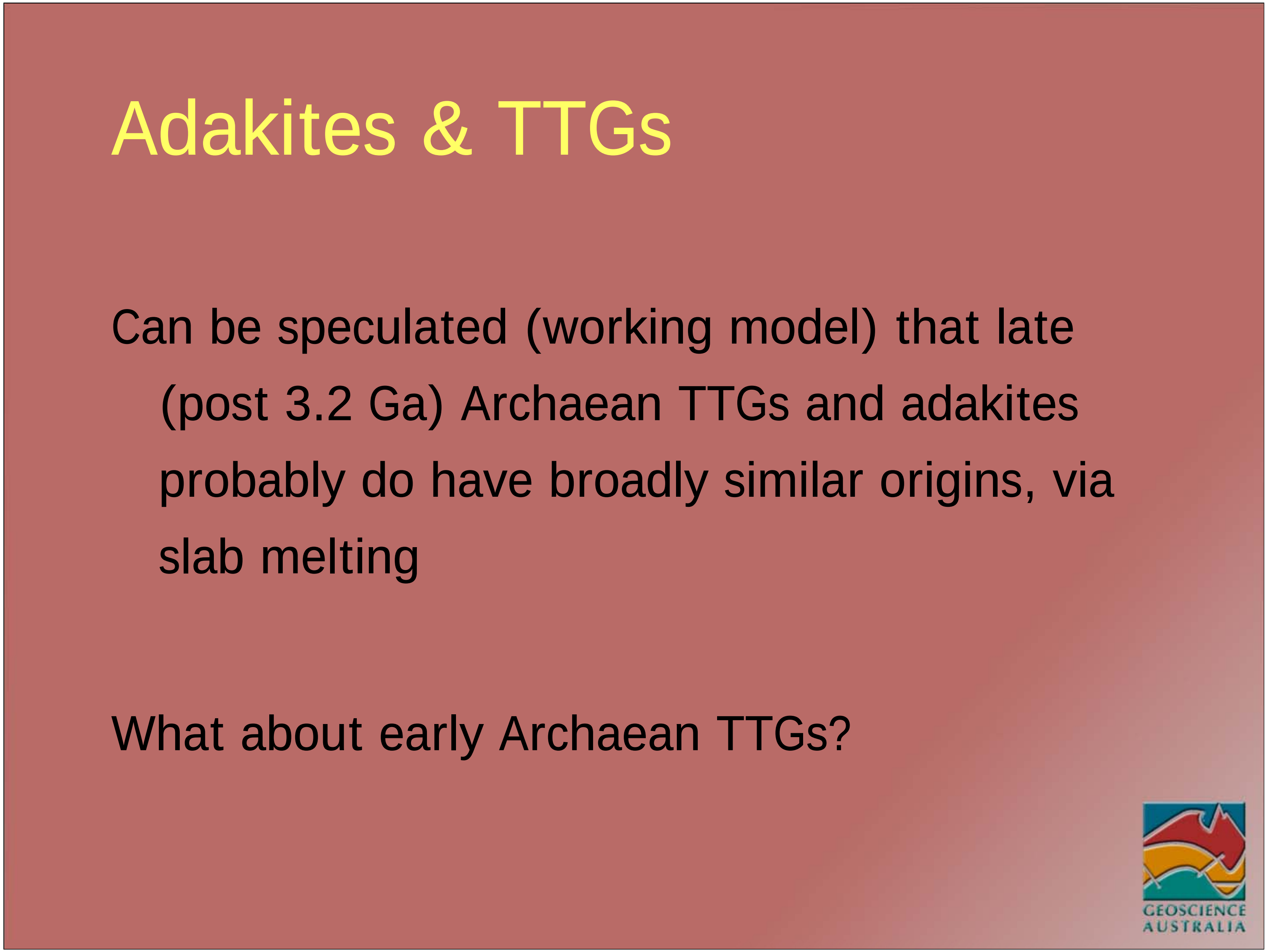


Smithies (2000)

Adakites & TTGs



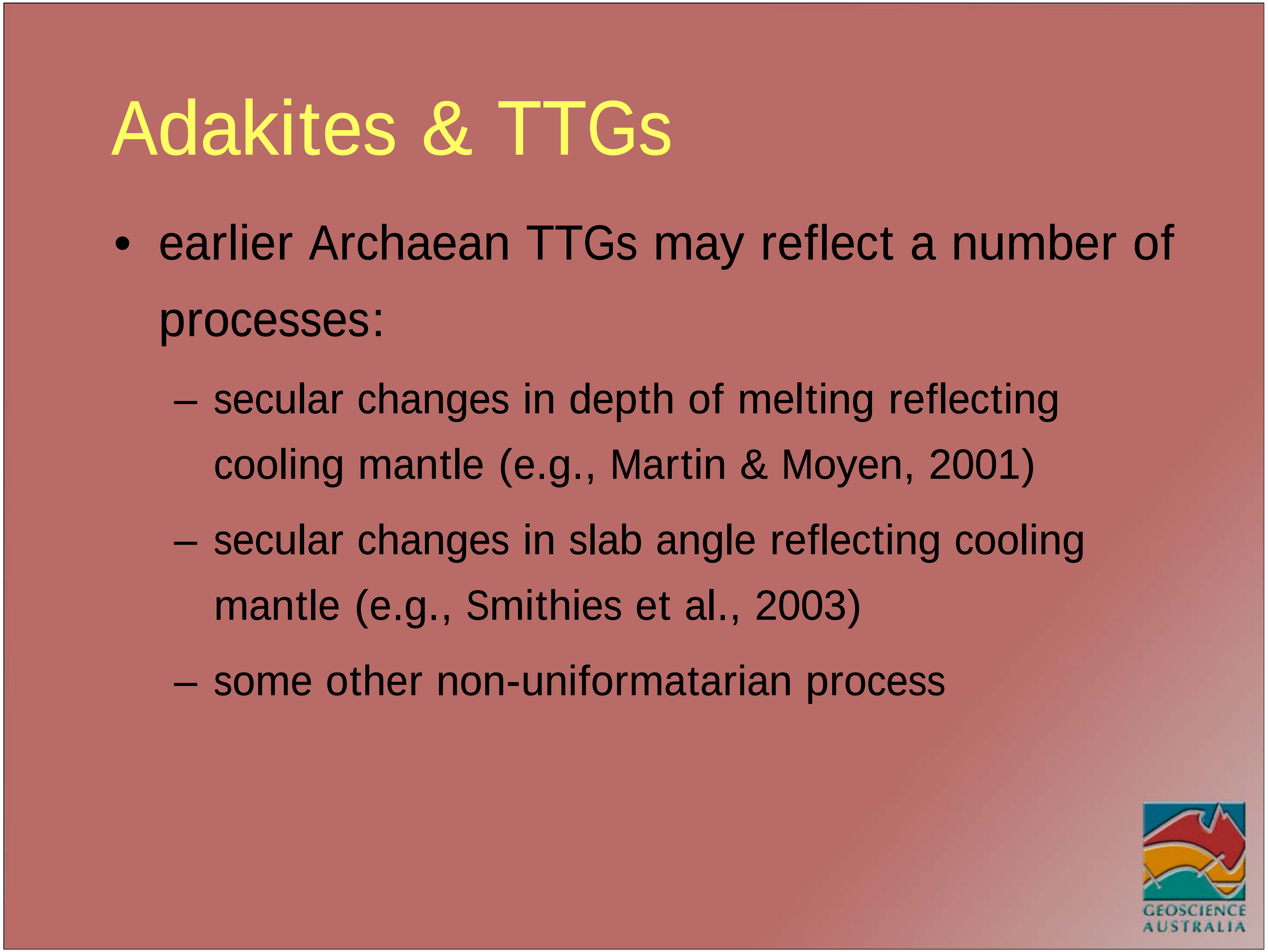
Data sources: Defant et al. (1992); Schiano et al. (1995); Kepezhinskas et al. (1996, 1997); Kay et al (1993); Futa & Stern (1988); Puig et al. (1984); Yogodzinski et al. (1994, 1995); Morris (1995); Sajona et al. (1993); Beate et al. (2001); Smith & Leeman (1987); Tatsumi & Ishizaka (1982); GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Feng & Kerrich (1992); Luais & Hawkesworth (1994); Nutman & Bridgewater (1986); Davis et al. (1994).



Adakites & TTGs

Can be speculated (working model) that late (post 3.2 Ga) Archaean TTGs and adakites probably do have broadly similar origins, via slab melting

What about early Archaean TTGs?

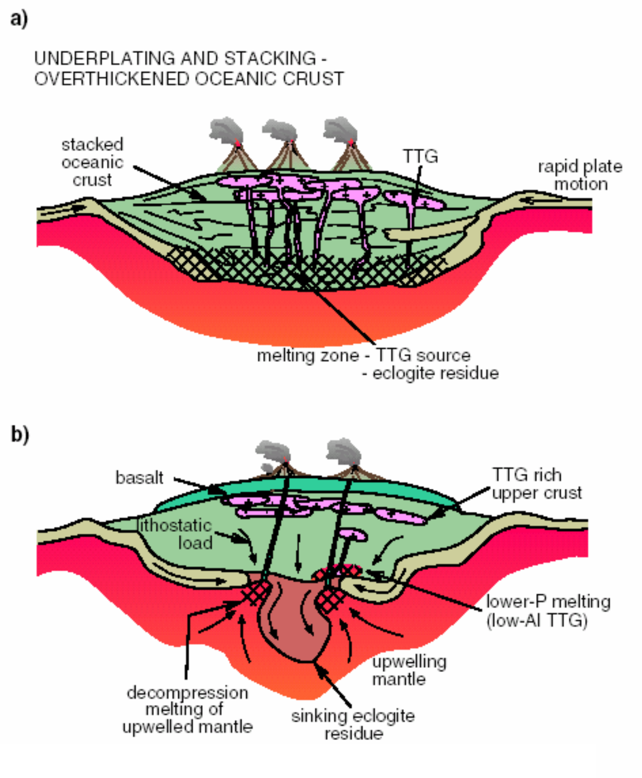


Adakites & TTGs

- earlier Archaean TTGs may reflect a number of processes:
  - secular changes in depth of melting reflecting cooling mantle (e.g., Martin & Moyen, 2001)
  - secular changes in slab angle reflecting cooling mantle (e.g., Smithies et al., 2003)
  - some other non-uniformatarian process

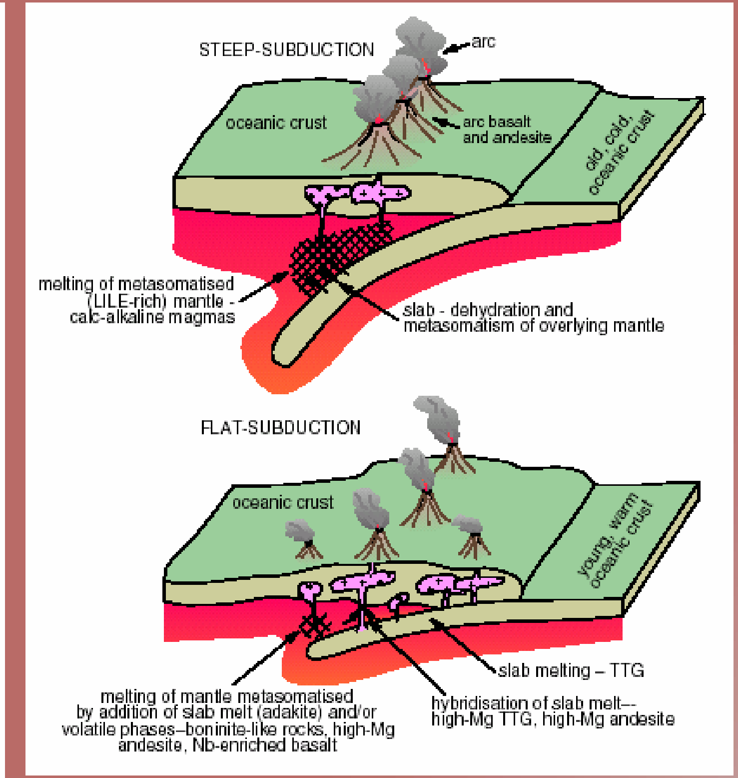
Secular changes

Early Archaean

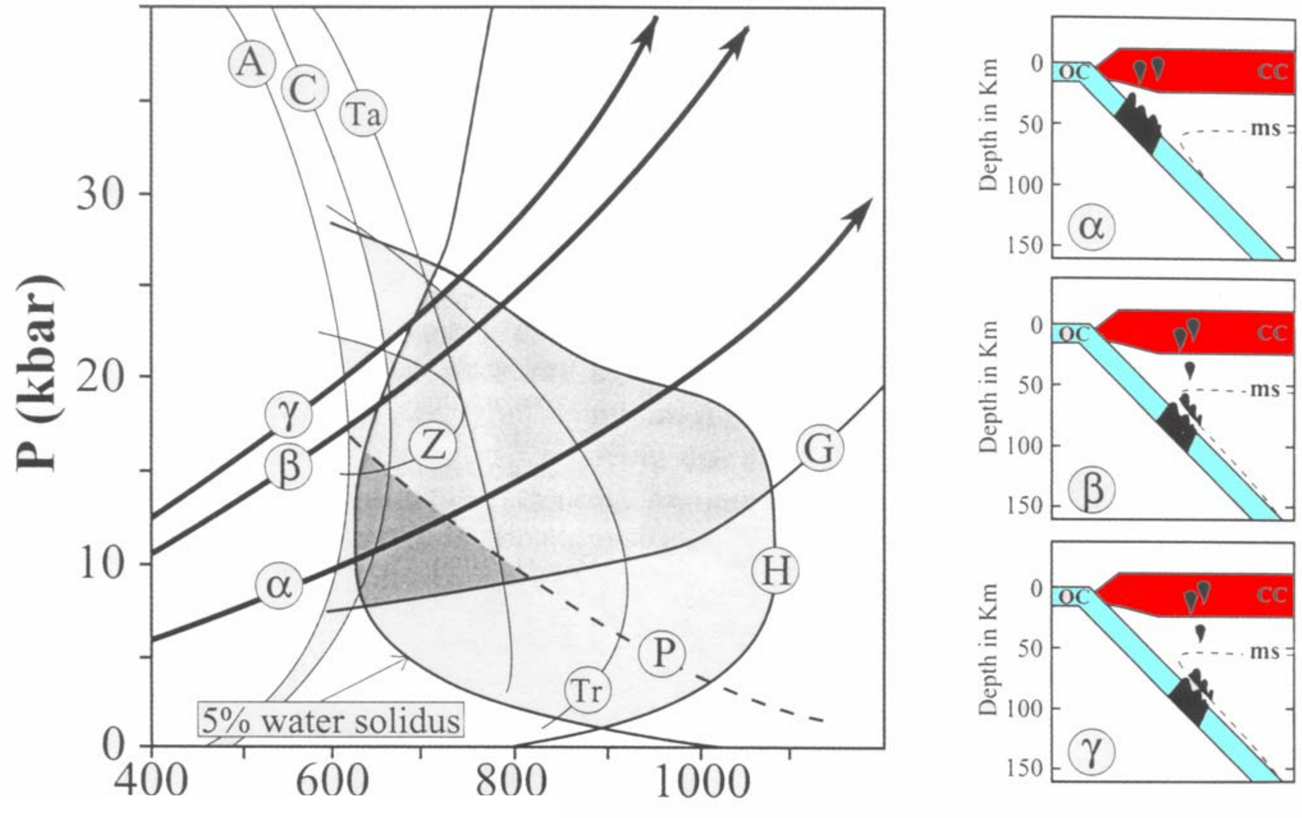


(Smithies et al., 2003)

Late Archaean



Secular changes



Early Archaean

Late Archaean

Present

(Martin & Moyen, 2002)

Transitional TTGs

Similar to TTGs in most respects, however,

- comprise trondhjemite, granodiorite, granite
- on average more silicic compositions (68-77%)
- have higher LILE contents, & LILEs (e.g. K_2O) show strong enrichment with silica

However, possess similar high-Al or Low-Al signature as in spatially associated TTGs

Often grouped with TTGs

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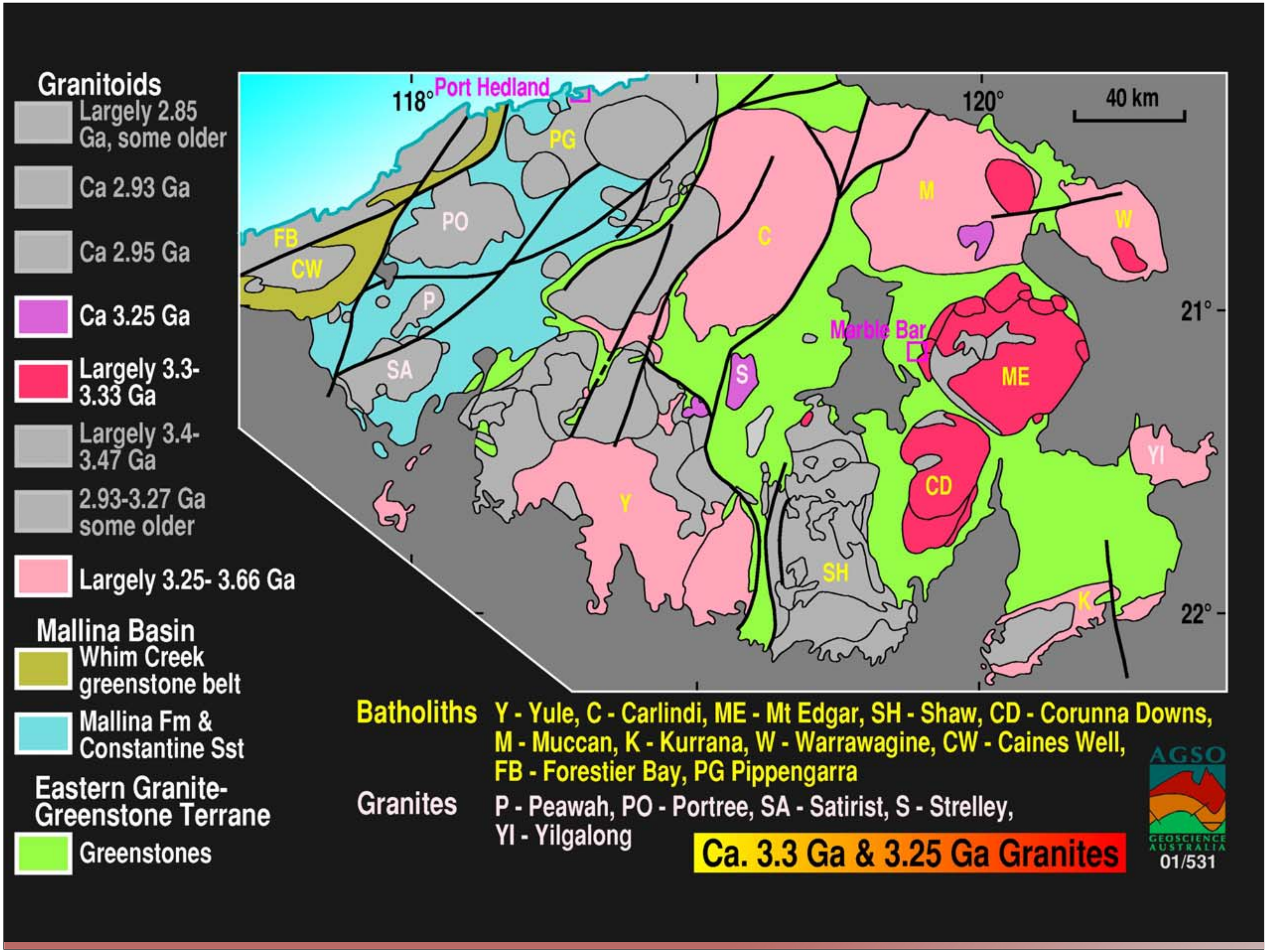


Ca. 3.3 Ga & 3.25 Ga Granites

Granitoids

- Largely 2.85 Ga, some older
- Ca 2.93 Ga
- Ca 2.95 Ga
- Ca 3.25 Ga
- Largely 3.3-3.33 Ga
- Largely 3.4-3.47 Ga
- 2.93-3.27 Ga some older
- Largely 3.25- 3.66 Ga

Mallina Basin

- Whim Creek greenstone belt
- Mallina Fm & Constantine Sst

Eastern Granite-Greenstone Terrane

- Greenstones

Batholiths Y - Yule, C - Carlindi, ME - Mt Edgar, SH - Shaw, CD - Corunna Downs, M - Muccan, K - Kurrana, W - Warrawagine, CW - Caines Well, FB - Forestier Bay, PG Pippengarra

Granites P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

HIGH-Ca GRANITES

🟩 **Greenstone**

Granite Group

🟥 **High-Ca**

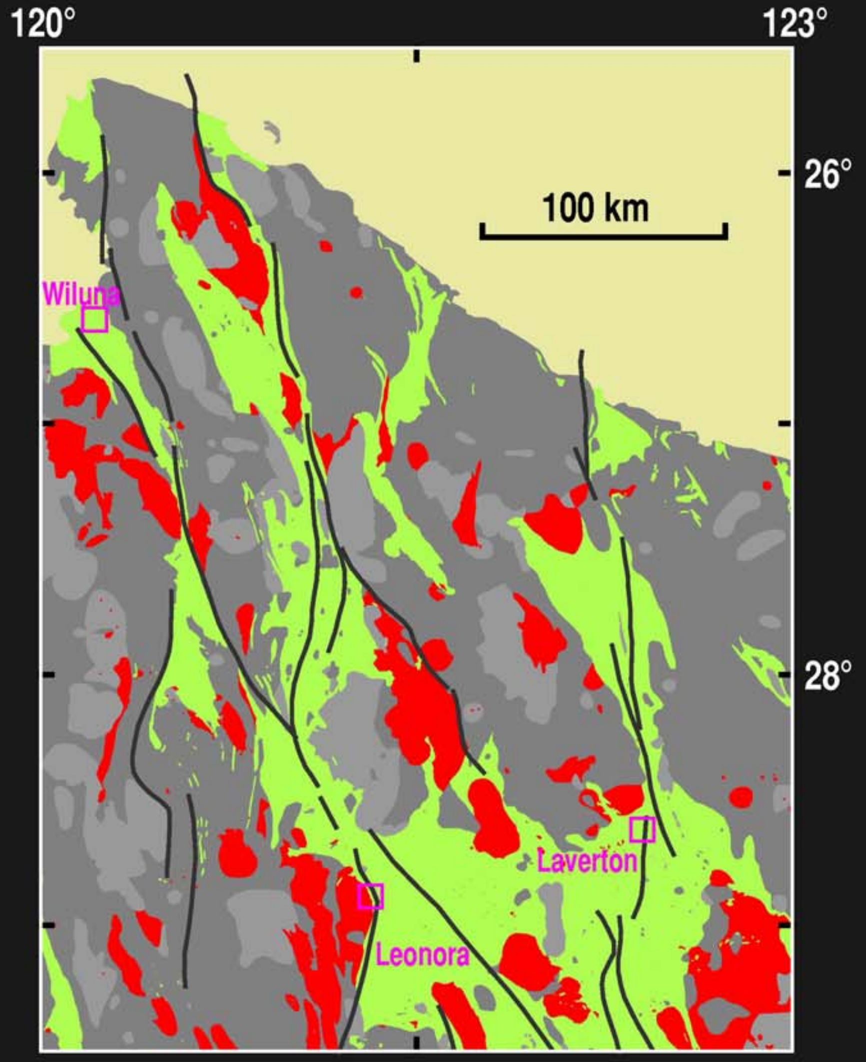
▨ Low-Ca

▨ High-HFSE

▨ Mafic

▨ Syenitic

▨ Unassigned



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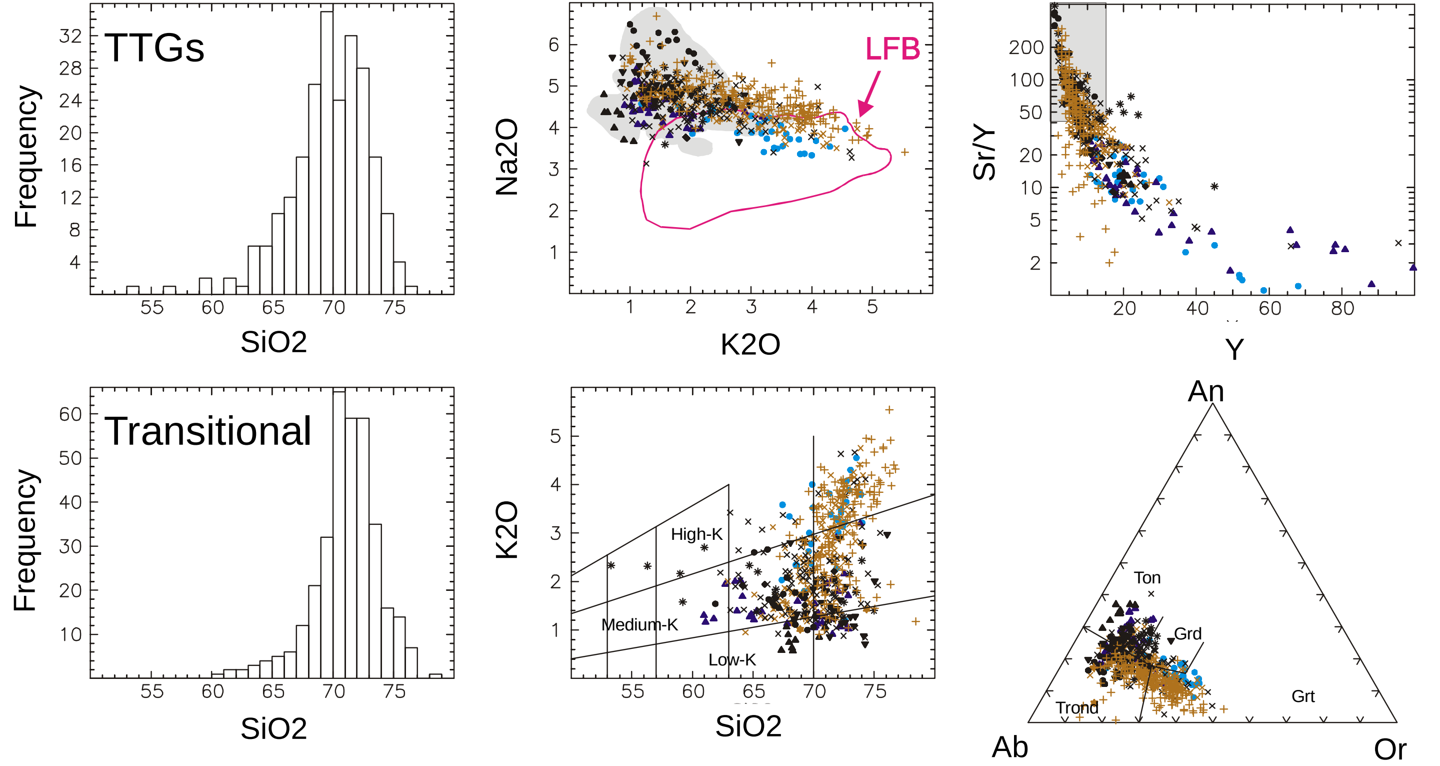
Transitional TTGs



TTGs (High-Al)

Transitional TTGs (High-Al)

TTGs (low-Al)

Trans TTGs (low-Al)

Data sources: GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Feng & Kerrich (1992); Luais & Hawkesworth (1994); Nutman & Bridgewater (1986); Davis et al. (1994); Brauhart & Morant (2000), Collins (1993), Davy (1988), McCulloch (1987)

Transitional TTGs

- May be contemporaneous with or postdate TTGs
- Often compositionally extend to more mafic end-members similar to TTGs
- Dominant granite-type in some cratons, e.g., Yilgarn, where high-Al transitional-TTGs comprise >60% of granites

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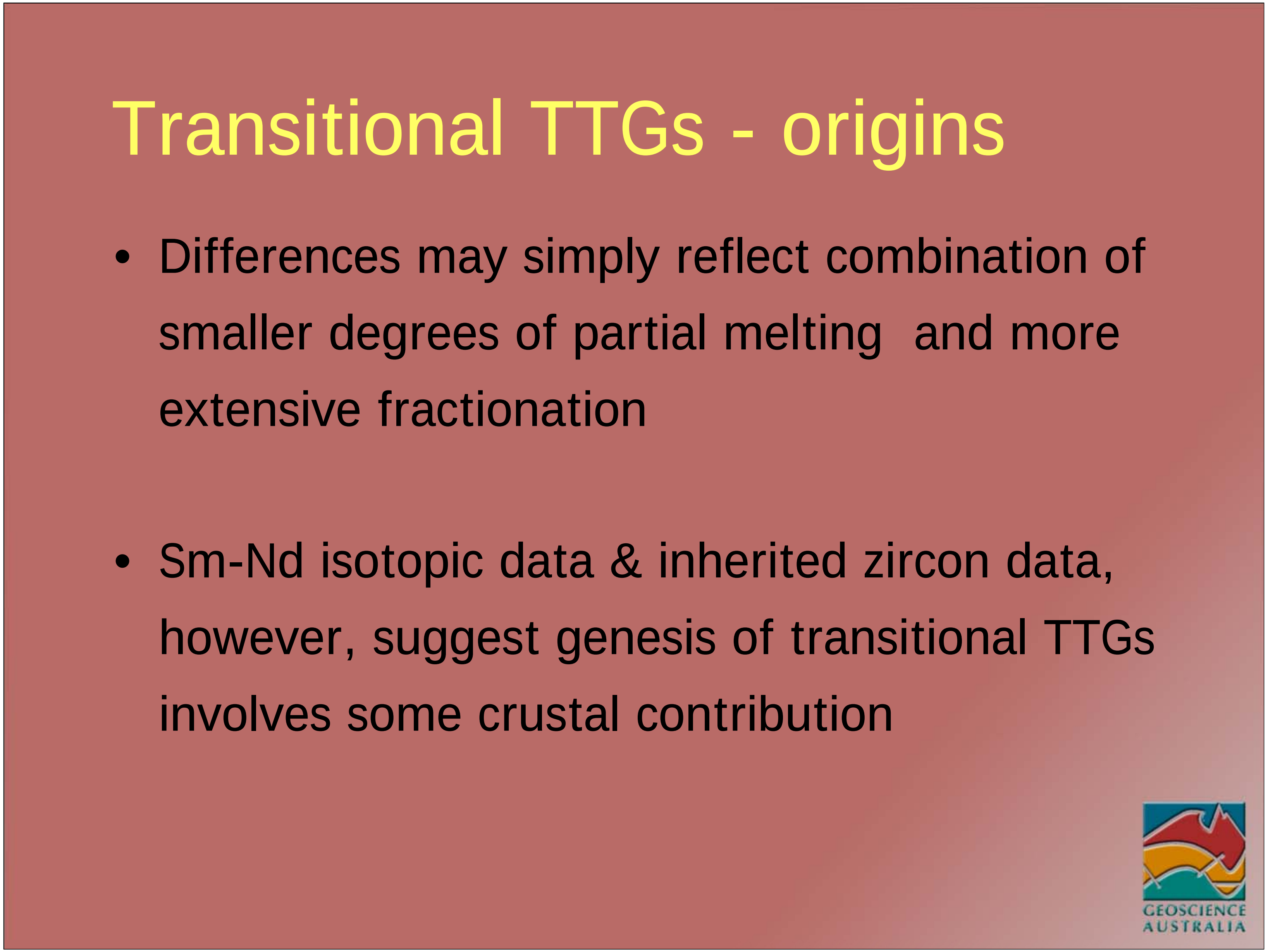
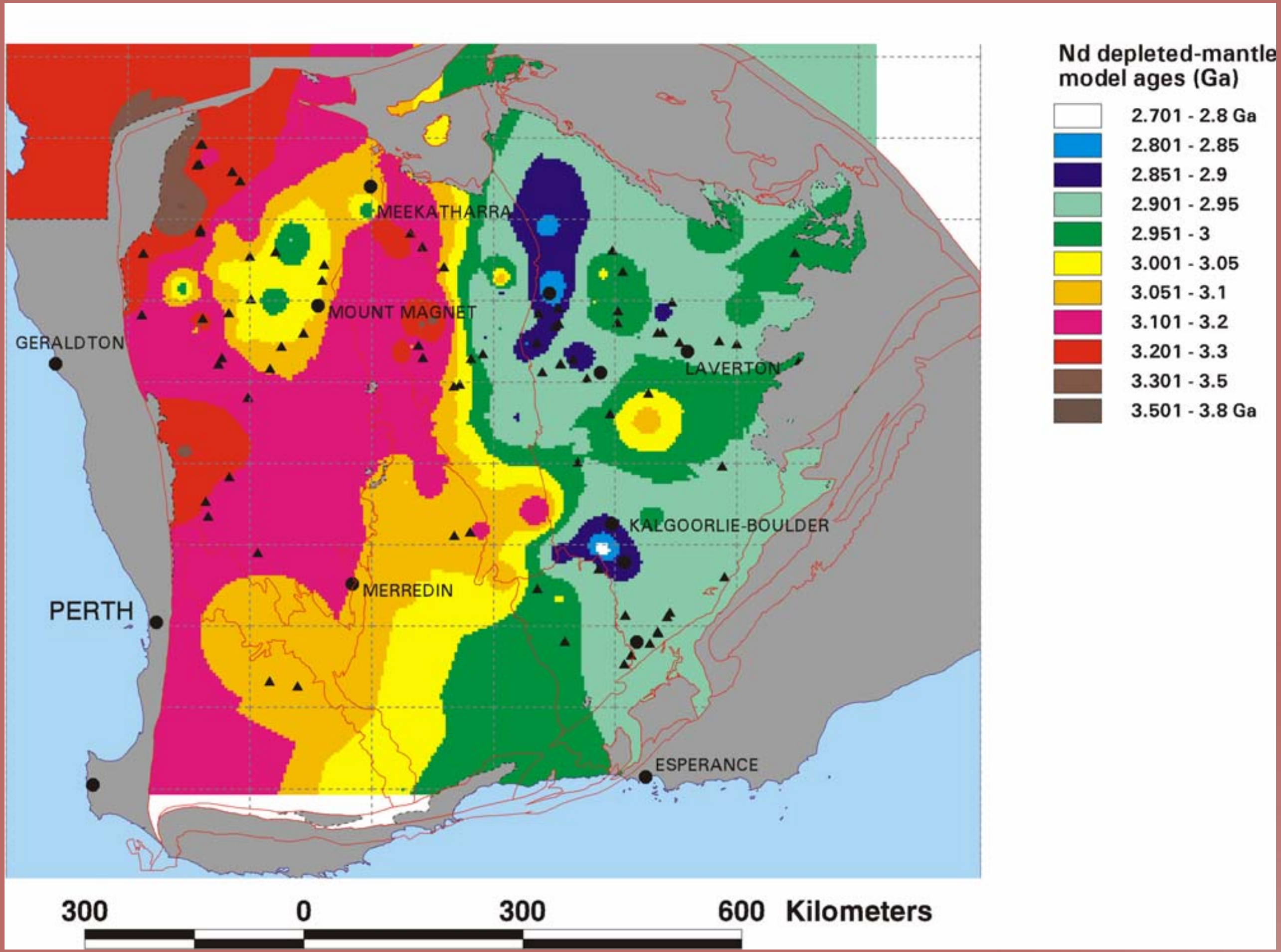


Transitional TTGs - origins

- Differences may simply reflect combination of smaller degrees of partial melting and more extensive fractionation

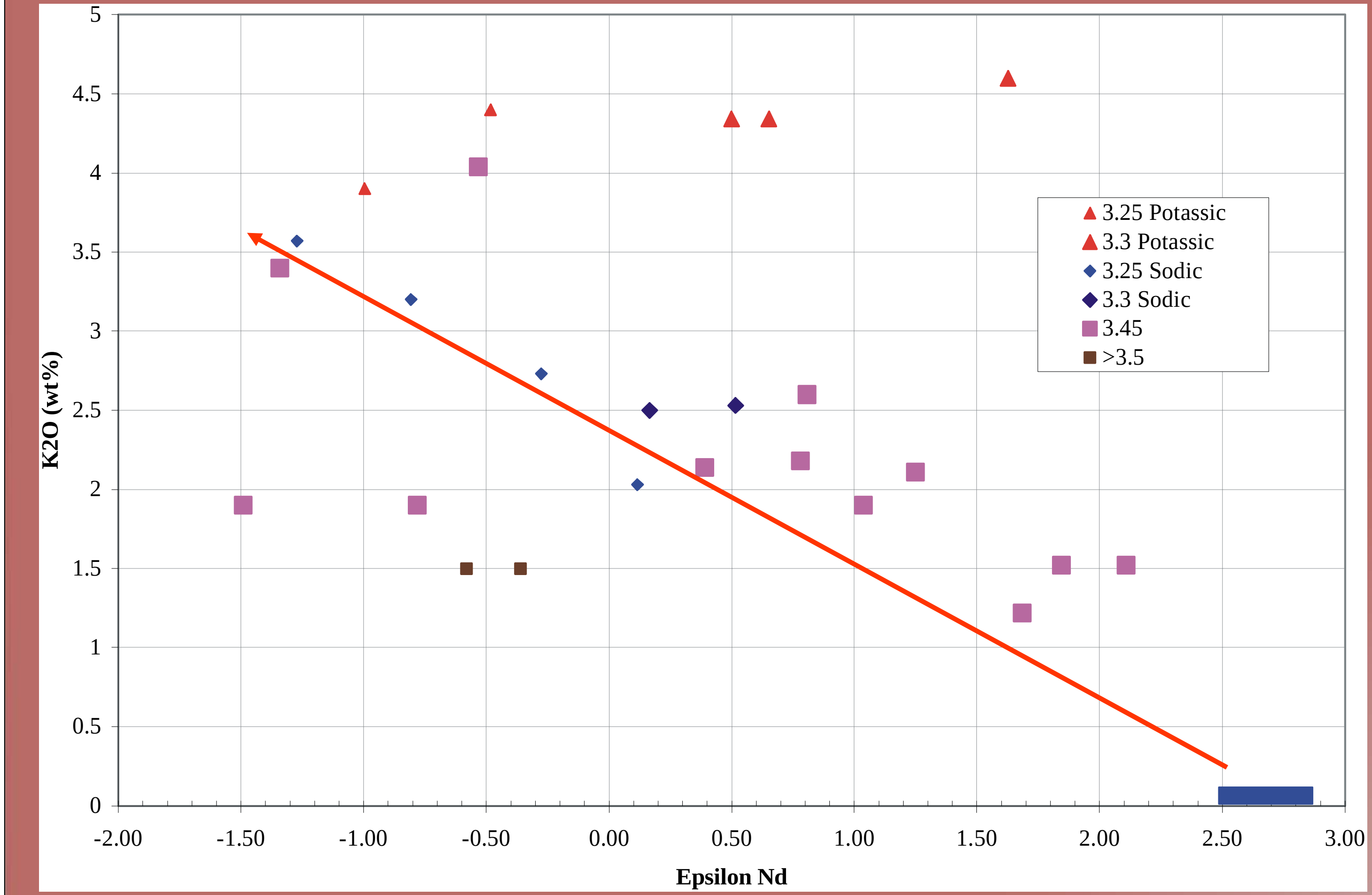
- Sm-Nd isotopic data & inherited zircon data, however, suggest genesis of transitional TTGs involves some crustal contribution

Transitional TTGs: Yilgarn Sm-Nd

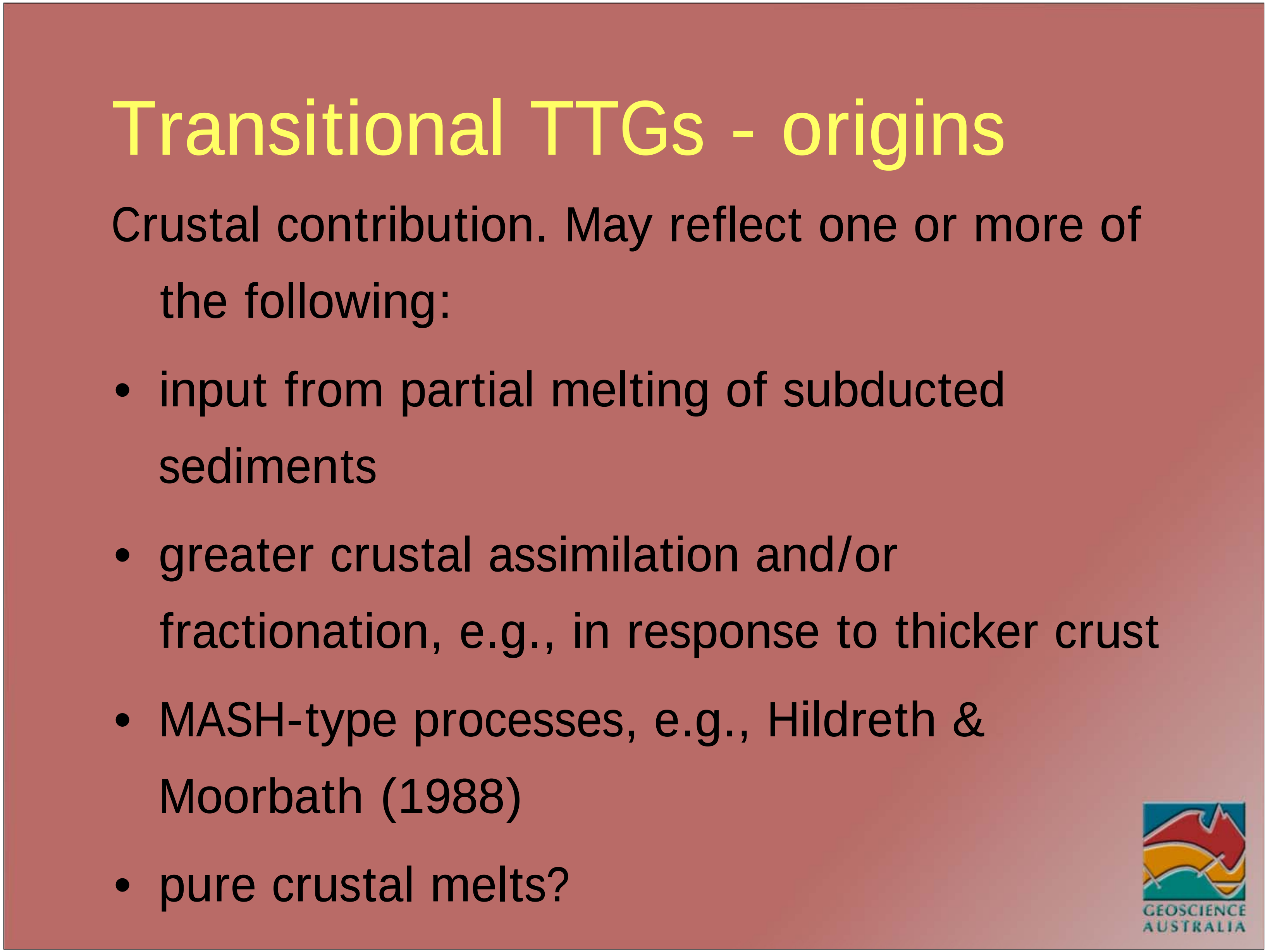


(Champion et al., in prep)

Transitional TTGs. Sm-Nd, Pilbara



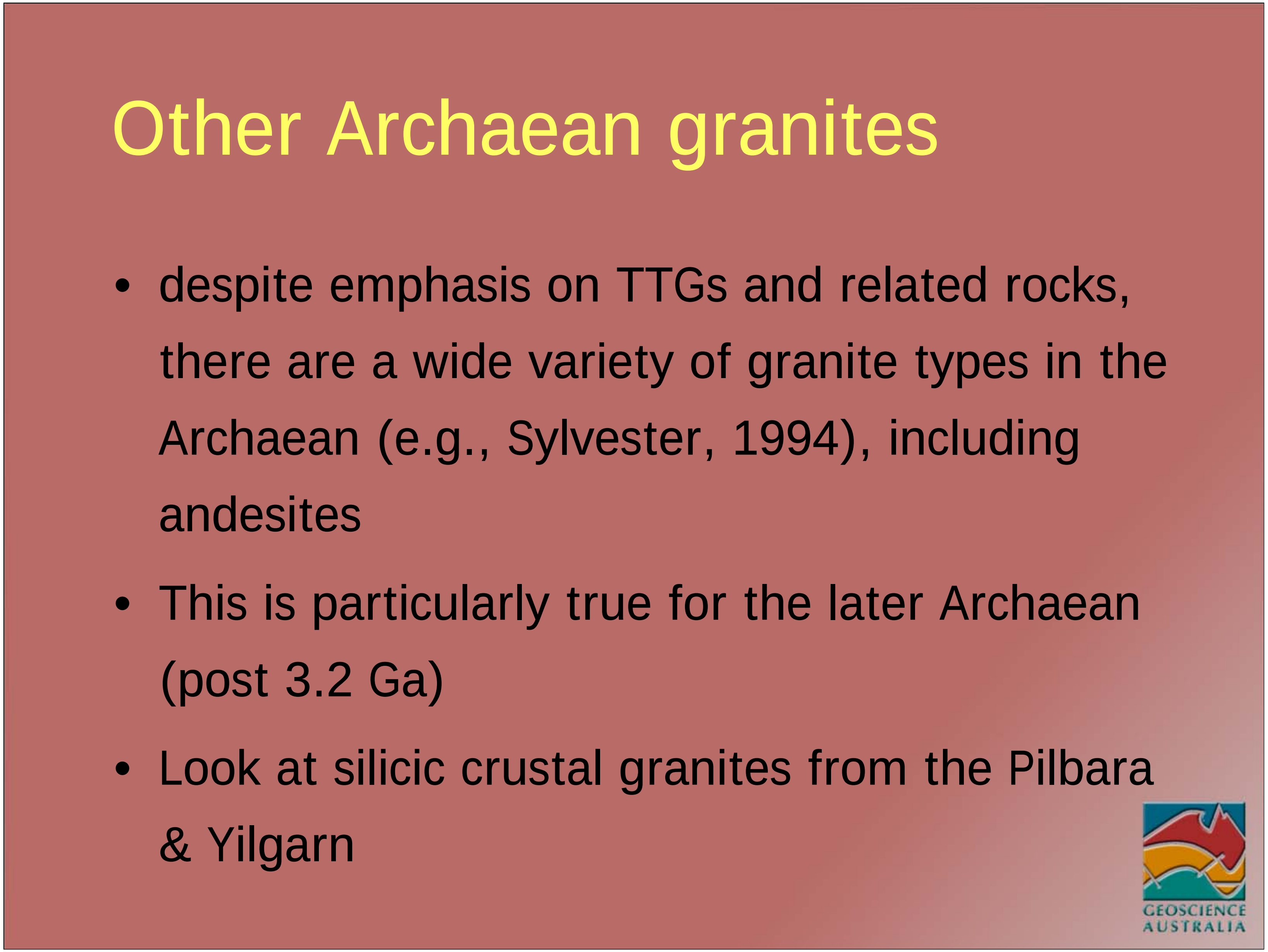
(Champion & Smithies., in prep)



Transitional TTGs - origins

Crustal contribution. May reflect one or more of the following:

- input from partial melting of subducted sediments
- greater crustal assimilation and/or fractionation, e.g., in response to thicker crust
- MASH-type processes, e.g., Hildreth & Moorbath (1988)
- pure crustal melts?



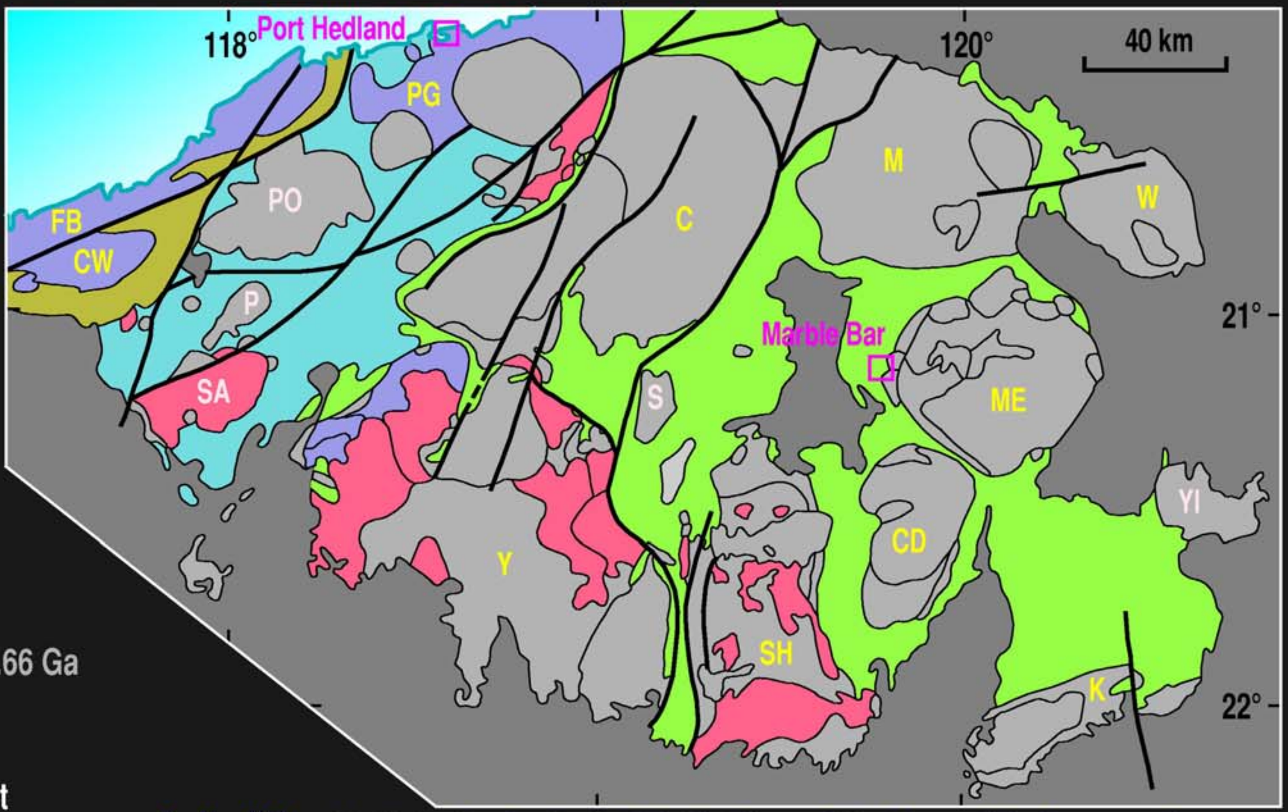
Other Archaean granites

- despite emphasis on TTGs and related rocks, there are a wide variety of granite types in the Archaean (e.g., Sylvester, 1994), including andesites
- This is particularly true for the later Archaean (post 3.2 Ga)
- Look at silicic crustal granites from the Pilbara & Yilgarn

Granitoids
- ⬜ Largely 2.85 Ga, some older
- 🟥 Ca 2.93 Ga
- ⬜ Ca 2.95 Ga
- ⬜ Ca 3.25 Ga
- ⬜ Largely 3.3-3.33 Ga
- ⬜ Largely 3.4-3.47 Ga
- 🟪 2.93-3.27 Ga some older
- ⬜ Largely 3.25- 3.66 Ga

Mallina Basin
- 🟨 Whim Creek greenstone belt
- 🟦 Mallina Fm & Constantine Sst

Eastern Granite-Greenstone Terrane
- 🟩 Greenstones



Batholiths Y - Yule, C - Carlindi, ME - Mt Edgar, SH - Shaw, CD - Corunna Downs, M - Muccan, K - Kurrana, W - Warrawagine, CW - Caines Well, FB - Forestier Bay, PG Pippengarra

Granites P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

Ca. 2.93 Ga Granites

01/534

Granitoids

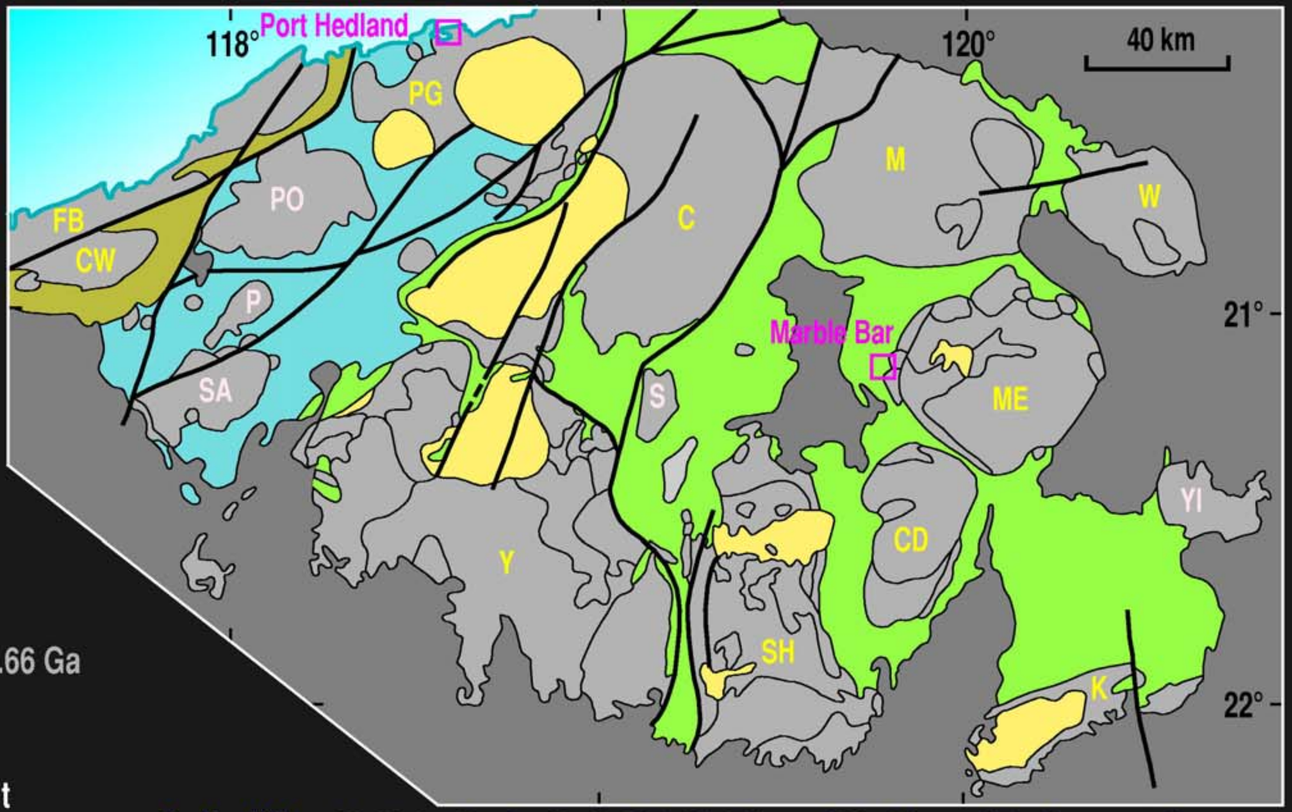
- 🟨 Largely 2.85 Ga, some older
- ⬜ Ca 2.93 Ga
- ⬜ Ca 2.95 Ga
- ⬜ Ca 3.25 Ga
- ⬜ Largely 3.3-3.33 Ga
- ⬜ Largely 3.4-3.47 Ga
- ⬜ 2.93-3.27 Ga some older
- ⬜ Largely 3.25- 3.66 Ga

Mallina Basin

- 🟫 Whim Creek greenstone belt
- 🟦 Mallina Fm & Constantine Sst

Eastern Granite-Greenstone Terrane

- 🟩 Greenstones



Batholiths Y - Yule, C - Carlindi, ME - Mt Edgar, SH - Shaw, CD - Corunna Downs, M - Muccan, K - Kurrana, W - Warrawagine, CW - Caines Well, FB - Forestier Bay, PG Pippengarra

Granites P - Peawah, PO - Portree, SA - Satirist, S - Strelley, YI - Yilgalong

Ca. 2.85 Ga Granites

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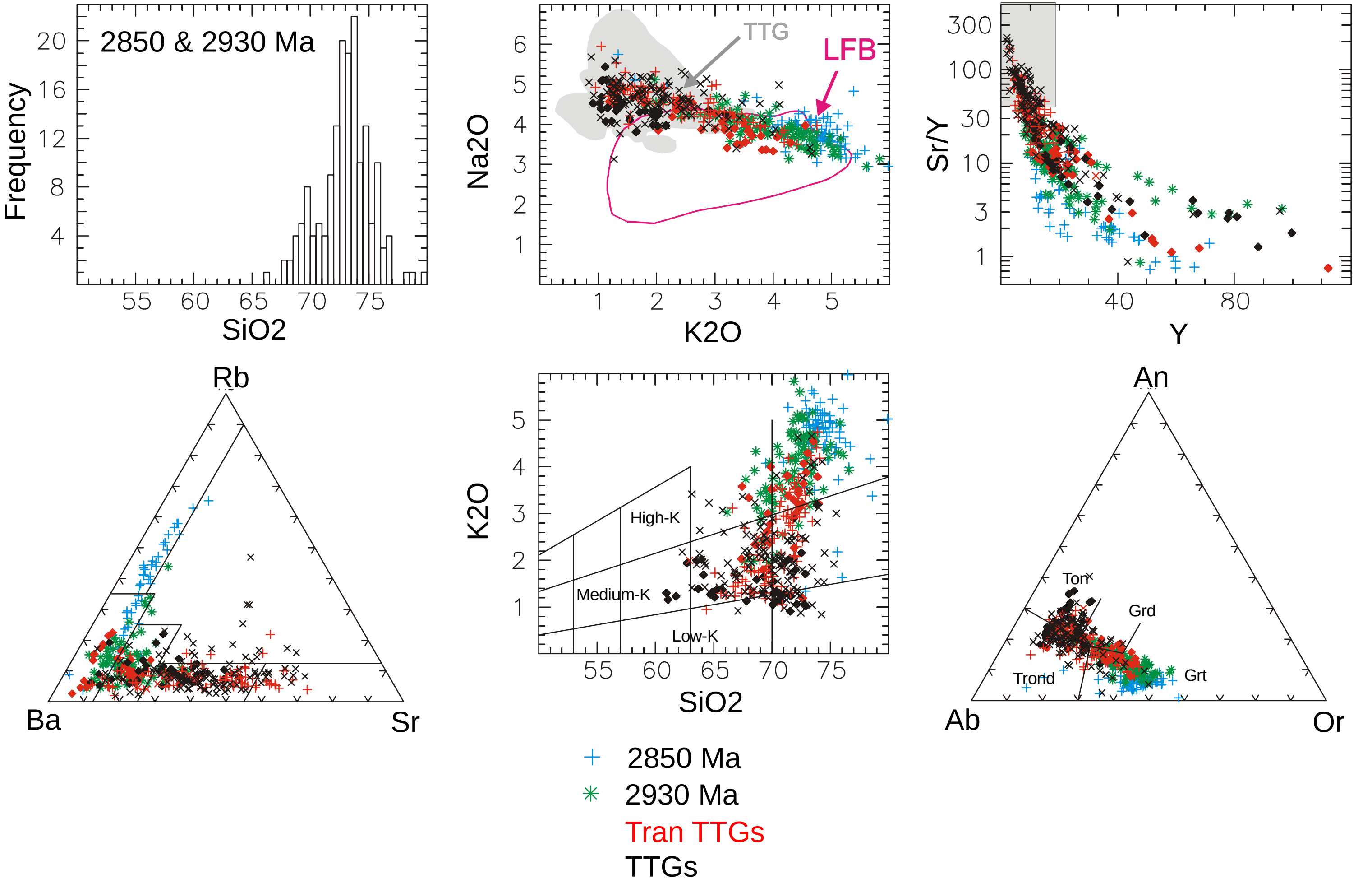
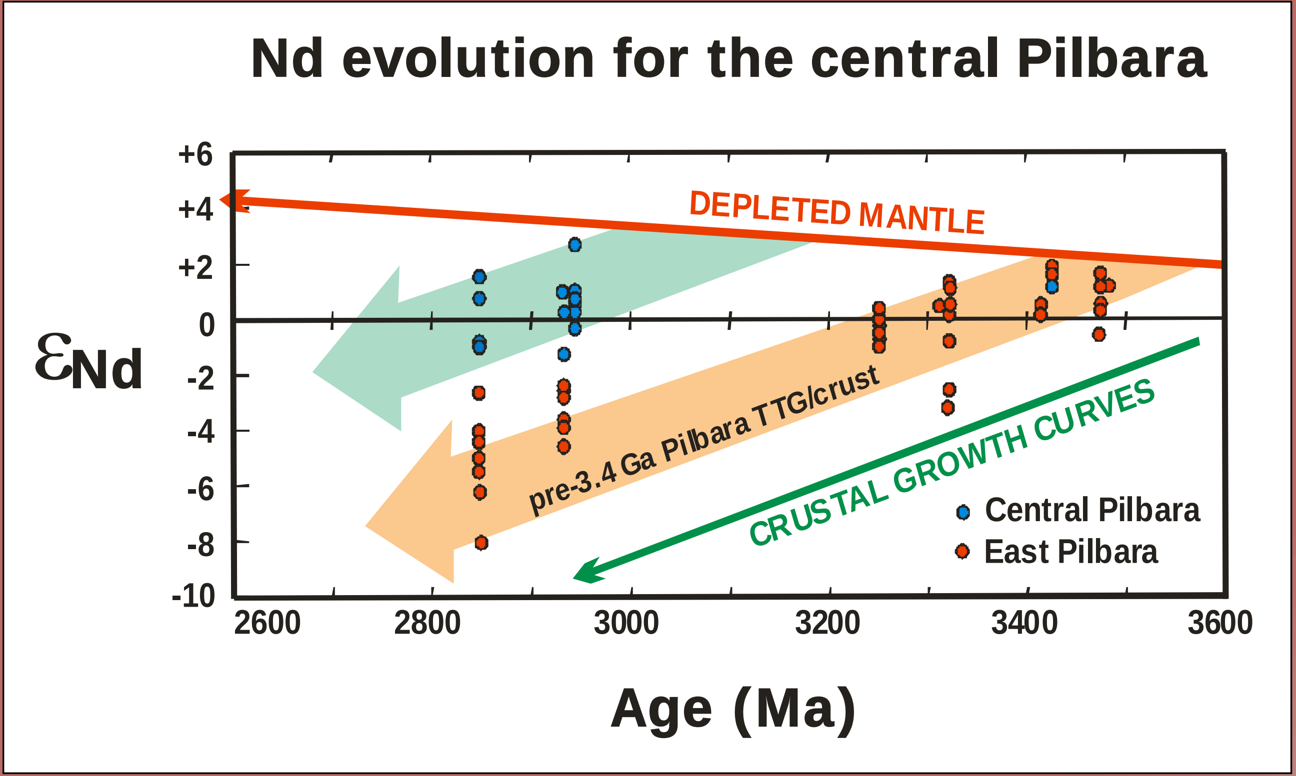
Pilbara Craton



Data sources: GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Brauhart & Morant (2000), Collins (1993), Davy (1988), McCulloch (1987)

Pilbara Craton



Data sources: GA_GSWA unpublished data; Bickle et al. (1983, 1989, 1993); Brauhart & Morant (2000), Collins (1993), Davy (1988), McCulloch (1987)

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East Yilgarn Craton

LOW-Ca GRANITES

🟩 Greenstone

Granite Group

▨ High-Ca

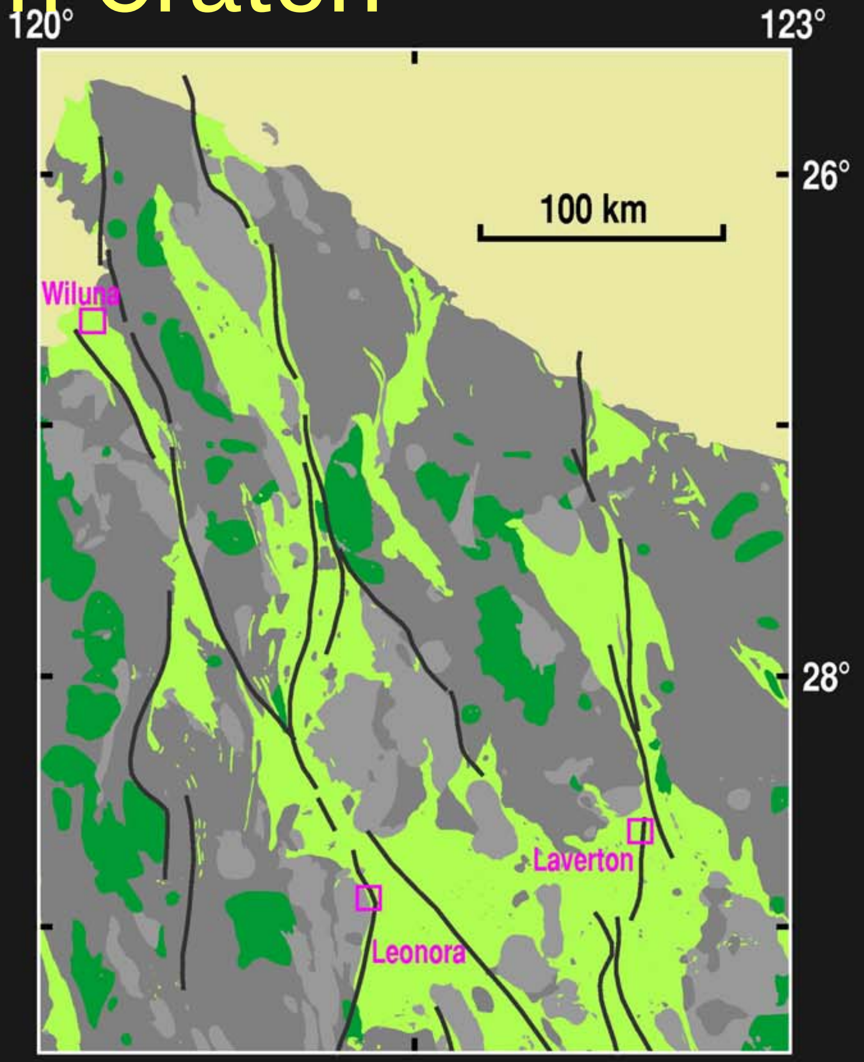
🟩 Low-Ca

▨ High-HFSE

▨ Mafic

▨ Syenitic

▨ Unassigned



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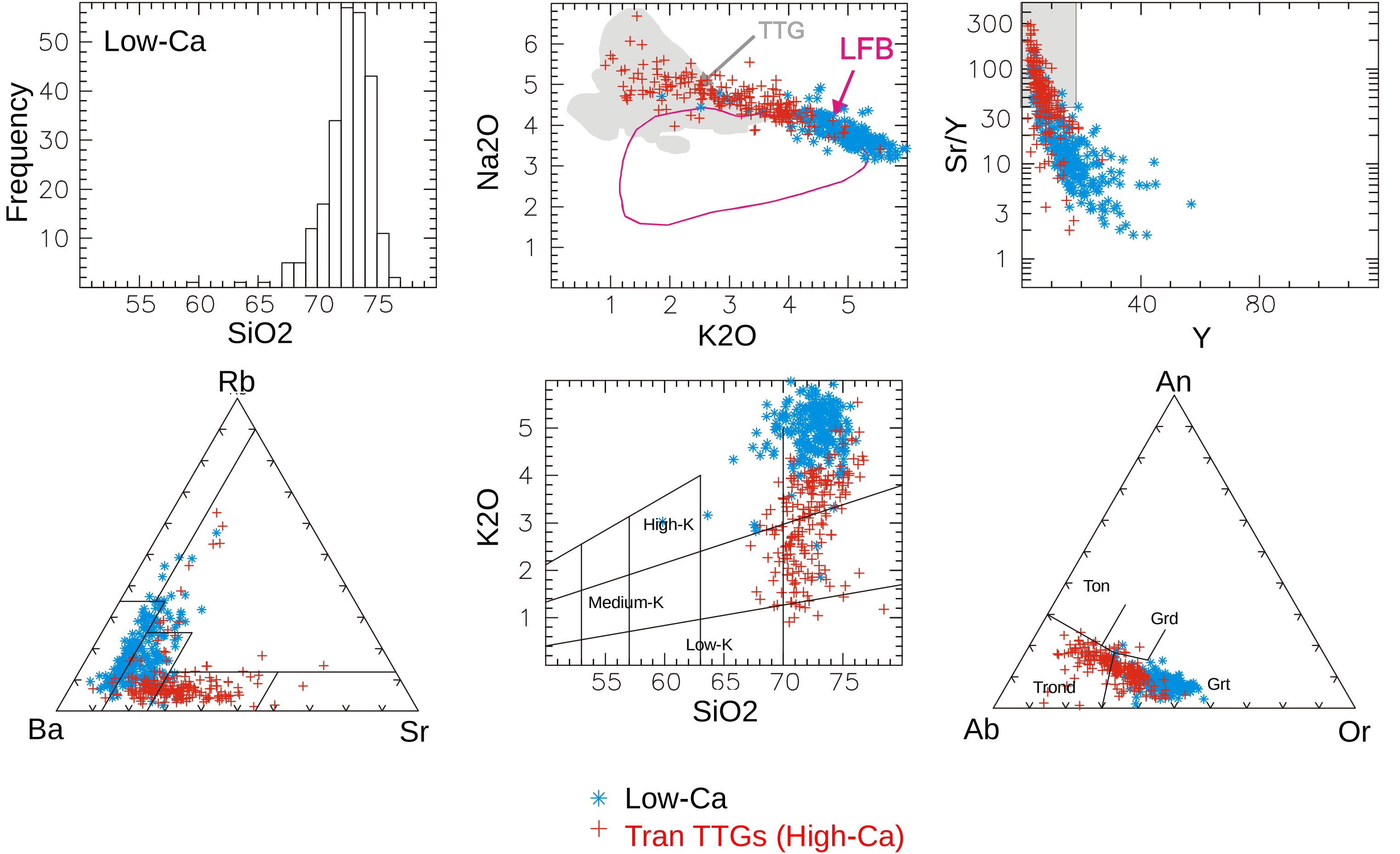
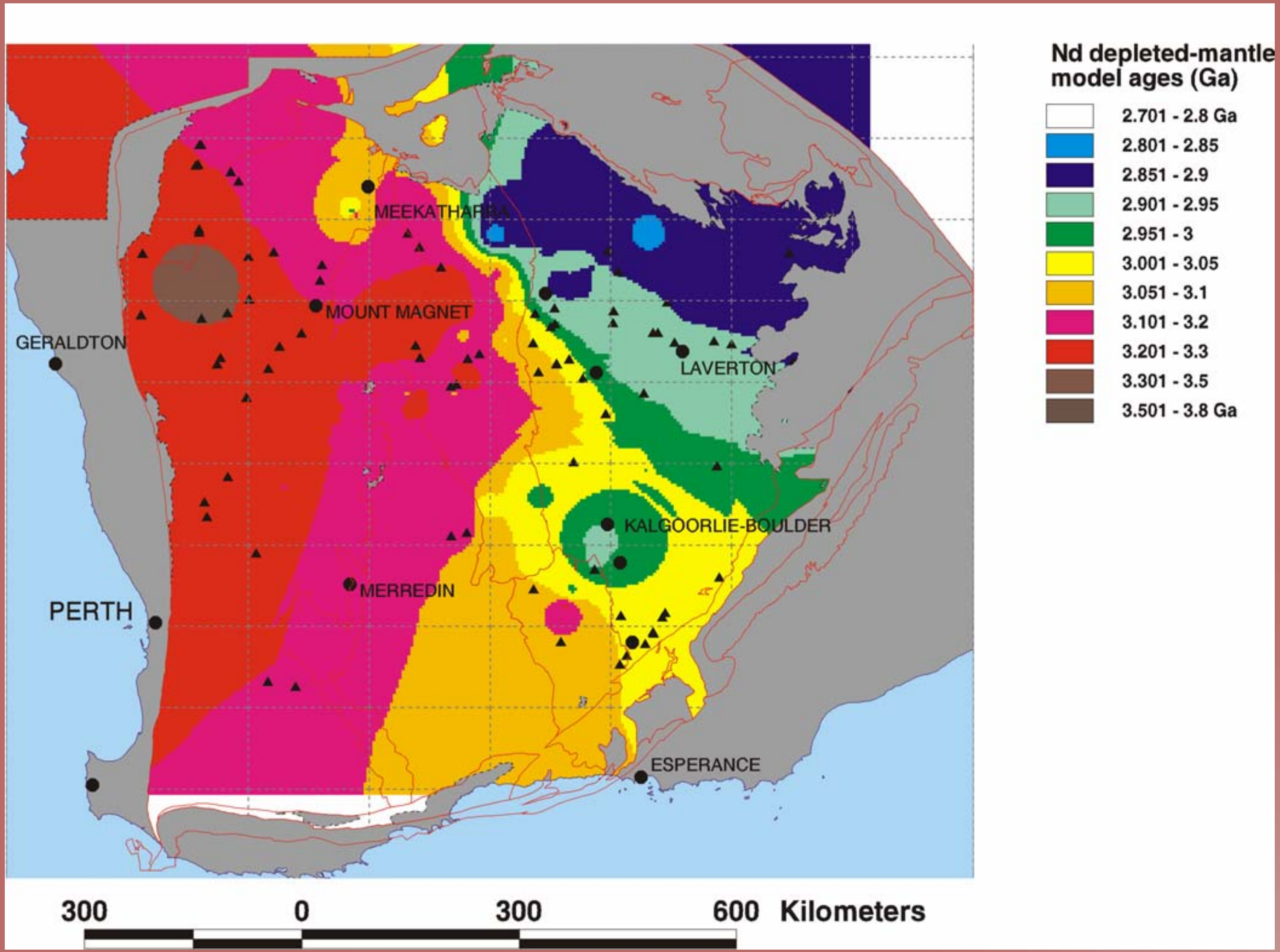
East Yilgarn Craton



Data sources: GA unpublished data

East Yilgarn Craton



(Champion et al., in prep)

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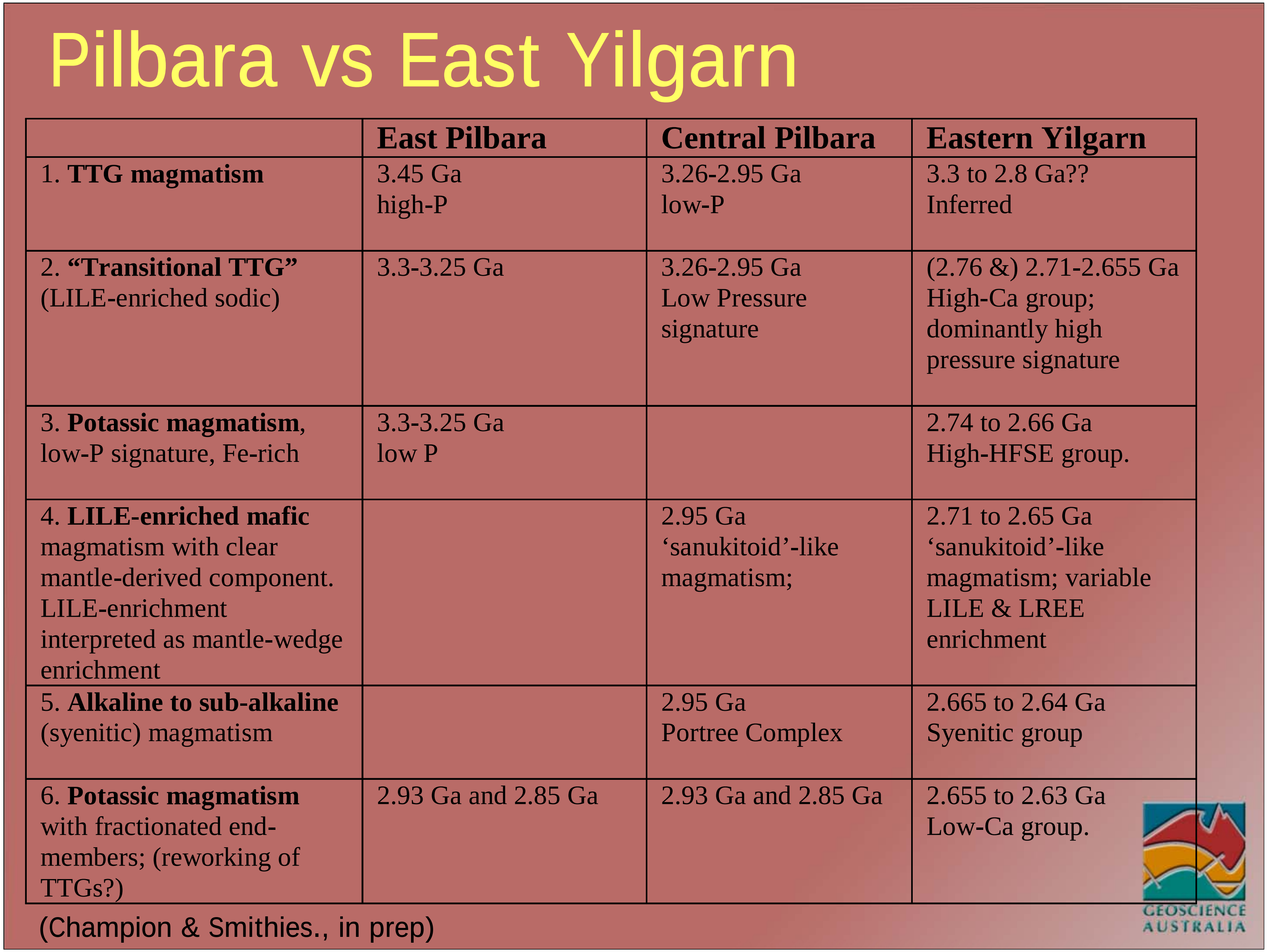
Late potassic granites

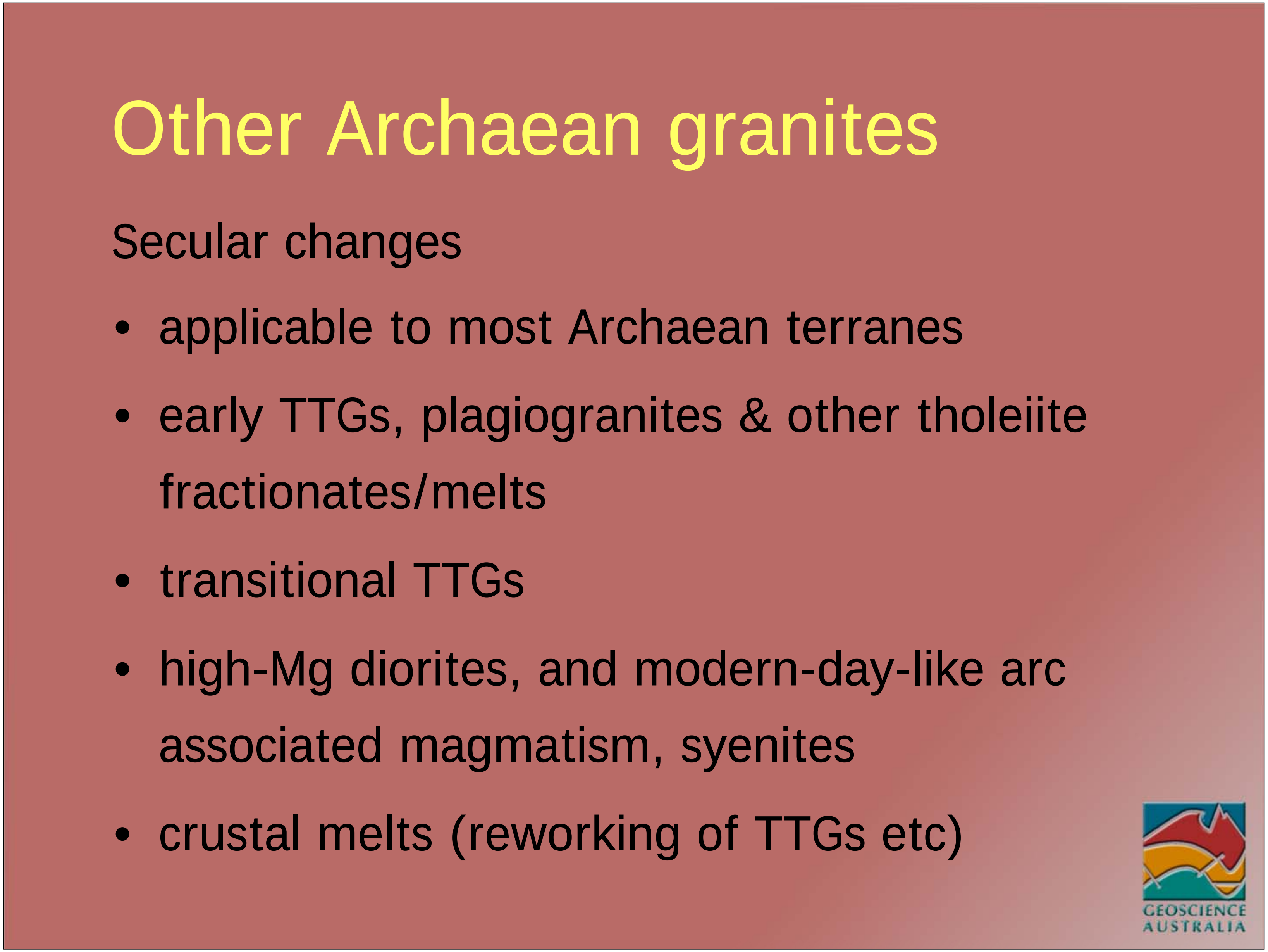
- Geochemistry and isotopes clearly suggest a dominant crustal component
- Sources probably similar to Archaean TTGs
- Reflect a response to crustal reworking, of an increasingly felsic crust, in the late Archaean (post 3.0 Ga)



Pilbara vs East Yilgarn

	East Pilbara	**Central Pilbara**	**Eastern Yilgarn**
1. **TTG magmatism**	3.45 Ga high-P	3.26-2.95 Ga low-P	3.3 to 2.8 Ga?? Inferred
2. **“Transitional TTG”** (LILE-enriched sodic)	3.3-3.25 Ga	3.26-2.95 Ga Low Pressure signature	(2.76 &) 2.71-2.655 Ga High-Ca group; dominantly high pressure signature
3. **Potassic magmatism**, low-P signature, Fe-rich	3.3-3.25 Ga low P		2.74 to 2.66 Ga High-HFSE group.
4. **LILE-enriched mafic** magmatism with clear mantle-derived component. LILE-enrichment interpreted as mantle-wedge enrichment		2.95 Ga ‘sanukitoid’-like magmatism;	2.71 to 2.65 Ga ‘sanukitoid’-like magmatism; variable LILE & LREE enrichment
5. **Alkaline to sub-alkaline** (syenitic) magmatism		2.95 Ga Portree Complex	2.665 to 2.64 Ga Syenitic group
6. **Potassic magmatism** with fractionated end-members; (reworking of TTGs?)	2.93 Ga and 2.85 Ga	2.93 Ga and 2.85 Ga	2.655 to 2.63 Ga Low-Ca group.

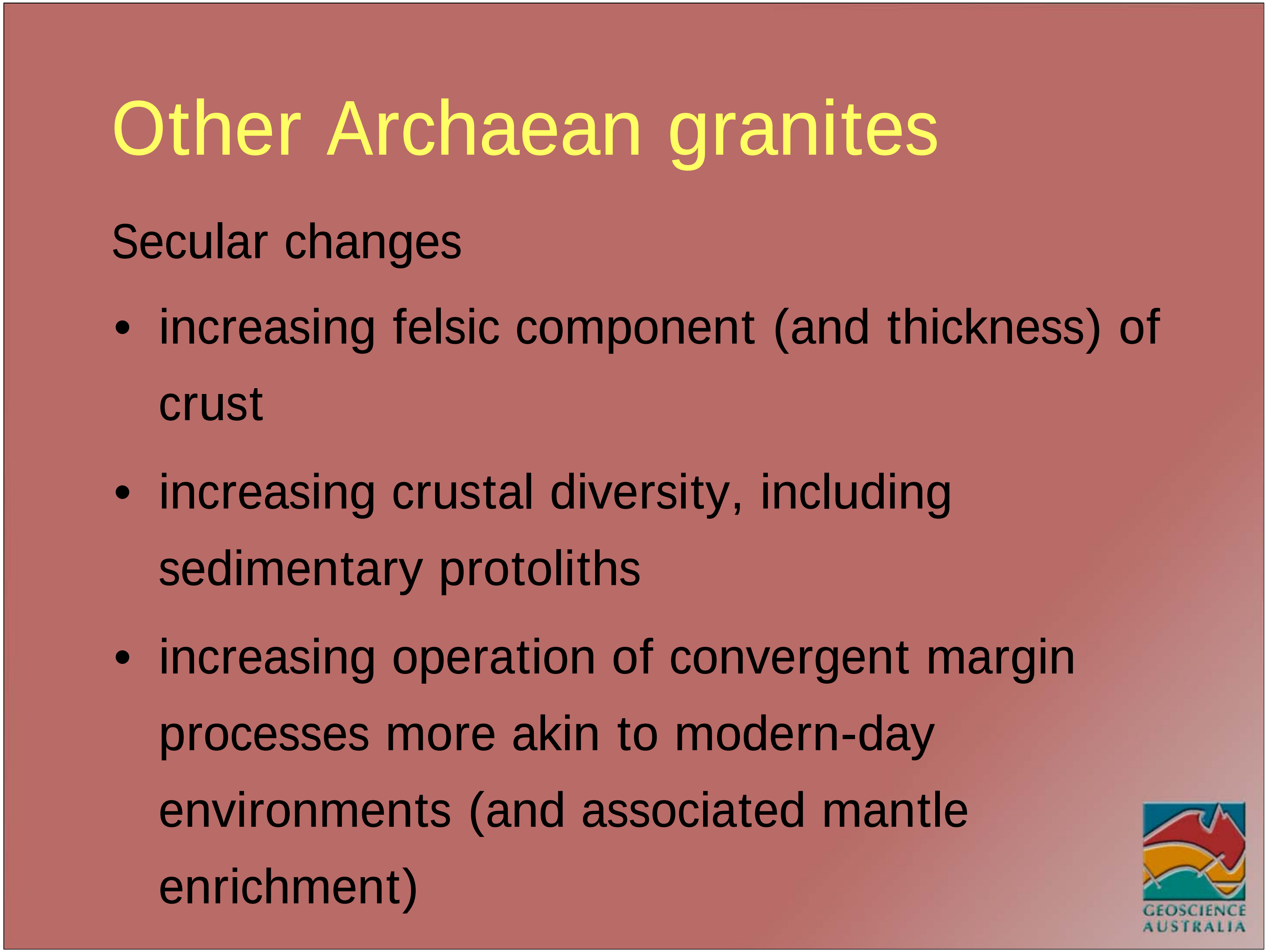
(Champion & Smithies., in prep)



Other Archaean granites

Secular changes

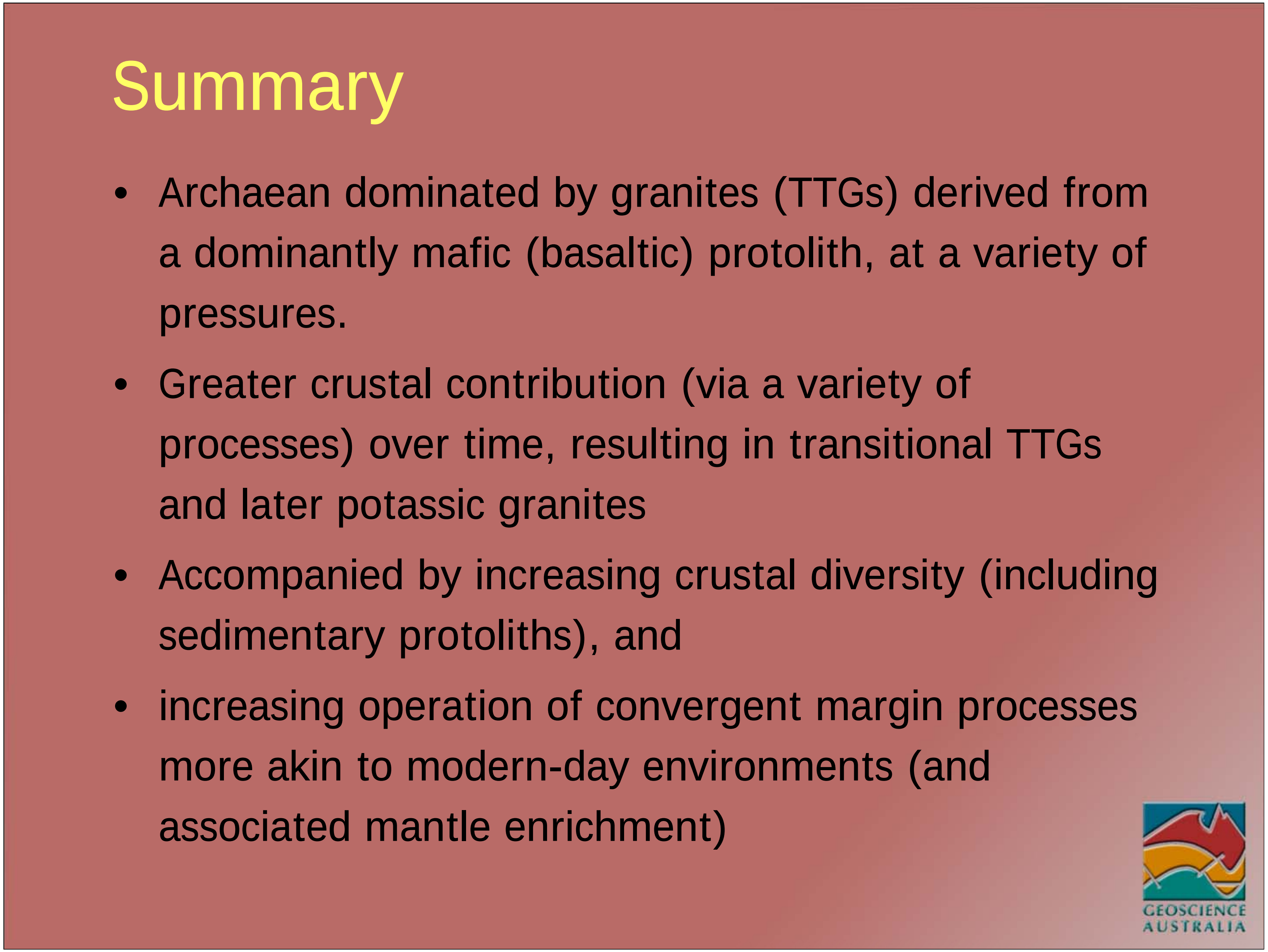
- applicable to most Archaean terranes
- early TTGs, plagiogranites & other tholeiite fractionates/melts
- transitional TTGs
- high-Mg diorites, and modern-day-like arc associated magmatism, syenites
- crustal melts (reworking of TTGs etc)



Other Archaean granites

Secular changes

- increasing felsic component (and thickness) of crust
- increasing crustal diversity, including sedimentary protoliths
- increasing operation of convergent margin processes more akin to modern-day environments (and associated mantle enrichment)



Summary

- Archaean dominated by granites (TTGs) derived from a dominantly mafic (basaltic) protolith, at a variety of pressures.
- Greater crustal contribution (via a variety of processes) over time, resulting in transitional TTGs and later potassic granites
- Accompanied by increasing crustal diversity (including sedimentary protoliths), and
- increasing operation of convergent margin processes more akin to modern-day environments (and associated mantle enrichment)