

## GRANITES OF THE SOUTHERN NEW ENGLAND OROGEN

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The New England Orogen (NEO) is easternmost and youngest portion of the Australian continent, generated as a consequence of Devonian to Triassic subduction-related activity. In the southern NEO this subduction-related volcanic and sedimentary assemblage is intruded by Late Carboniferous–Triassic I-, S- and more rarely A-type granites of the New England Batholith (NEB).

### S-type Granites

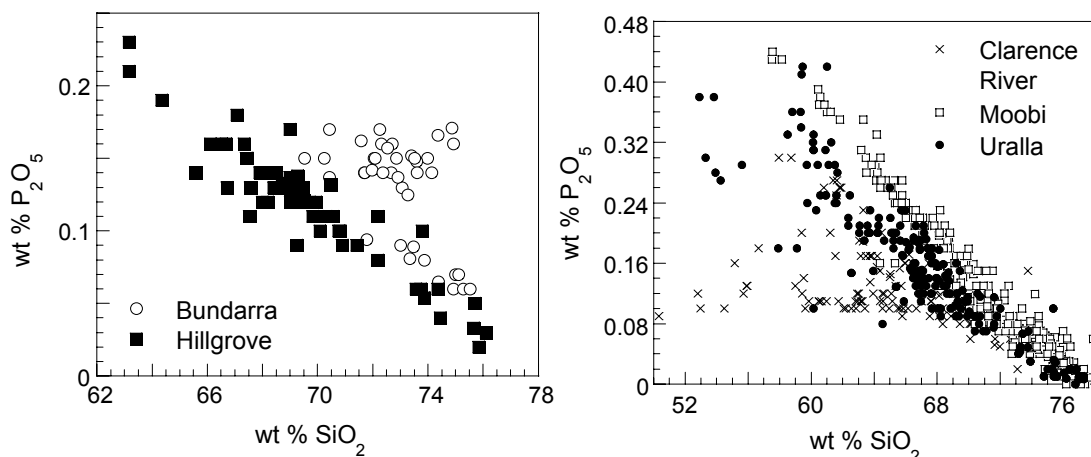
Two temporally and geochemically distinct phases of S-type plutonism are recorded at ~303 Ma (Hillgrove Supersuite) and ~280 Ma (Bundarra Supersuite).

### Hillgrove Supersuite

Granites of the Hillgrove Supersuite are commonly intensely foliated. Although they have low CaO, Na<sub>2</sub>O and Sr, and are strongly reduced (locally contain graphite), other typical S-type characteristics are poorly developed; (i) they are not particularly peraluminous; ferromagnesian minerals include dominant aluminous russet red biotite, and minor almandine-rich garnet, actinolitic amphibole and cummingtonite, (ii) are comparatively mafic and compositionally diverse (65-75 wt % SiO<sub>2</sub>), (iii) P<sub>2</sub>O<sub>5</sub> is negatively correlated with SiO<sub>2</sub>, as for I-type granites, (iv) isotopically relatively primitive for S-type granites (<sup>87</sup>Sr/<sup>86</sup>Sr = 0.705-0.706<sup>1</sup>). Granites of the Hillgrove Supersuite are interpreted to have been derived from young volcano-sedimentary materials<sup>2</sup>. The granites record subtle regional variation in sediment chemistry.

### Bundarra Supersuite

The Bundarra Supersuite is almost universally coarse-grained and generally porphyritic, containing large K-feldspar crystals. Although distinct groupings have been identified<sup>3</sup>, these granites are chemically very coherent. They are strongly reduced (white K-feldspar; ilmenite; δ<sup>18</sup>O > 12‰<sup>4</sup>), and are more classically S-type than those of the Hillgrove Supersuite, being more felsic (typically >71 wt % SiO<sub>2</sub>), having higher Al<sub>2</sub>O<sub>3</sub> and P<sub>2</sub>O<sub>5</sub>, and containing characteristic alumina-rich minerals (cordierite>muscovite>Fe-rich garnet). The greater peraluminosity of Bundarra granites is consistent with higher degrees of weathering of the sedimentary source materials. However, comparably low <sup>87</sup>Sr/<sup>86</sup>Sr ratios indicate rapid reworking of juvenile crustal source components. Subtle, yet significant differences in Th, U, LREE, and Na<sub>2</sub>O, indicate that the sediments involved in the genesis of the Bundarra and Hillgrove supersuites were derived from chemically distinct crustal protoliths.



**Figure 1:**  $P_2O_5$  Harker diagrams for NEB S-type (Bundarra and Hillgrove supersuites) and I-type granites (Clarence River, Moonbi and Uralla).

### NEB I-type granites

I-type granites in the NEB are primarily Late Permian–Early Triassic<sup>2</sup> in age. Three major supersuites are recognized.

### Moonbi Supersuite

The Moonbi Supersuite (MSS) consists of strongly oxidised, high-K hornblende-biotite ( $\pm$ augite) granites that are characterised by abundant pink K-feldspar megacrysts, titanite and magnetite. Overall, Moonbi granites have high  $K_2O$ , Rb, Sr, Ba, Th, U,  $P_2O_5$  and Pb. Nevertheless, geographically significant geochemical variations exist; southern MSS granites have distinctly higher  $K_2O$ , Rb, Sr, Ba etc, are more mafic and have lower Y and HREE than the northern MSS intrusions. The latter are dominated by more highly fractionated leucogranites.

Moonbi granites have geochemical similarities with those of the Sierra Nevada batholith and show distinct chemical overlaps with Carboniferous LFB granites<sup>5</sup>. Southern MSS granites are possibly derived partial melting of a garnet-bearing shoshonitic crustal source<sup>3</sup>.

### Uralla Supersuite

The Uralla Supersuite is compositionally diverse (47–77 wt %  $SiO_2$ ), consisting of speckled black and white, and typically equigranular granites. Although some overlap exists, they generally have lower  $K_2O$ ,  $P_2O_5$ , Rb, Th, U, light REE (LREE) and Ba and higher Y and HREE than the neighbouring southern MSS intrusions, being more equivalent to the northern MSS in this regard. Although classified as I-type, the Uralla granites have many characteristics that are transitional between NEB S- and I-type granites (*c.f.*, ilmenite-series granites of *Ishihara*<sup>6</sup>), including lower redox states (lower  $Fe_2O_3/FeO$ ;  $\delta^{18}O$  typically  $> 9^4$ ), lower normative diopside, higher initial  $^{87}Sr/^{86}Sr$  ratios ( $\sim 0.7046$ – $0.707$ )<sup>2</sup> and lower  $\delta^7Li$ <sup>7</sup>, indicating the involvement both infracrustal and sedimentary source components. The supersuite can be subdivided into a number of distinct spatially associated geochemical groups.

### Clarence River Supersuite

The Clarence River Supersuite consists of calcic and sodic, predominantly dioritic, tonalitic and granodiorite intrusive rocks that are characterized by variable but generally low

abundances of K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, Rb, Ba, Nb, Pb, Th, U, LREE, and Sr. They are isotopically juvenile, typically having <sup>87</sup>Sr/<sup>86</sup>Sr<sub>initial</sub> of 0.7032 to 0.7038 and commonly having ε<sub>Nd</sub> of >+4<sup>8</sup>, and δ<sup>7</sup>Li of +8 to +2.2‰<sup>7</sup>. They are geochemically and isotopically equivalent to intraoceanic arc lavas. The Clarence River Supersuite is very similar to the Cordilleran granites of the western Peninsular Ranges Batholith, and are likely to have formed either as a direct product of arc magmatism or by partial melting of juvenile arc-derived materials<sup>8</sup>.

### “Coastal” granites

The granites within the most eastern portion of the NEB incorporate a heterogeneous assortment of I- and more rarely A-type granites. Although distinct geochemical differences are evident, I-type granites from this region share similarities with those of the Clarence River Supersuite, typically having higher Na<sub>2</sub>O, relatively low K<sub>2</sub>O, Rb, Th, U, and Pb, and more juvenile isotopic signatures. These features suggest minimal contributions from more enriched and evolved continental crustal materials.

### A comparison with the Lachlan Fold Belt

NEB granites differ markedly from the Devonian LFB granites<sup>5</sup>. The NEO clearly has elements that derive recent subduction-related processes, and this is reflected within the chemistry of the granites and in the relative distribution of granite types. Notably, S-types are less common within the NEB, and overall the S-type features are less pronounced. Tonalitic I-type granites (Clarence River Supersuite) are more typical of the younger Cordilleran granite belts. Moonbi granites also have a distinctly arc character, although a direct linkage between with subduction zone magmatism is perhaps more difficult to establish.

NEB granites are demonstrably more heterogeneous over similar distances than their LFB counterparts. Consequently, few suites<sup>9</sup> contain more than one pluton. This heterogeneity is also manifested in the transitional chemistry between the Moonbi and Uralla granites, and the greater overlap observed between S- and I-type granites. These features, combined with the comparably low initial <sup>87</sup>Sr/<sup>86</sup>Sr of both S- and I-type granites are consistent with rapid reworking of a young, isotopically juvenile and tectonically complex crustal assemblage. The NEO as a whole perhaps represents a classic example of how we go about building and differentiating continental crust through subduction environment.

### References

- <sup>1</sup>Hensel, H.D., M.T. McCulloch & B.W. Chappell, 1985, *Geochim. Cosmochim. Acta*, 49, 369-384
- <sup>2</sup>Shaw, S.E. & Flood, R.H., 1981, *J. Geophys. Res.*, 86, 10530-10544. 1981.
- <sup>3</sup>Chappell, B.W., 1978, *J. Geol. Soc. Aust.*, 25, 267-283.
- <sup>4</sup>O’Neil, J.R., S.E. Shaw & R.H. Flood, 1977, *Contrib. Mineral. Petrol.*, 62, 313-328.
- <sup>5</sup>Chappell, B.W., 1994, *J. Proc. Royal Soc. N.S.W.*, 127, 47-59.
- <sup>6</sup>Ishihara, S., 1977, *Mining Geol.*, 27, 293-305.
- <sup>7</sup>Bryant, C., B. Chappell, V. Bennett & M. McCulloch, 2003, *Hutton Conference Japan, 2003, abstracts*.
- <sup>8</sup>Bryant, C.J., R.J. Arculus, & B.W. Chappell, 1997, *J. Pet.*, 38, 975-1001.
- <sup>9</sup>Hine, R., I.S. Williams, B.W. Chappell & A.J.R. White, 1978, *J. Geol. Soc. Aust.*, 25, 219-234.

# Granites of the southern New England Orogen



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## Co-workers

- Bruce Chappell
- Phillip Blevin
- Robert Bultitude

## Other Workers

- Stirling Shaw, Dick Flood and co-workers
- Hans Hensel
- Bill Landenberger
- Numerous other workers who have contributed to our understanding of the granite magmatism in the southern New England Orogen

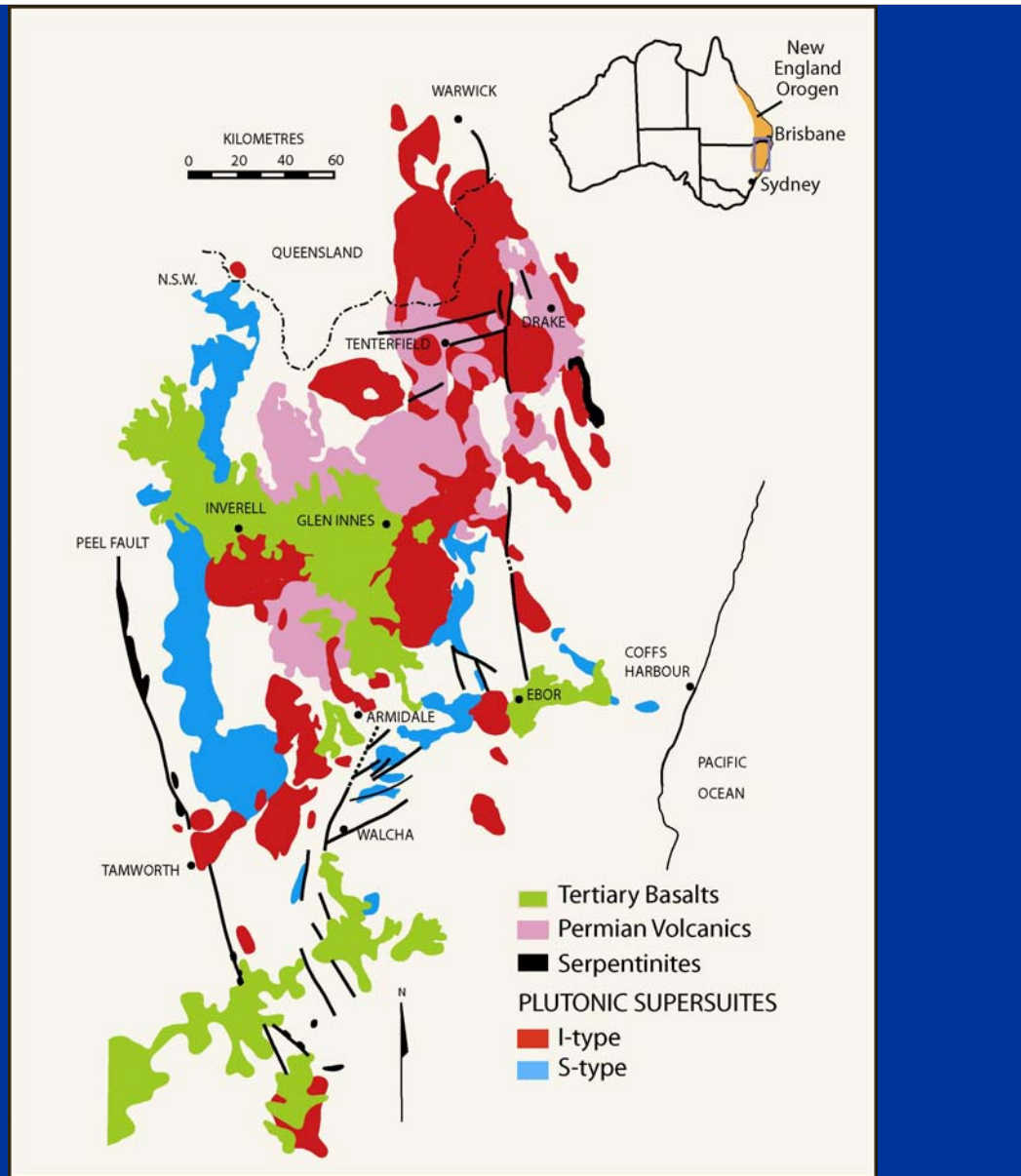
## **Southern New England Orogen**

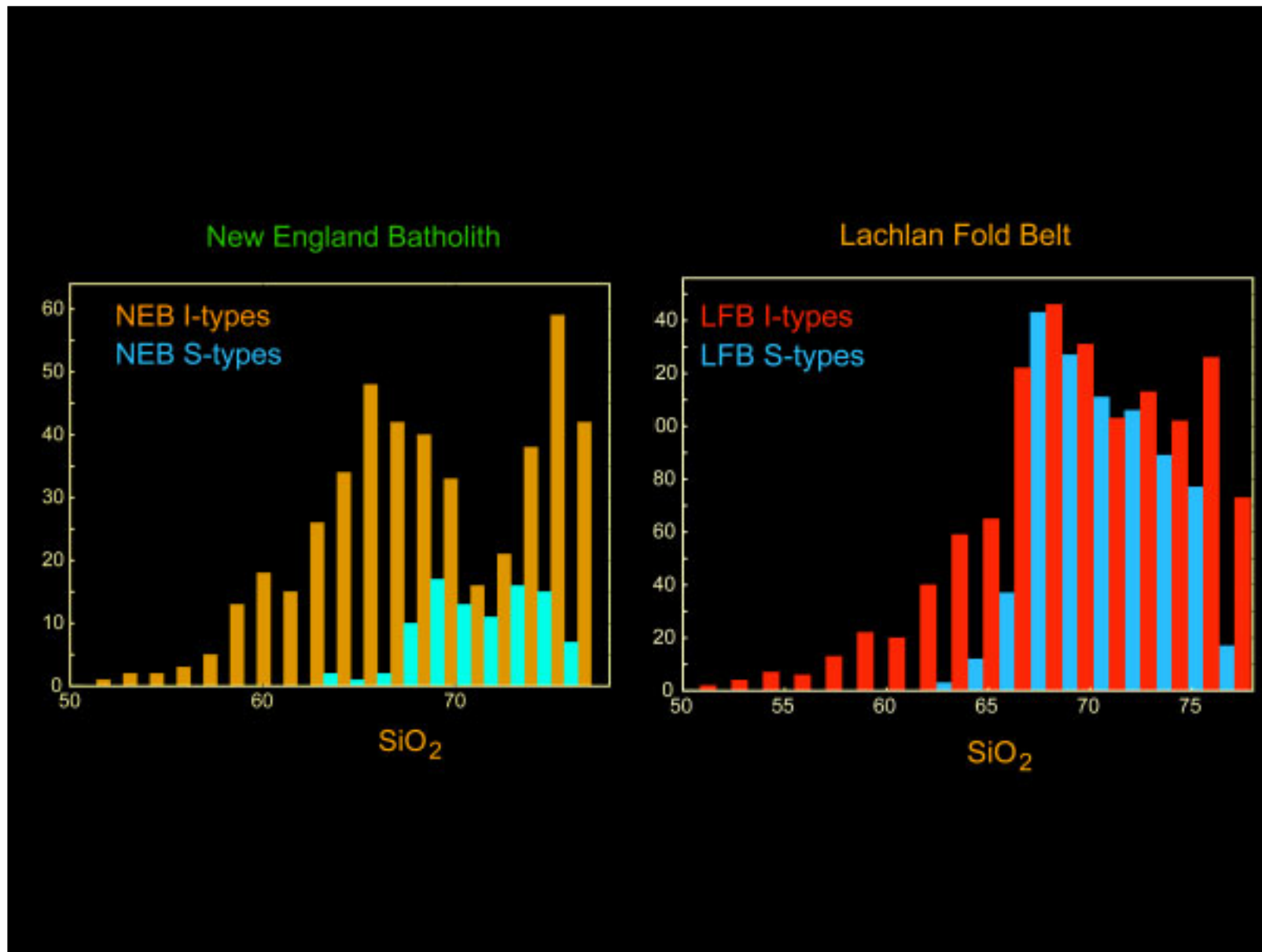
The NEB, Eastern Australia was emplaced in a Devonian-Triassic intraoceanic-continental marginal arc sequence.

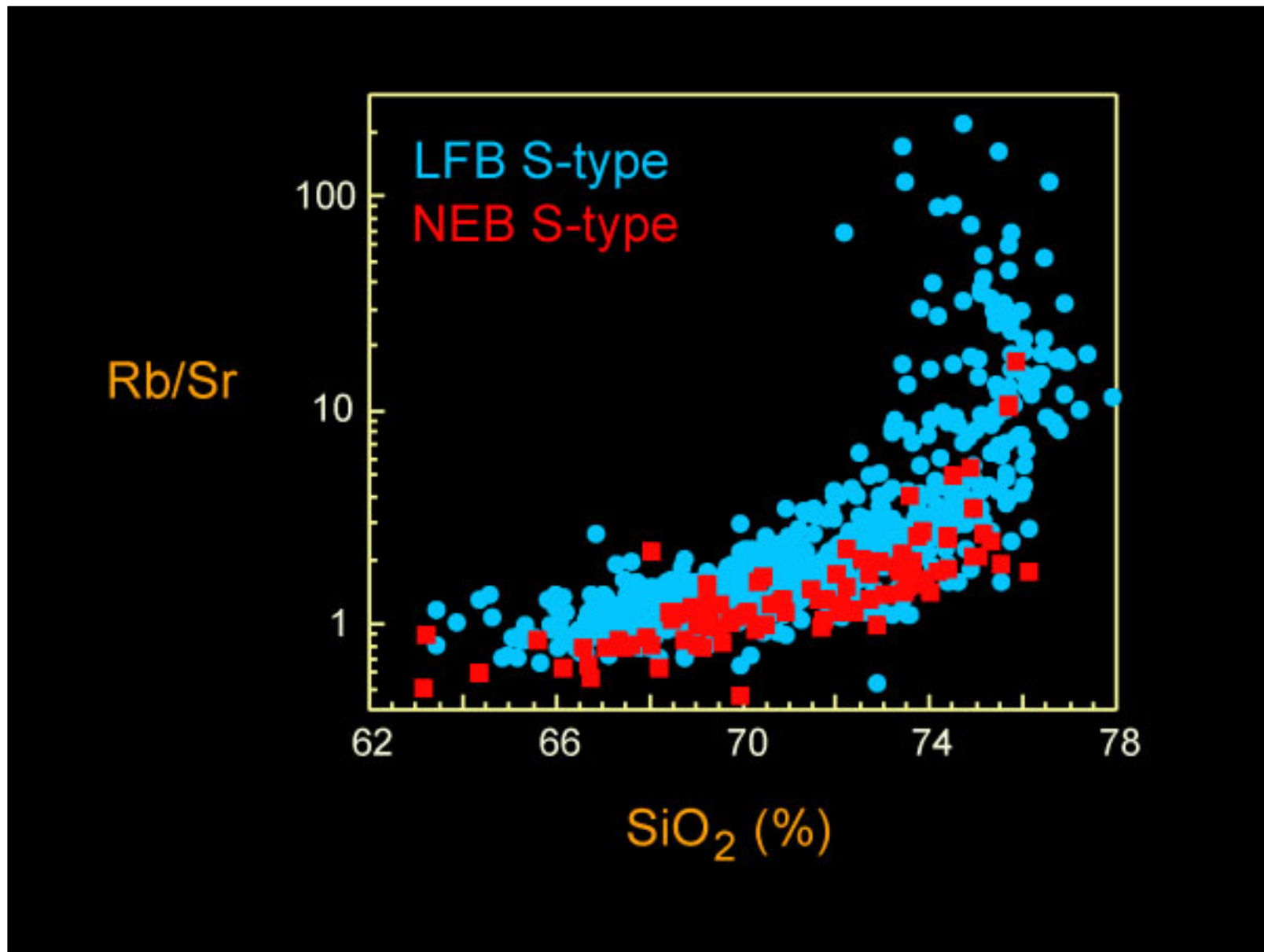
The New England Orogen itself consists of series of terranes generated in a variety of arc settings including intraoceanic arc, continental arc, backarc, forearc and accretionary wedge settings.

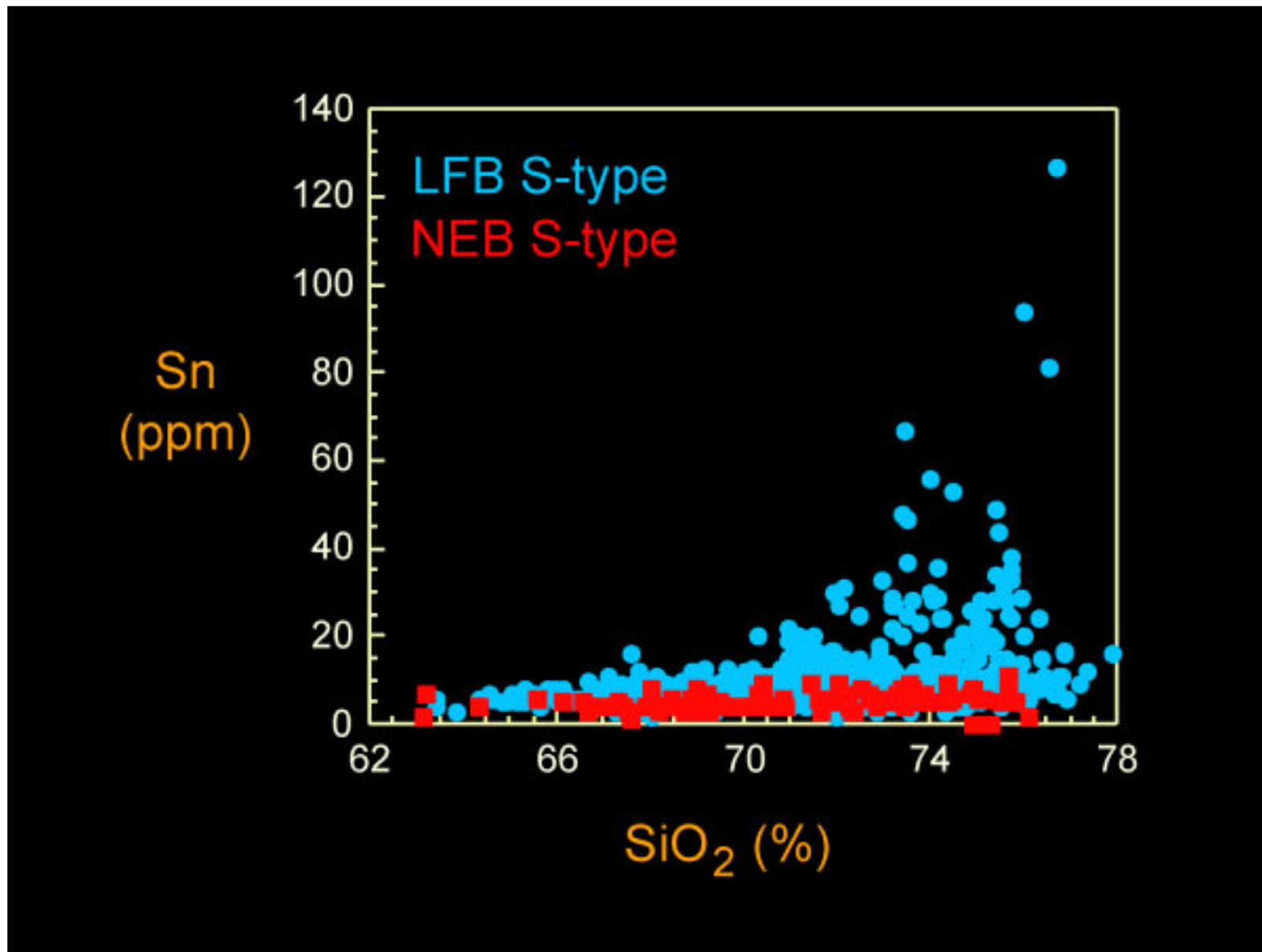
The very juvenile nature of the crustal materials in this region is reflected in the composition of the granites intruded in this region.

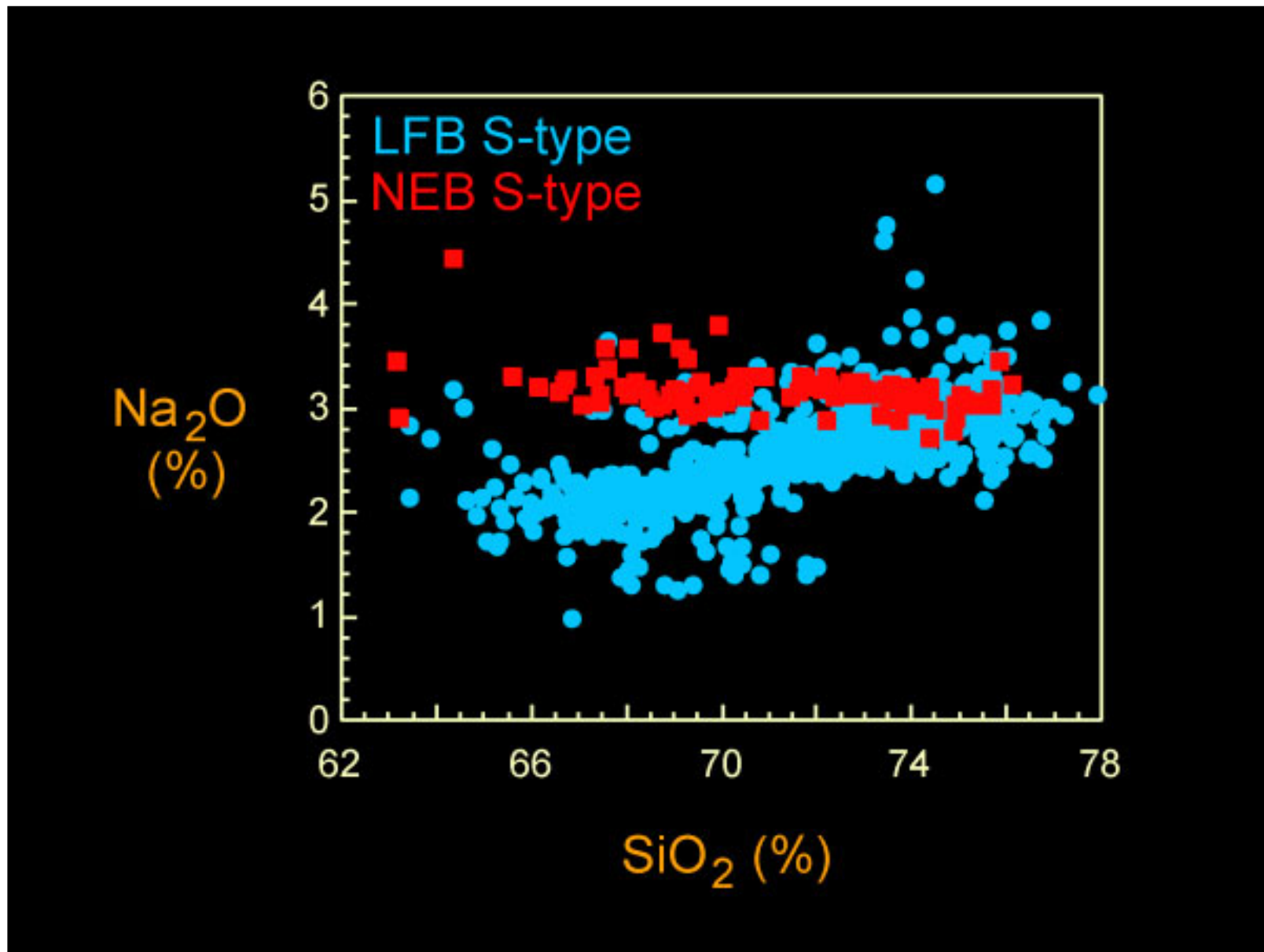
**Southern  
New England  
Batholith**

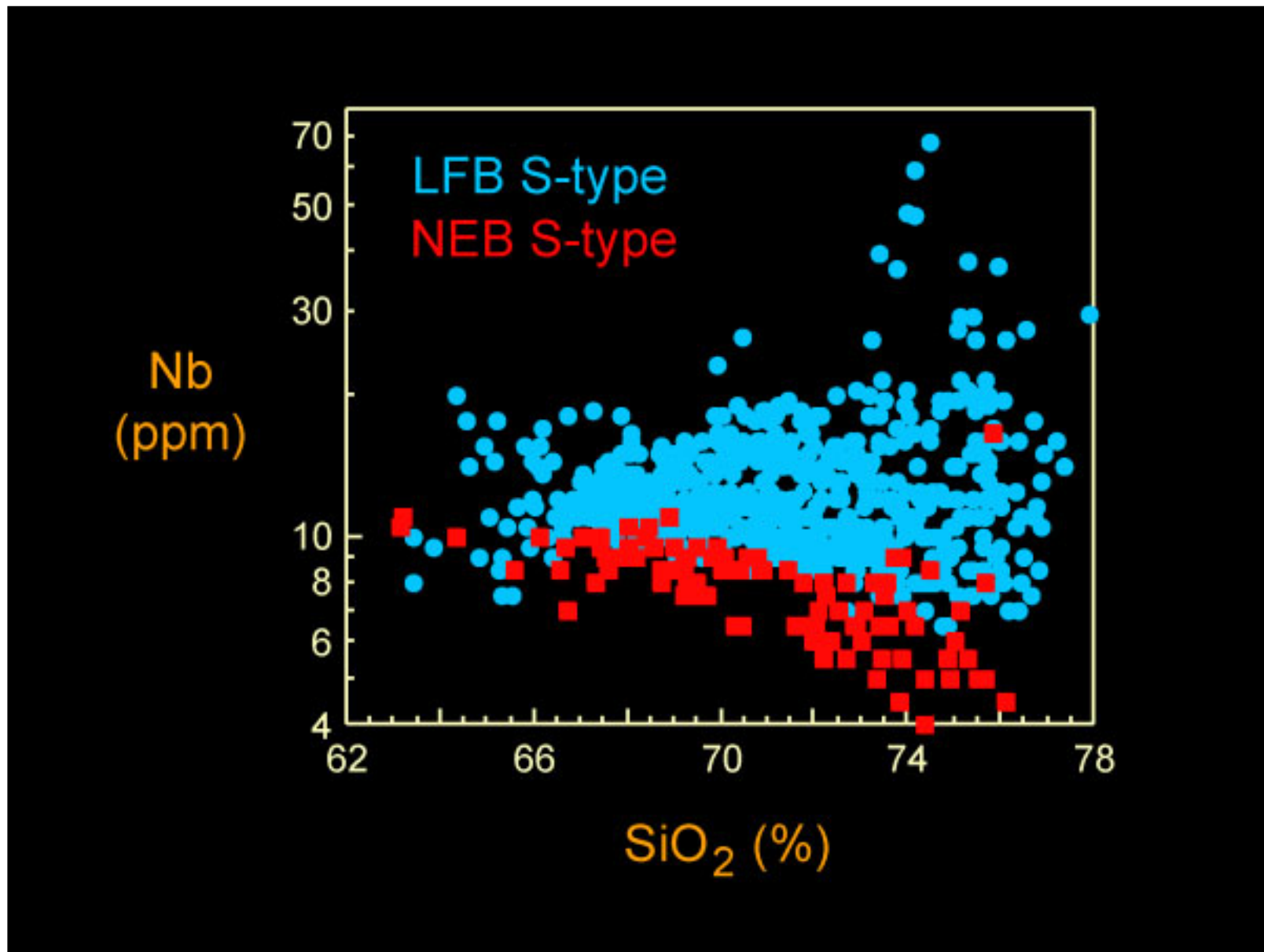


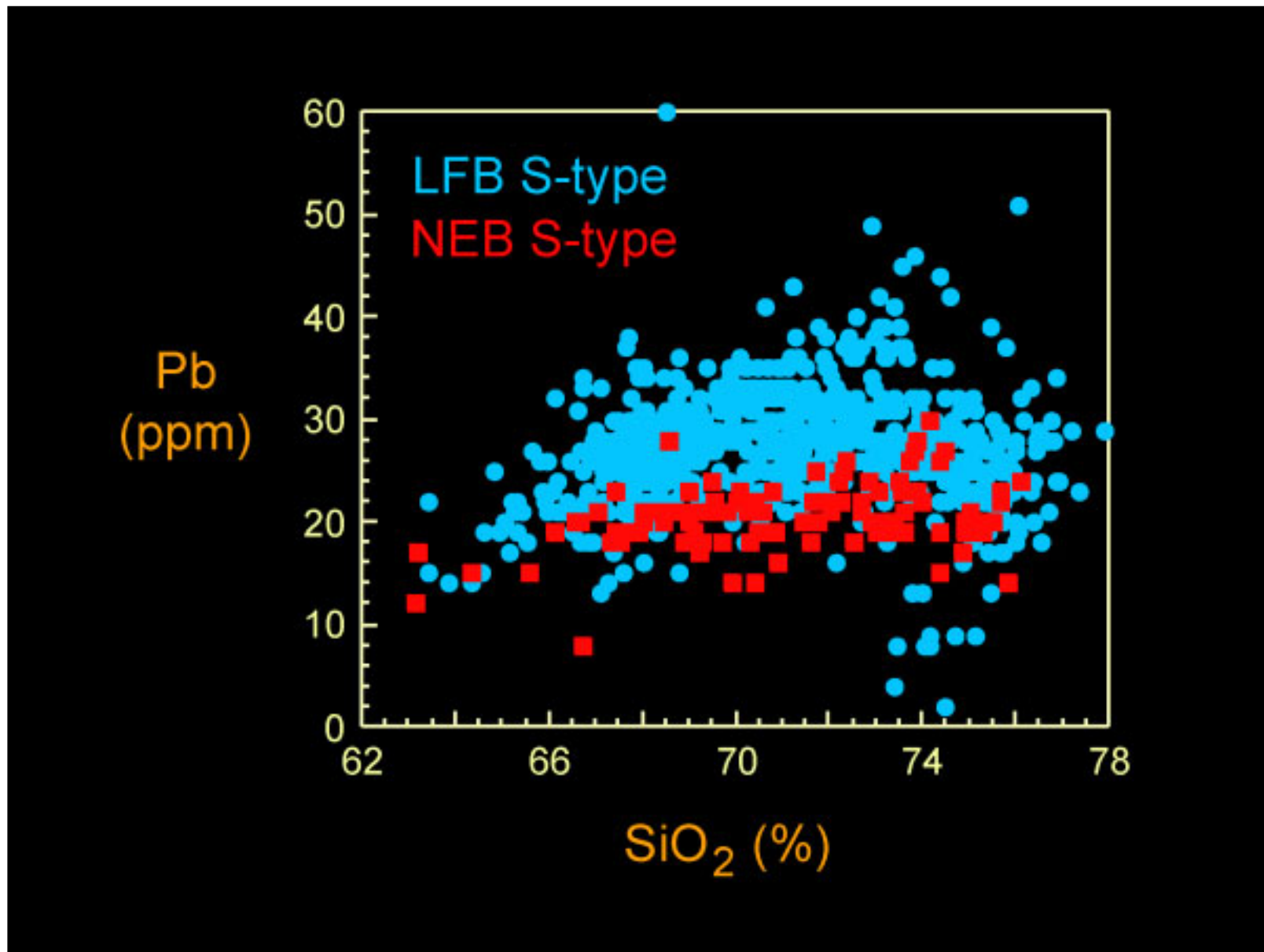


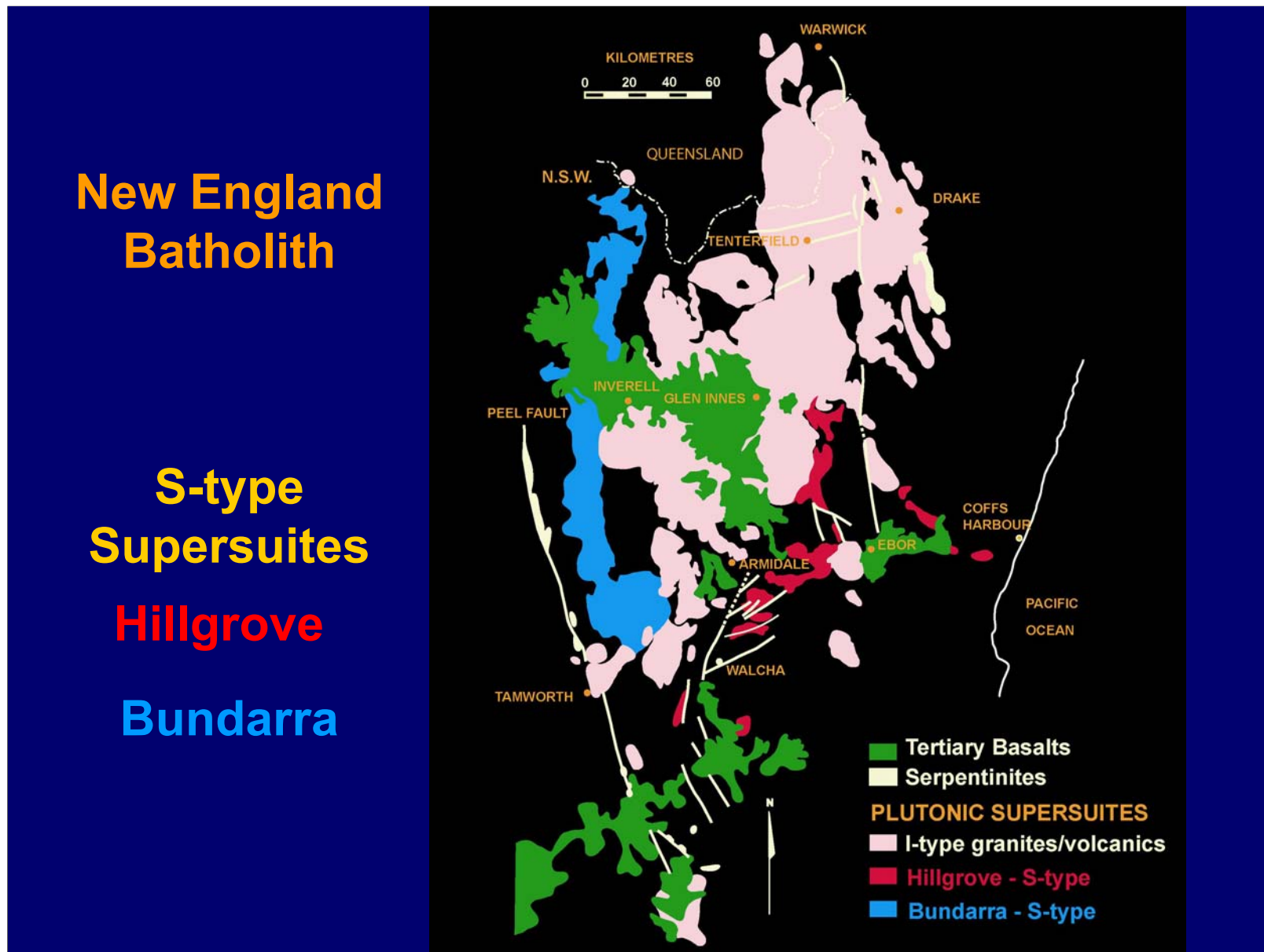












## HILGROVE SUPERSUITE



- oldest - ~303 Ma; 20 plutons
- blue-grey, granodiorites and monzogranites
- moderately to intensely deformed; 2 plutons have a well-developed regional aureole - migmatites and cord-K-feld-gnt gneisses
- ferromagnesian minerals: aluminous russet red biotite (dominant), minor almandine-rich garnet, actinolitic amphibole and cummingtonite
- strongly reduced – ilmenite, graphite (locally)

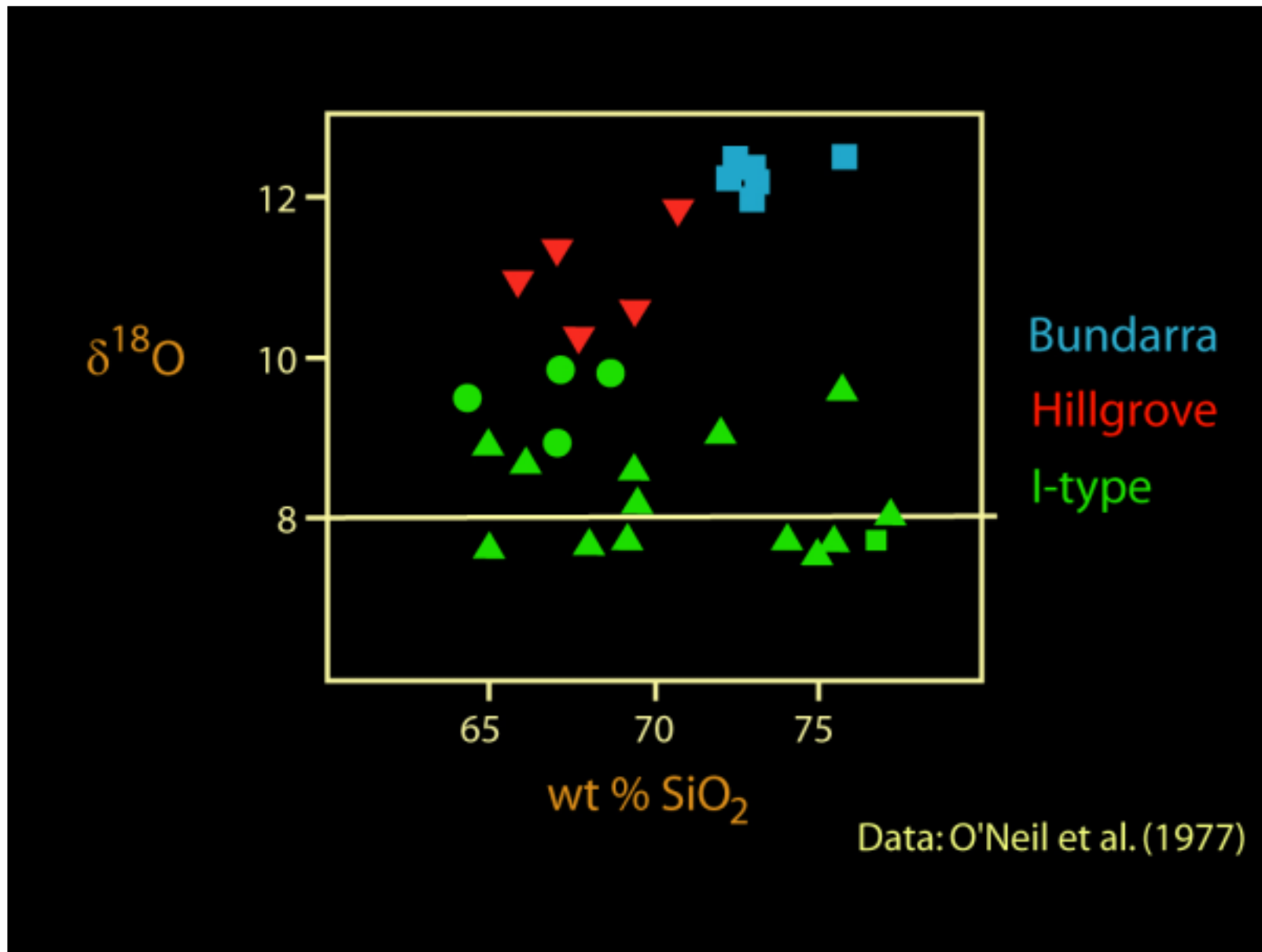


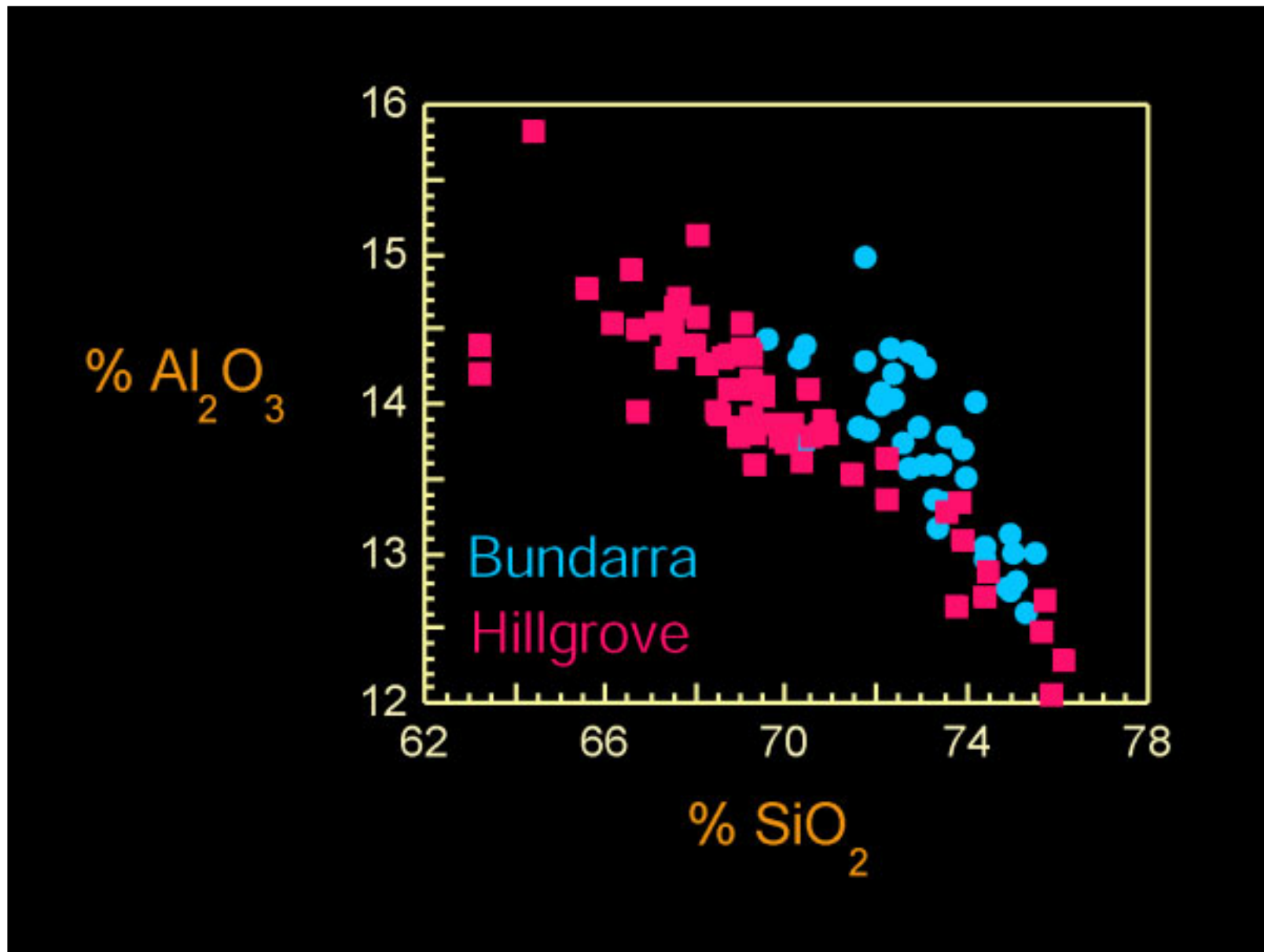
## BUNDARRA SUPERSUITE

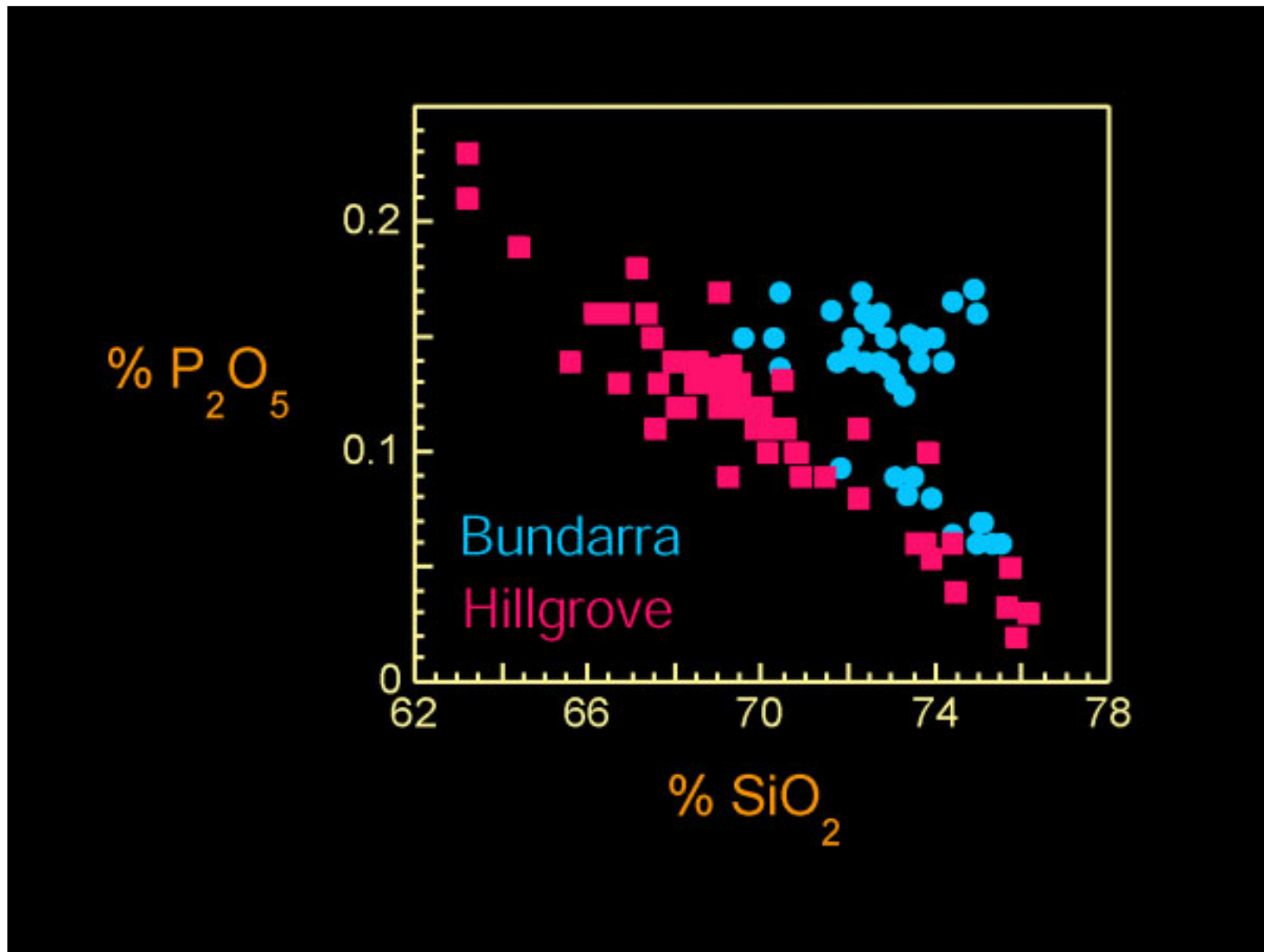


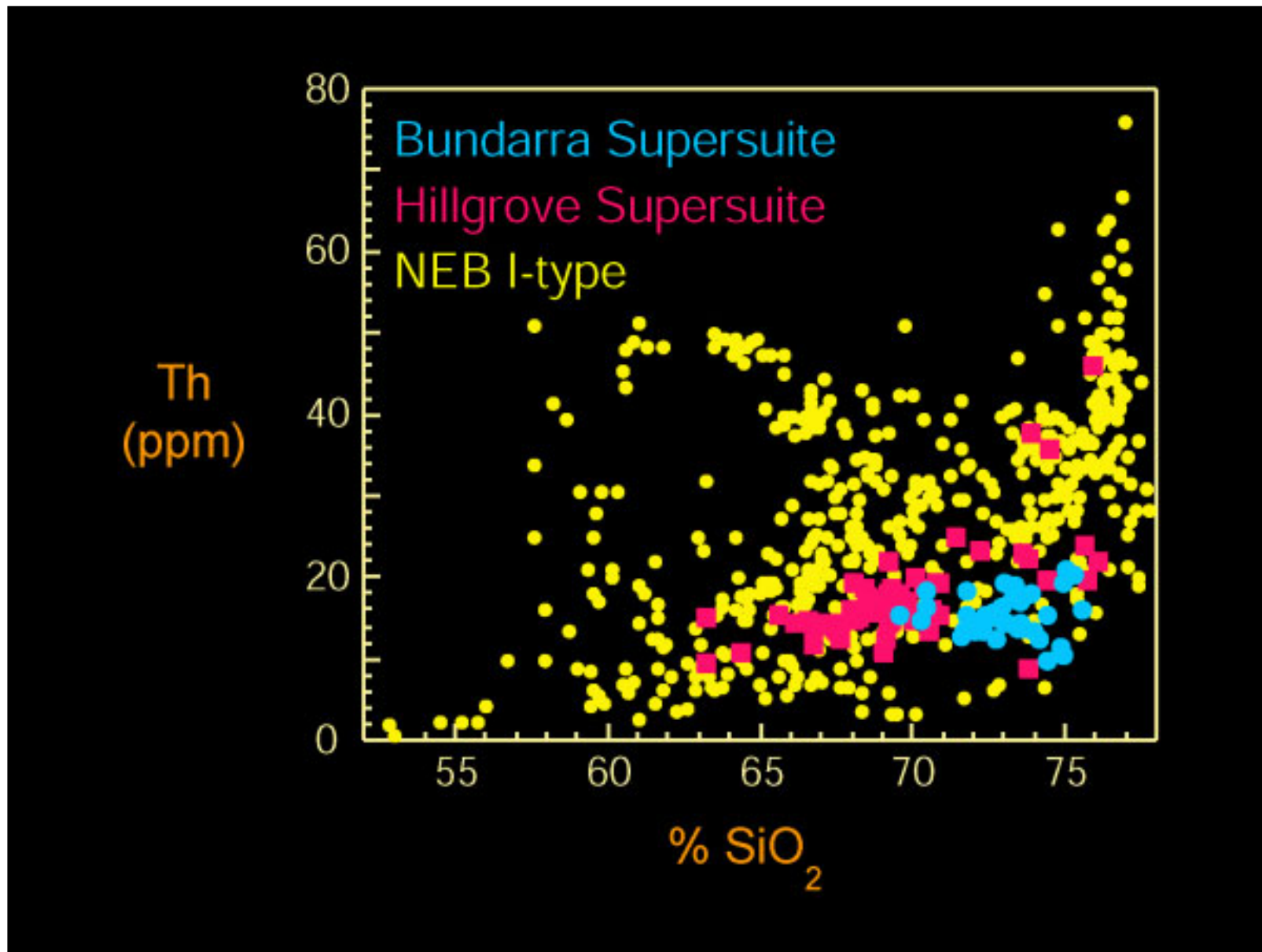
- ~280 Ma
- coarse-grained and generally porphyritic - large K-feldspar crystals (up to 80 mm).
- strongly peraluminous - cordierite (often altered), muscovite and less commonly Fe-rich garnet.
- apatite occurs as large crystals.
- reduced – ilmenite, white K-feldspar, high  $\delta^{18}\text{O}$  ( $> 12\text{‰}$ ; O'Neil *et al.*, 1977)
- deeply weathering: difficult to map separate plutonic units and to collect fresh rock samples
- 11 units - internal contacts are not well particularly well defined

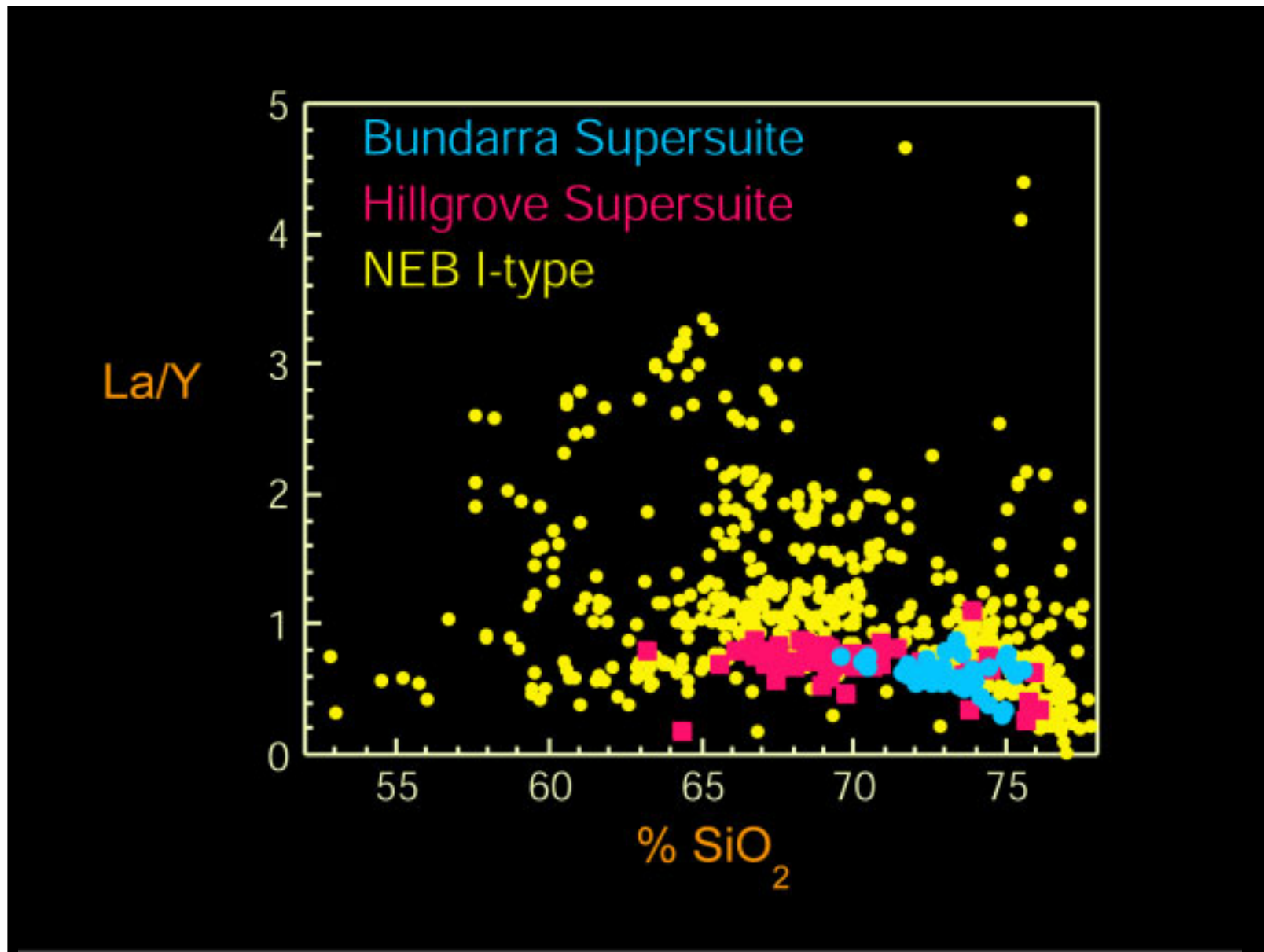


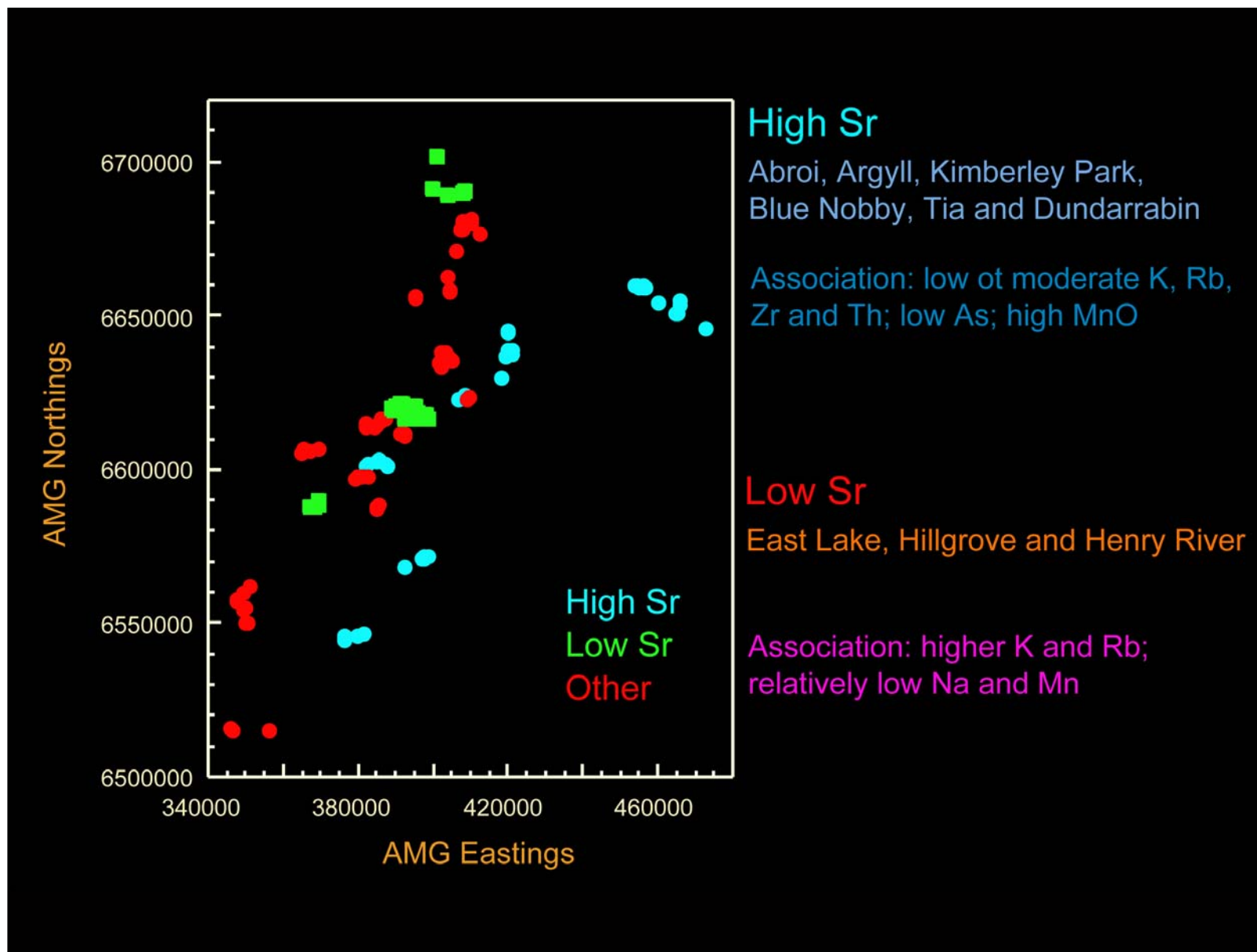


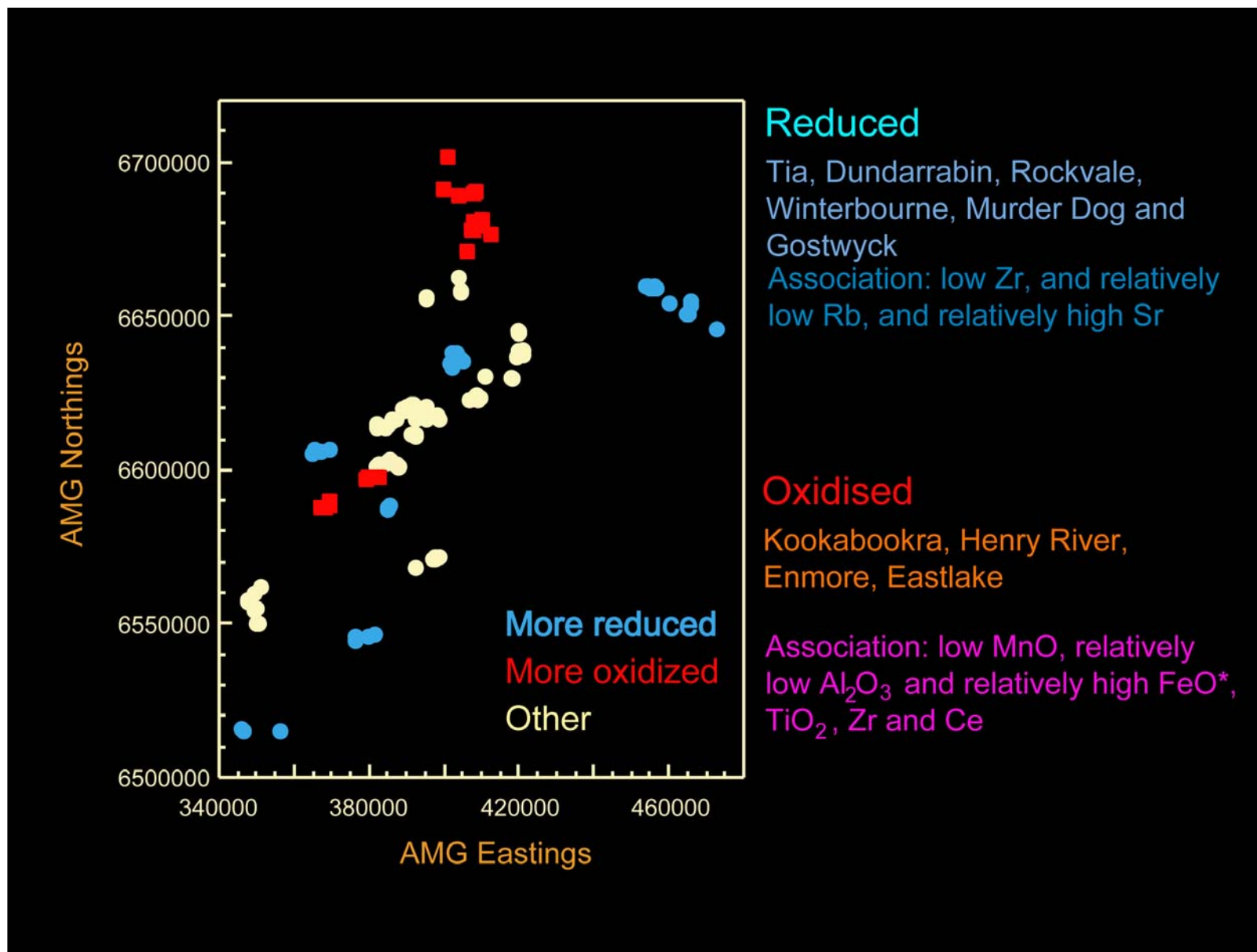


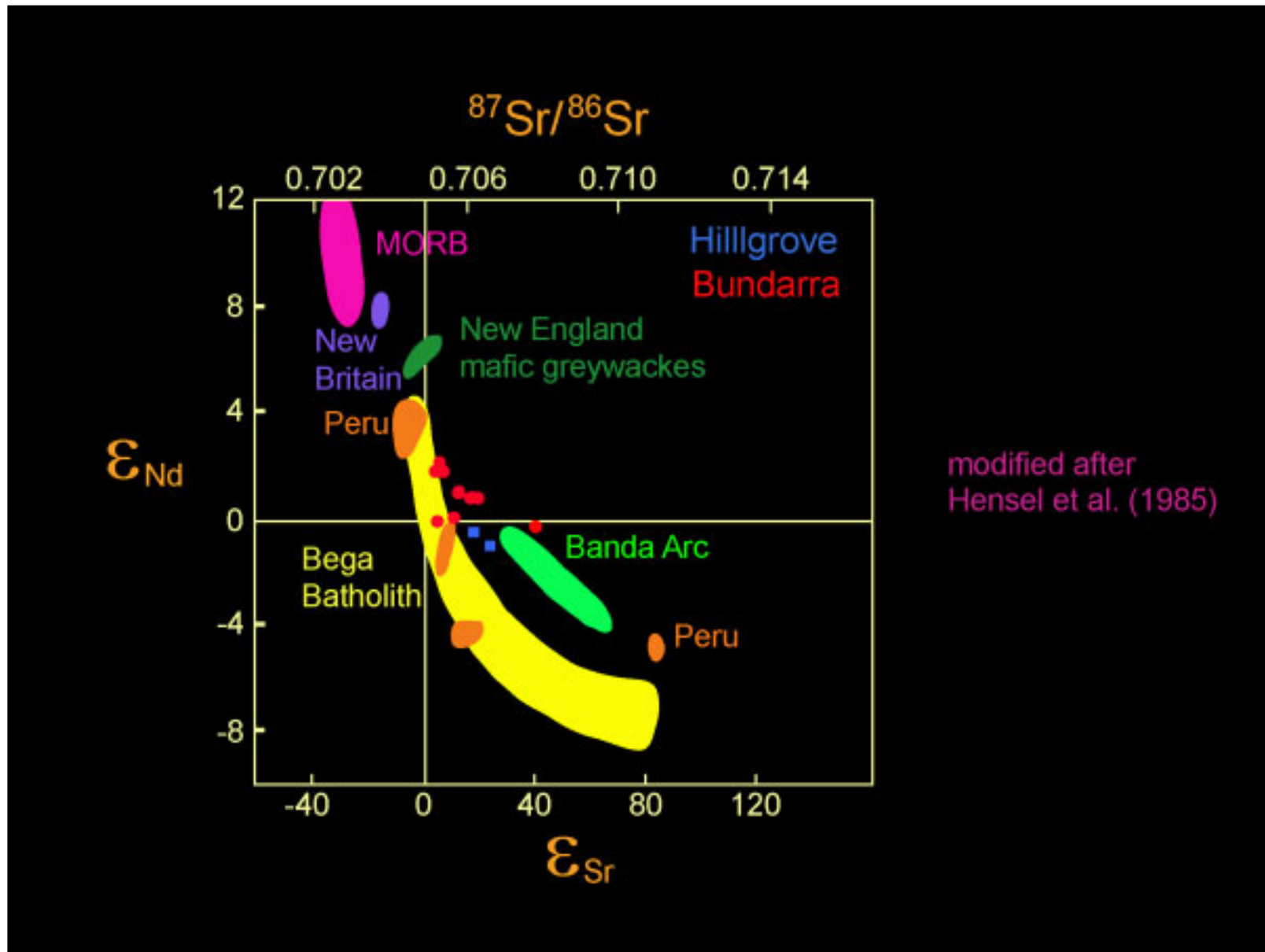












## Hillgrove and Bundarra – Source Rocks

- low CaO, Na<sub>2</sub>O and Sr – source rocks weathered
- relatively sodic for S-type granites
- low Rb, Pb, Th, and Nb relative to Lachlan granites
- low  $^{87}\text{Sr}/^{86}\text{Sr}_{\text{initial}}$  and  $\epsilon_{\text{Nd}}$
- derivation from juvenile sediments - derived from the weathering of juvenile arc rocks
  - **Bundarra** – more classic S-type (felsic, compositionally relatively homogenous, strongly peraluminous)
  - **Hillgrove** – transitional I-S type characteristics (comparatively mafic; less peraluminous, P<sub>2</sub>O<sub>5</sub> decreases with SiO<sub>2</sub>) – less weathered source rocks

- **relatively low La/Y and Th and “continental crustal elements” – sedimentary rocks likely derived from low- to med-K (?intraoceanic) arc rocks**
- **inter- and intra-supersuite geochemical variations - chemical zonation within the early NEB crust - ?original variations in arc chemistry**
  - **Bundarra spatially associated with intraoceanic arc lavas of the western NEO (e.g., Baldwin Formation)**
  - **Hillgrove – slightly higher Th, lower Sr relative to Bundarra (despite less extensive weathering) may relate lateral variations in sediment and possibly arc chemistry**
  - **Variations within Hillgrove indicate strong decrease in Sr eastwards within the easterly New England crust**

## New England Batholith I-type granites

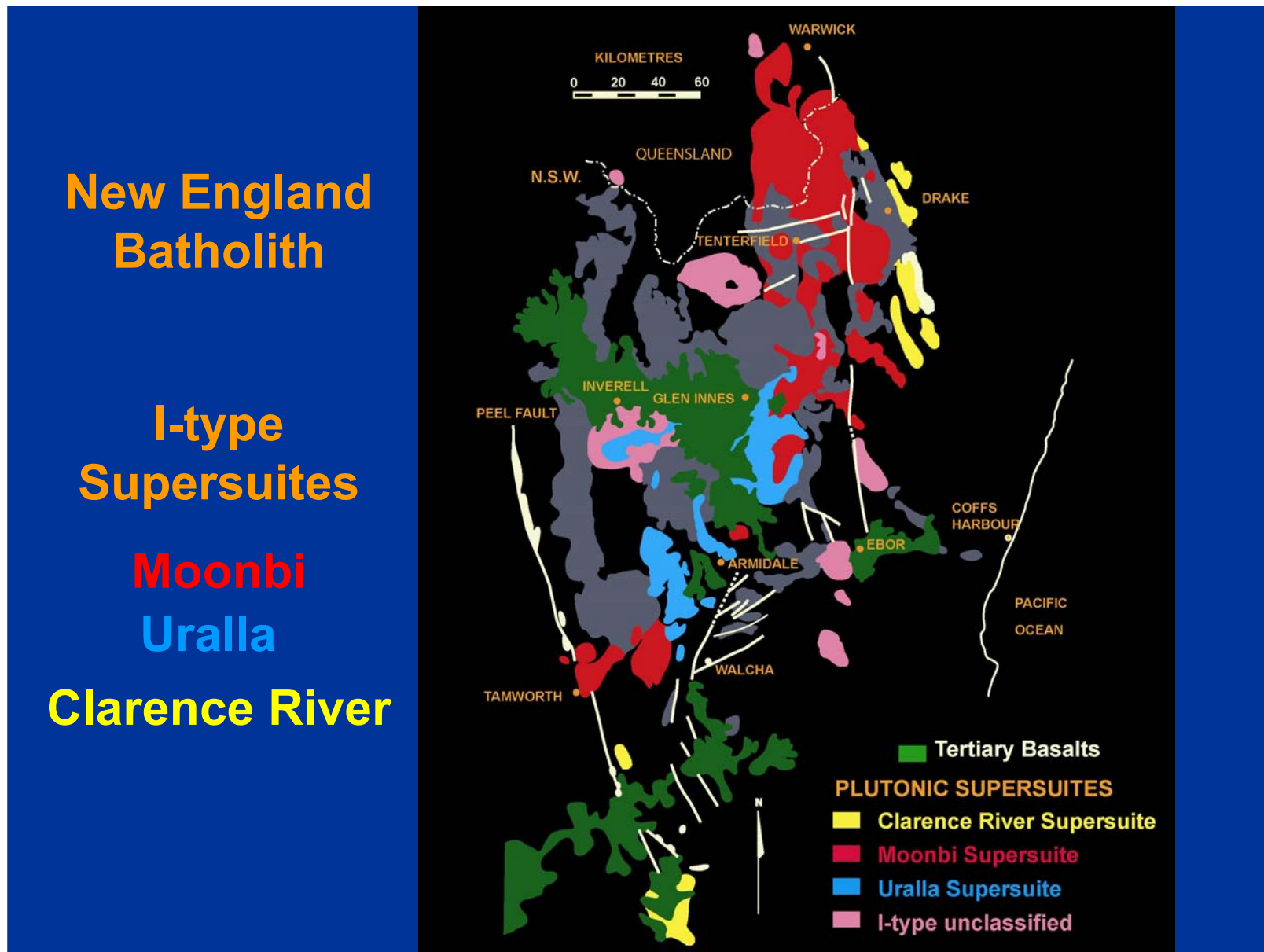
### Supersuites:

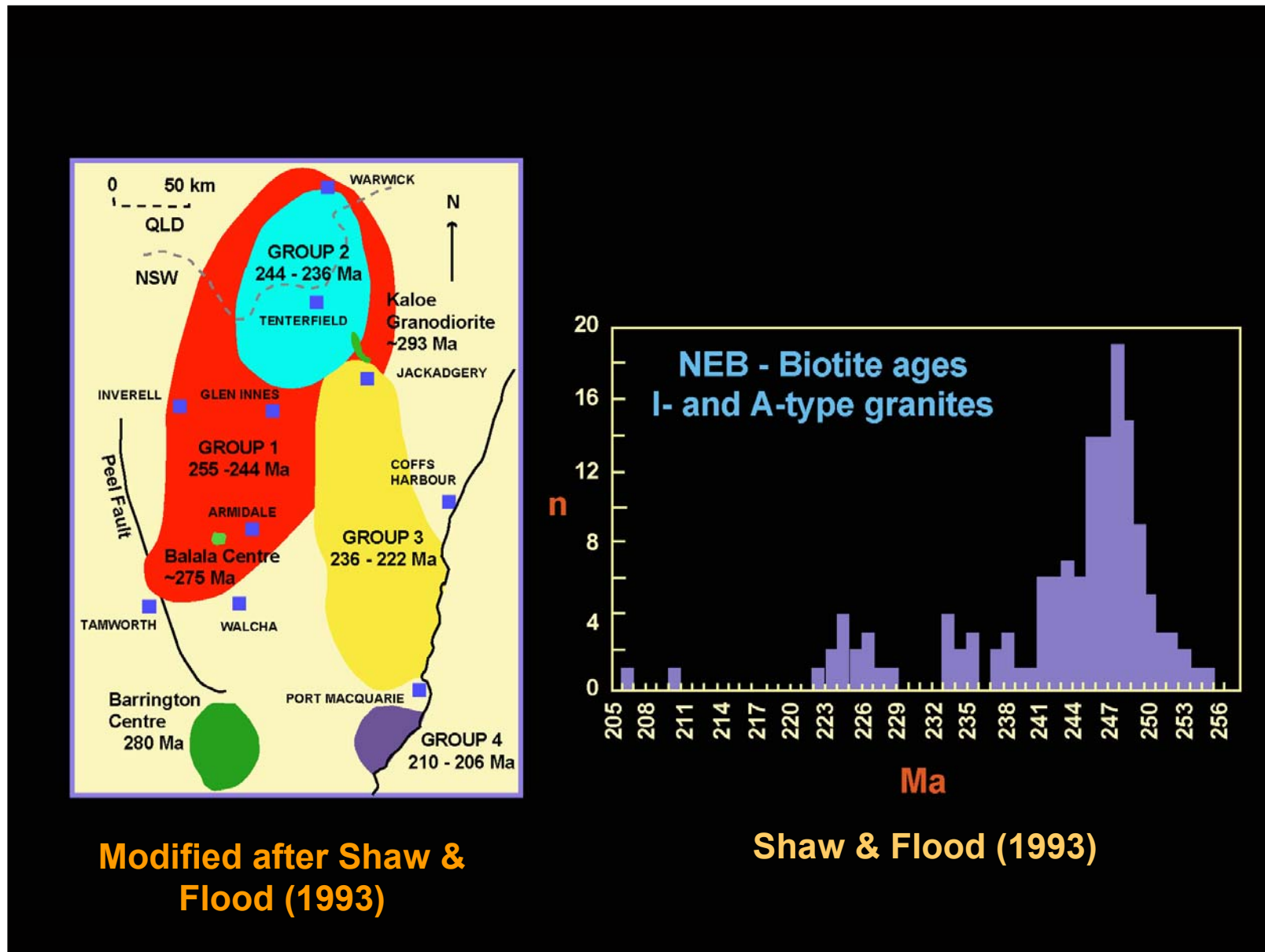
- Moonbi
- Uralla
- Clarence River



### Other I-type granites:

- Leucogranites
- Coastal I-type granites





## MOONBI SUPERSUITE



- southern and northern extensions of NEB
- compositionally and chemically diverse
- high-K - monzogranite, quartz monzonite and leucogranite
- abundant pink K-feldspar megacrysts
- ferromagnesian minerals: hornblende, biotite, minor augite
- strongly oxidised: titanite and magnetite
- apatite and zircon - accessory minerals.

- *southern Moonbi* – more mafic, more geochemically extreme (higher K, Rb, Th, Ba, Sr), low Y and HREE
- *northern Moonbi* – higher proportion of leucogranites, generally lower abundances K, Rb, Th, Ba, Sr; higher Y and HREE





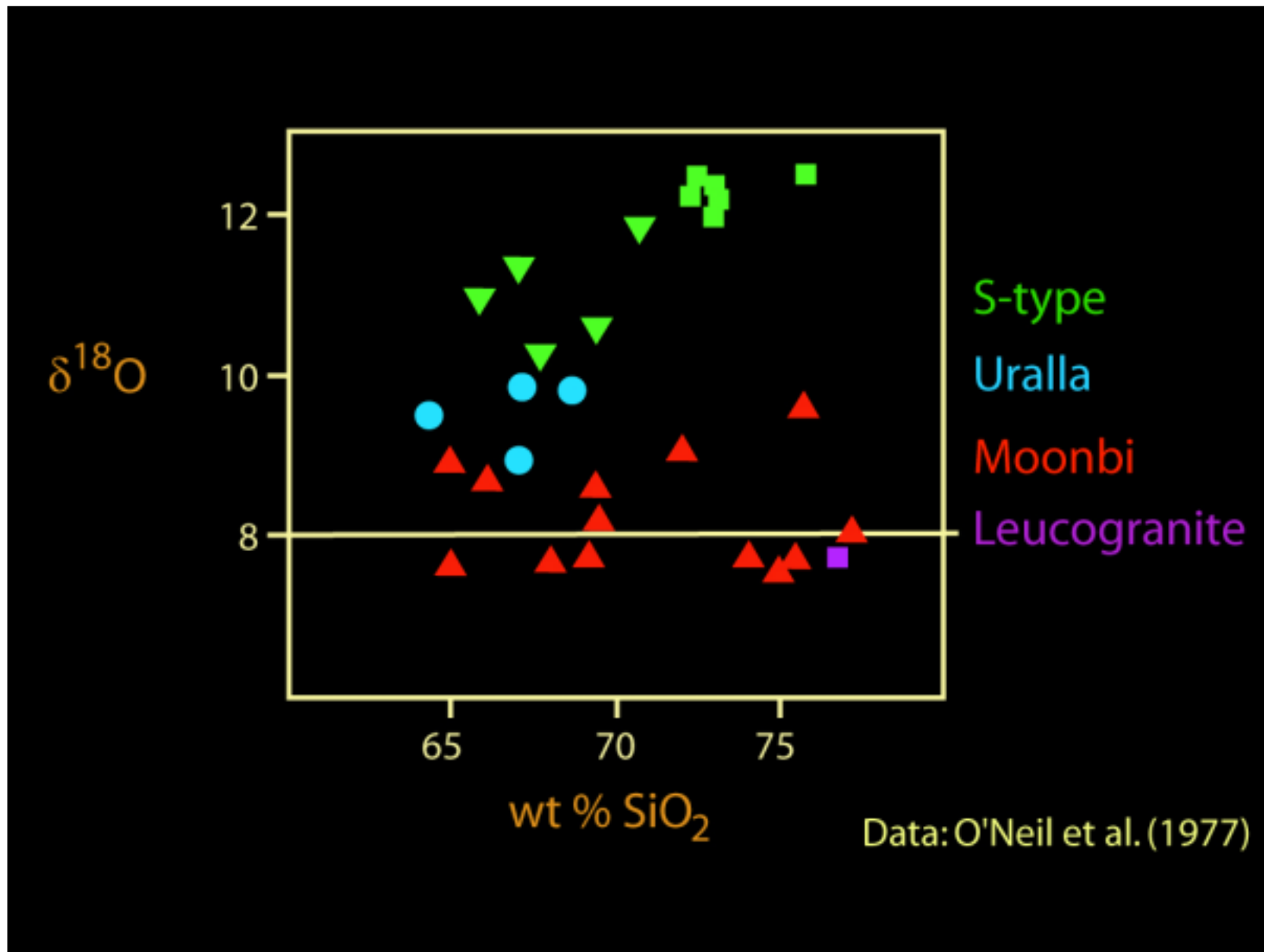
## URALLA SUPERSUITE

- central portion of the NEB
- compositionally diverse – gabbro, diorite to monzogranite
- fewer highly fractionated granites - some leucogranites
- equigranular and speckled black and white - some porphyritic variants
- ferromagnesian minerals; actinolite, hornblende, red-brown biotite, clinopyroxene, orthopyroxene (mafic variants)

### Transitional

- lower normative diopside
- reduced (ilmenite-series)-low  $\text{Fe}_2\text{O}_3/\text{FeO}$ ;  $\delta^{18}\text{O} > \sim 9$  (O'Neil *et al.*, 1977)



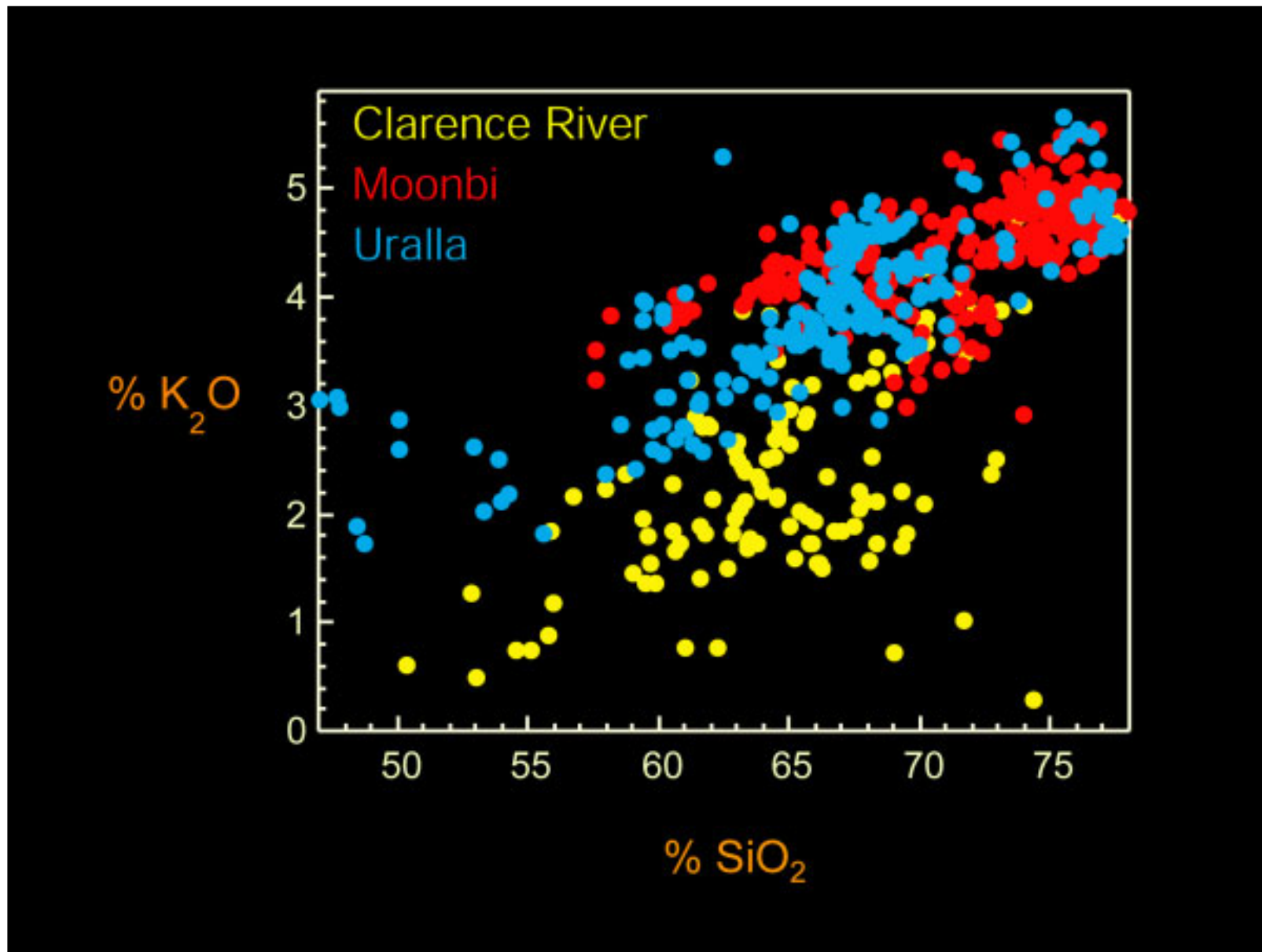


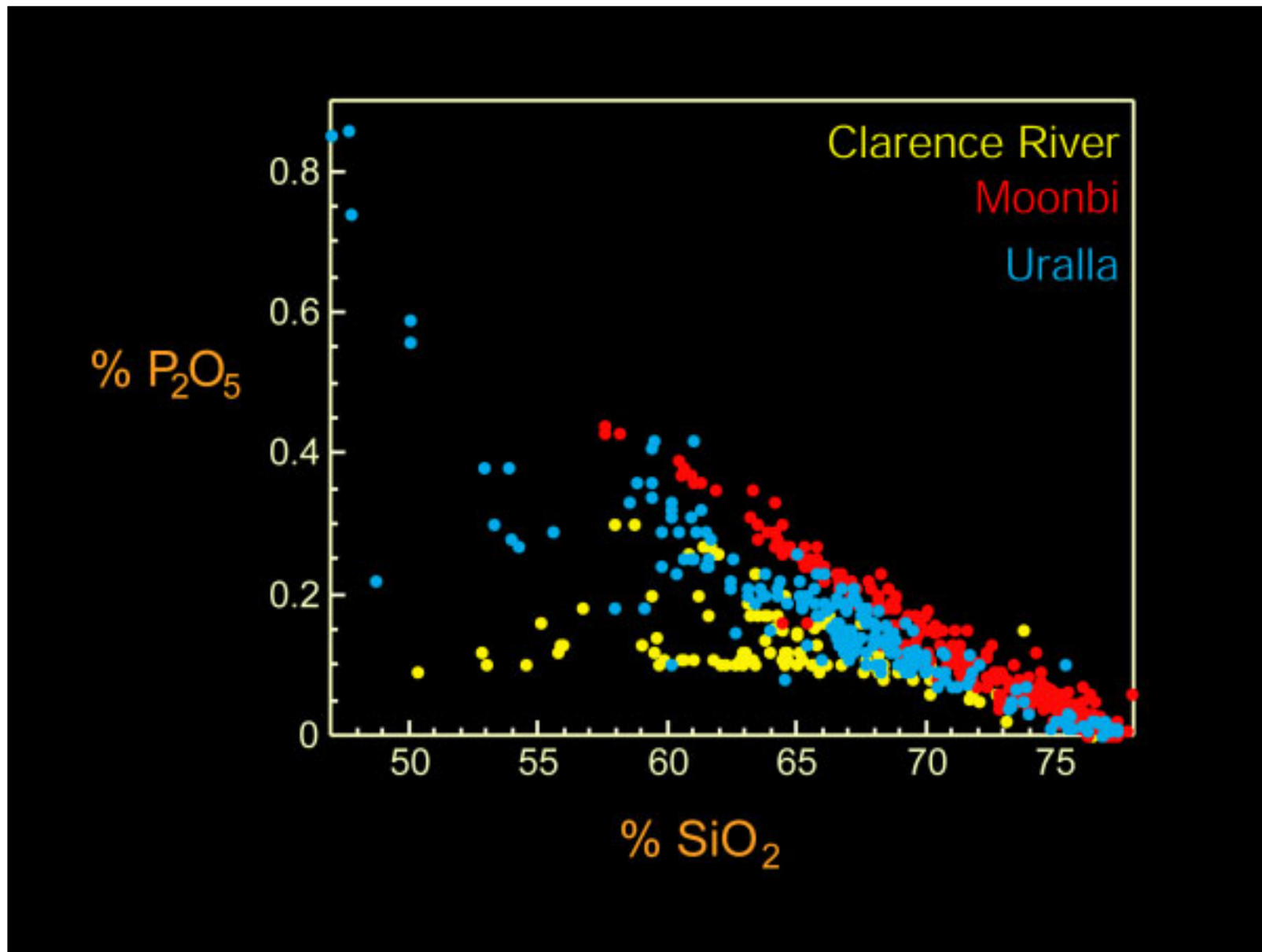
## CLARENCE RIVER SUPERSUITE

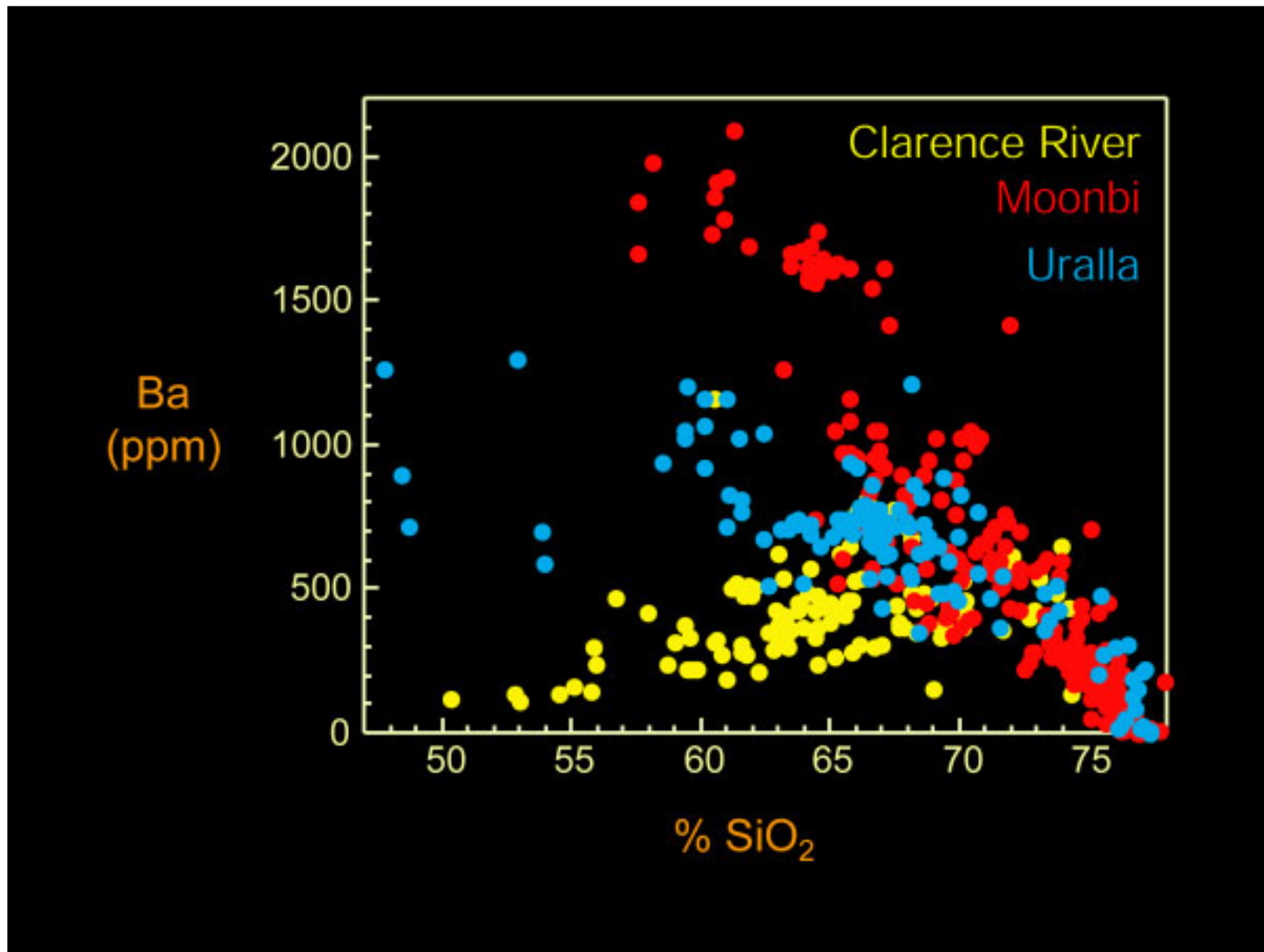


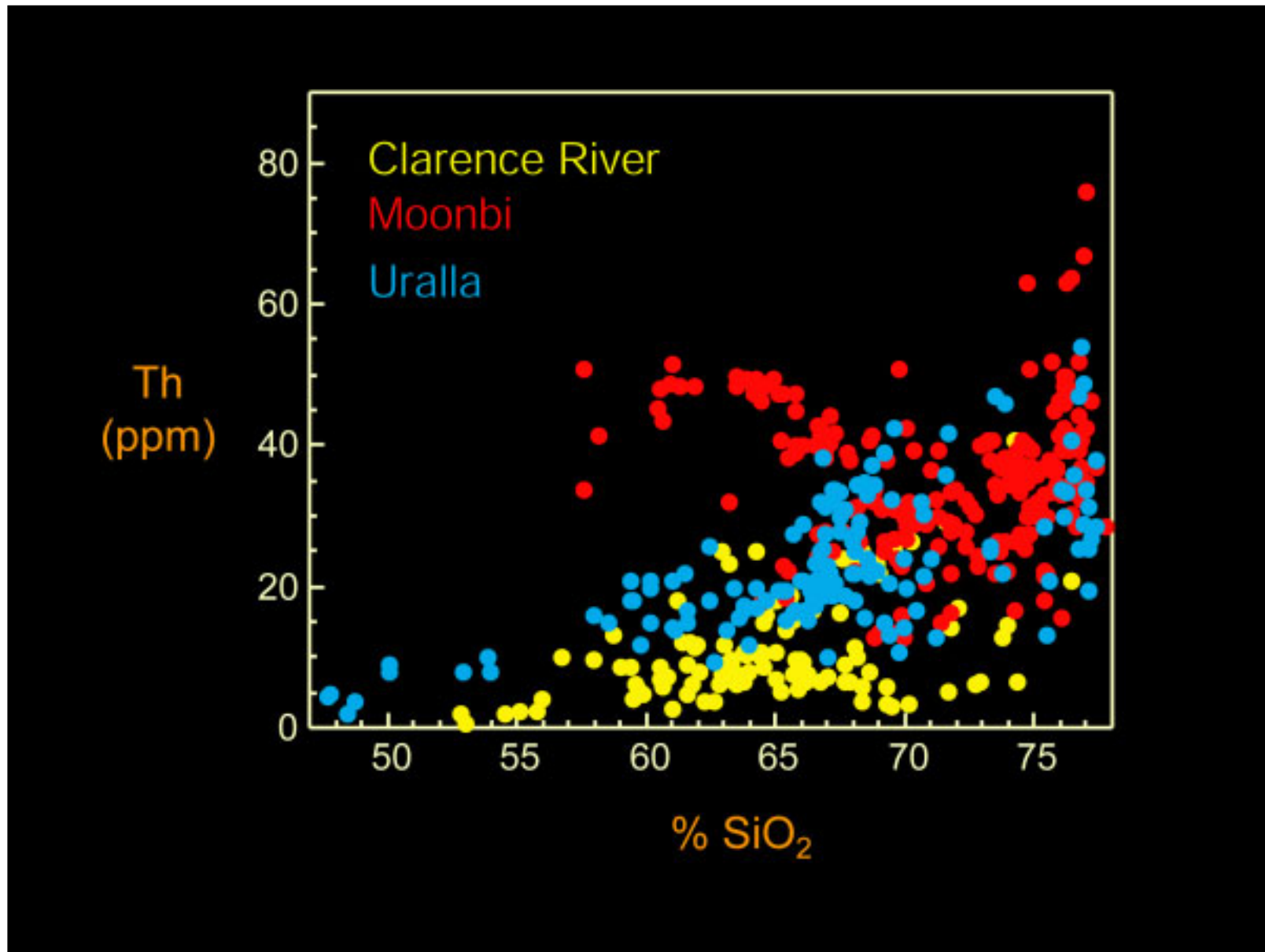
- 13 small intrusions - northern and southern NEB (Nundle Suite, *Hensel et al.*, 1985)
- primarily 255-244 Ma –Barrington Tops (280 Ma; Kimbrough et al., 1993?); Kaloe (290 Ma; *Bryant et al.*, 1996)
- compositionally diverse - gabbro to monzogranite
- Mafic, low-K granites– quartz diorites, tonalites and granodiorite few differentiated granites
- typically speckled black and white in colour-high proportion of ferromagnesian minerals, low K-feldspar
- ferromagnesian minerals:  $\text{cpx} \pm \text{opx} \rightarrow \text{hornblende} \rightarrow \text{biotite}$
- crystallisation from melt - glomerophyric aggregates - reaction between early-formed minerals with the evolving melt

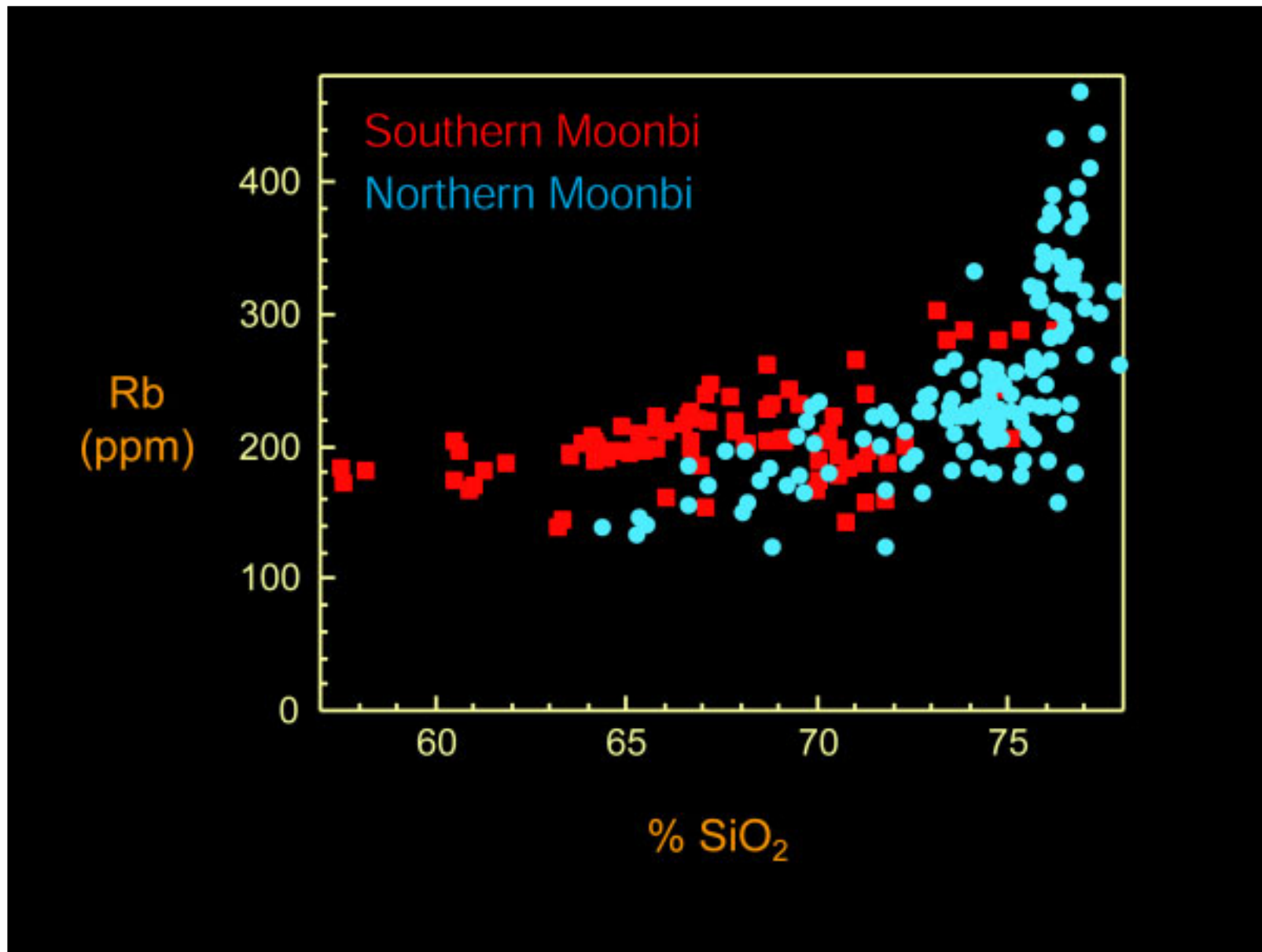


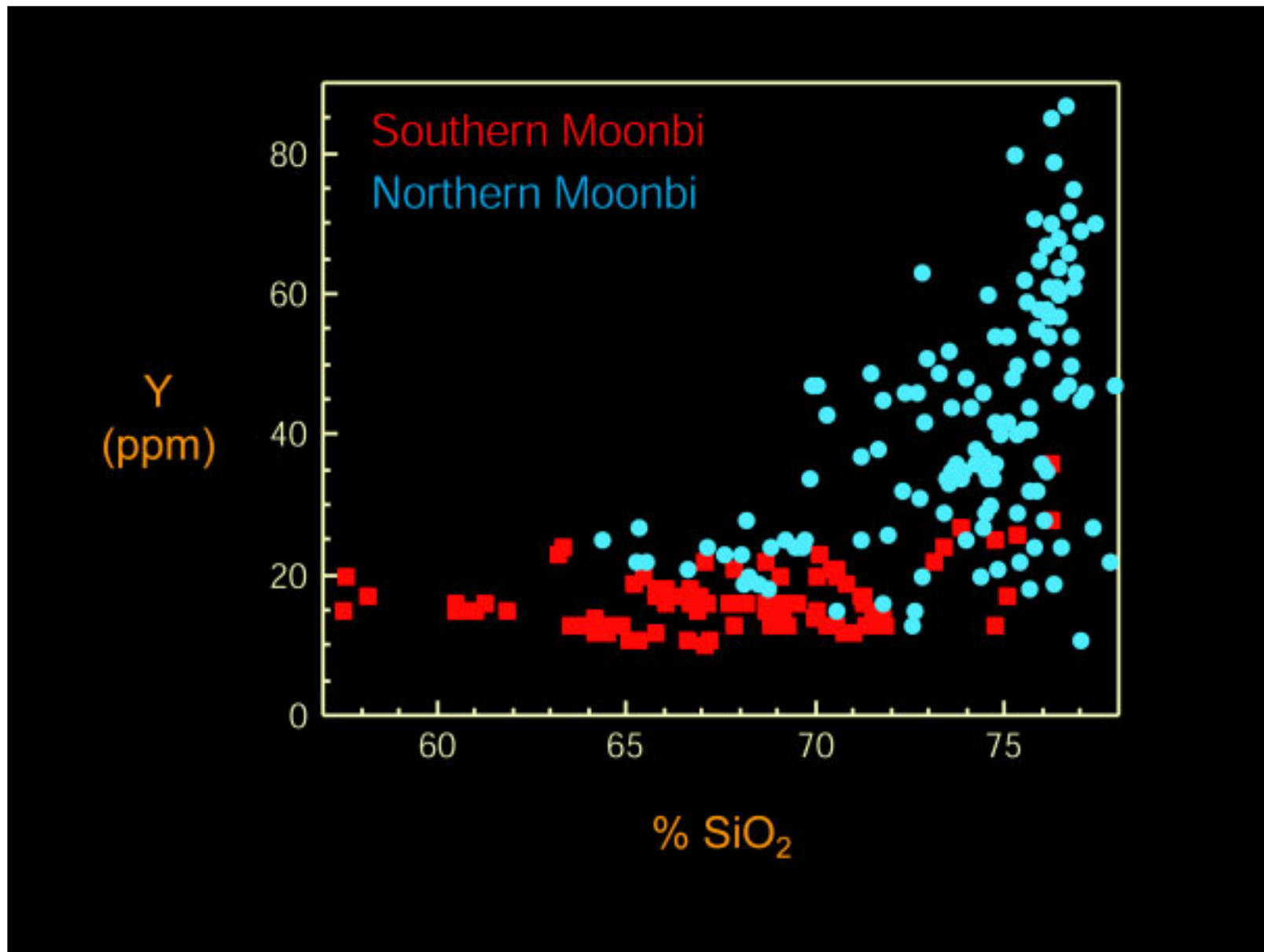


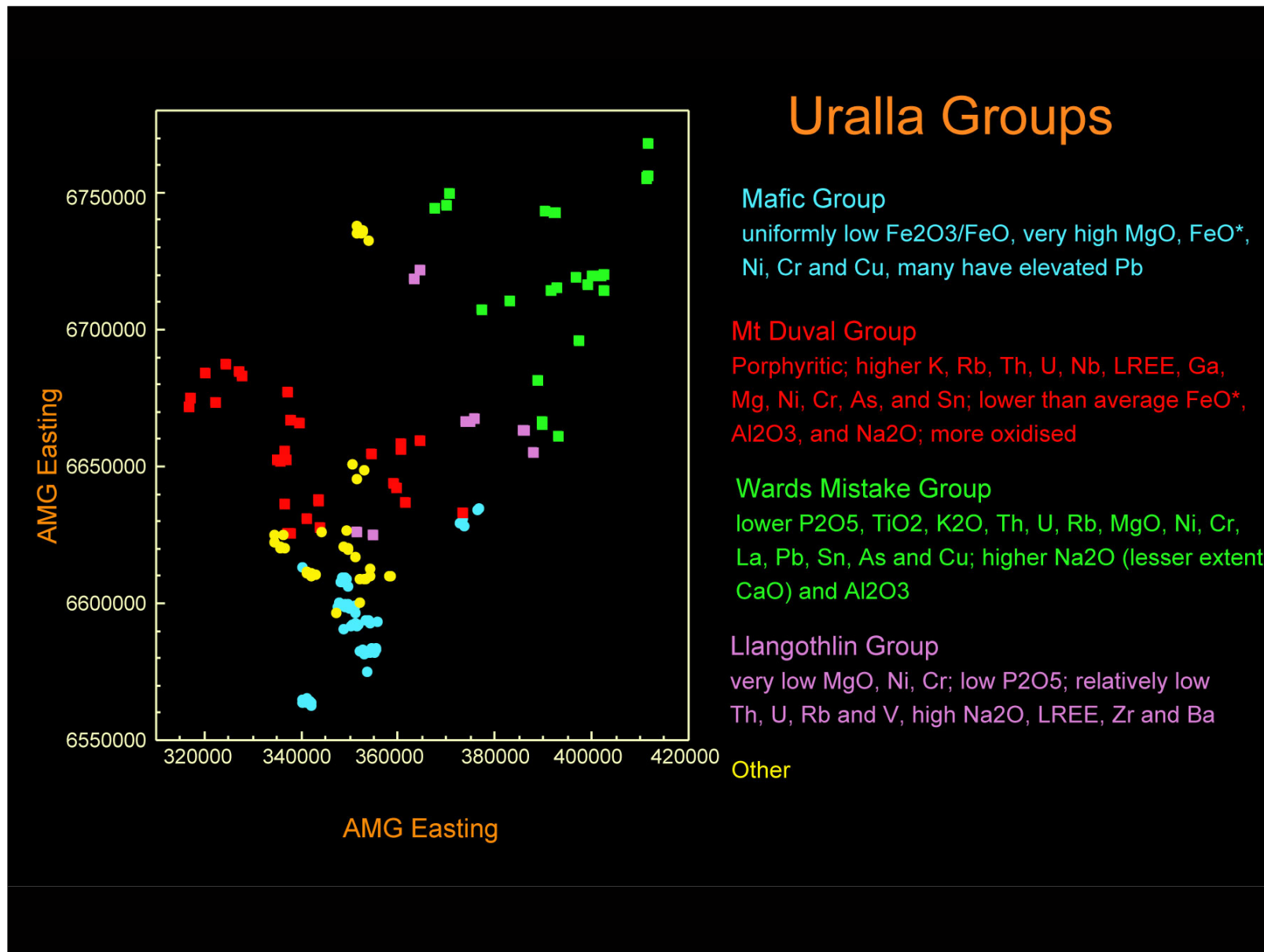












## Regional variations –Clarence River

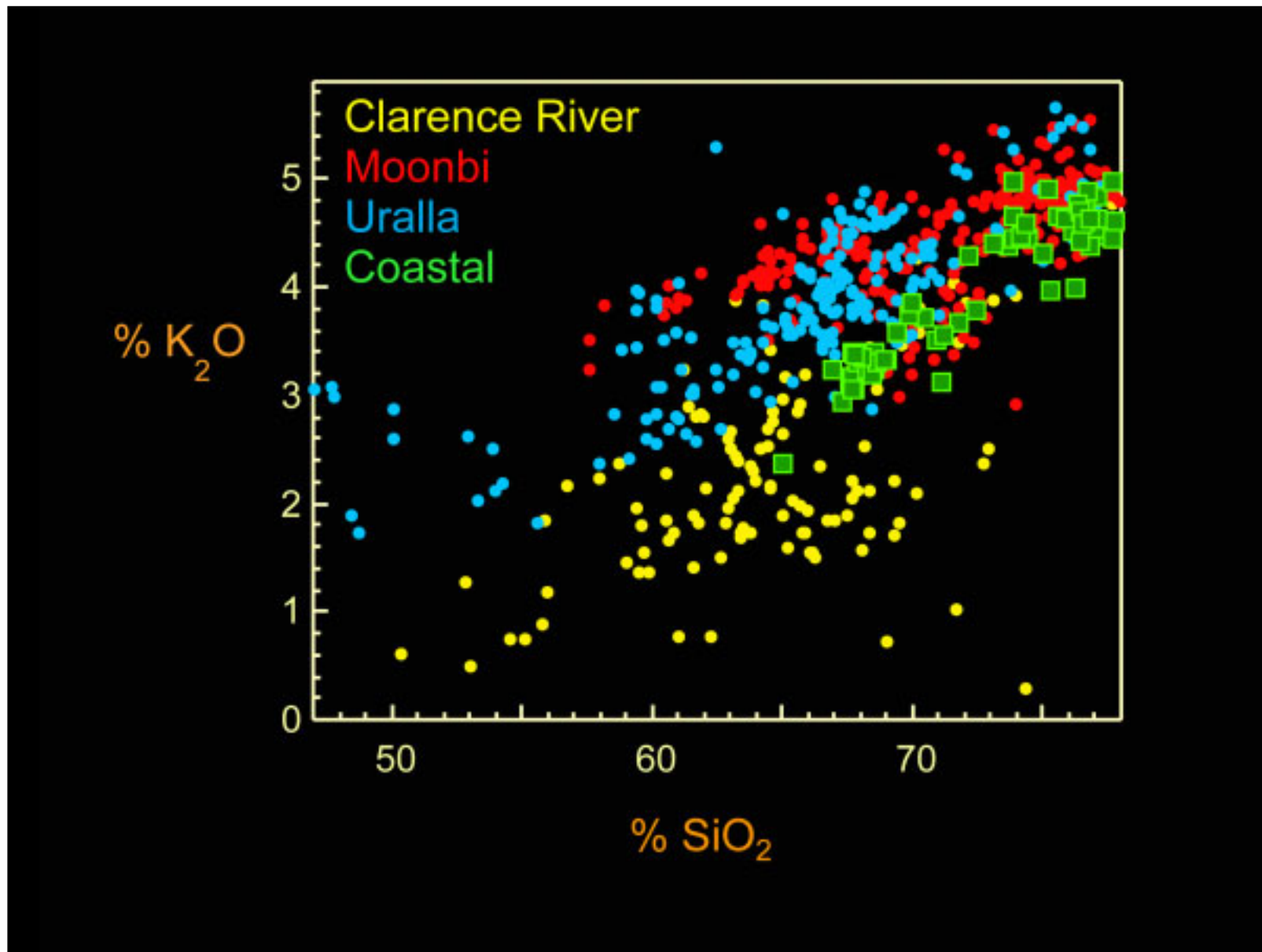
No two intrusions are identical (no suites)

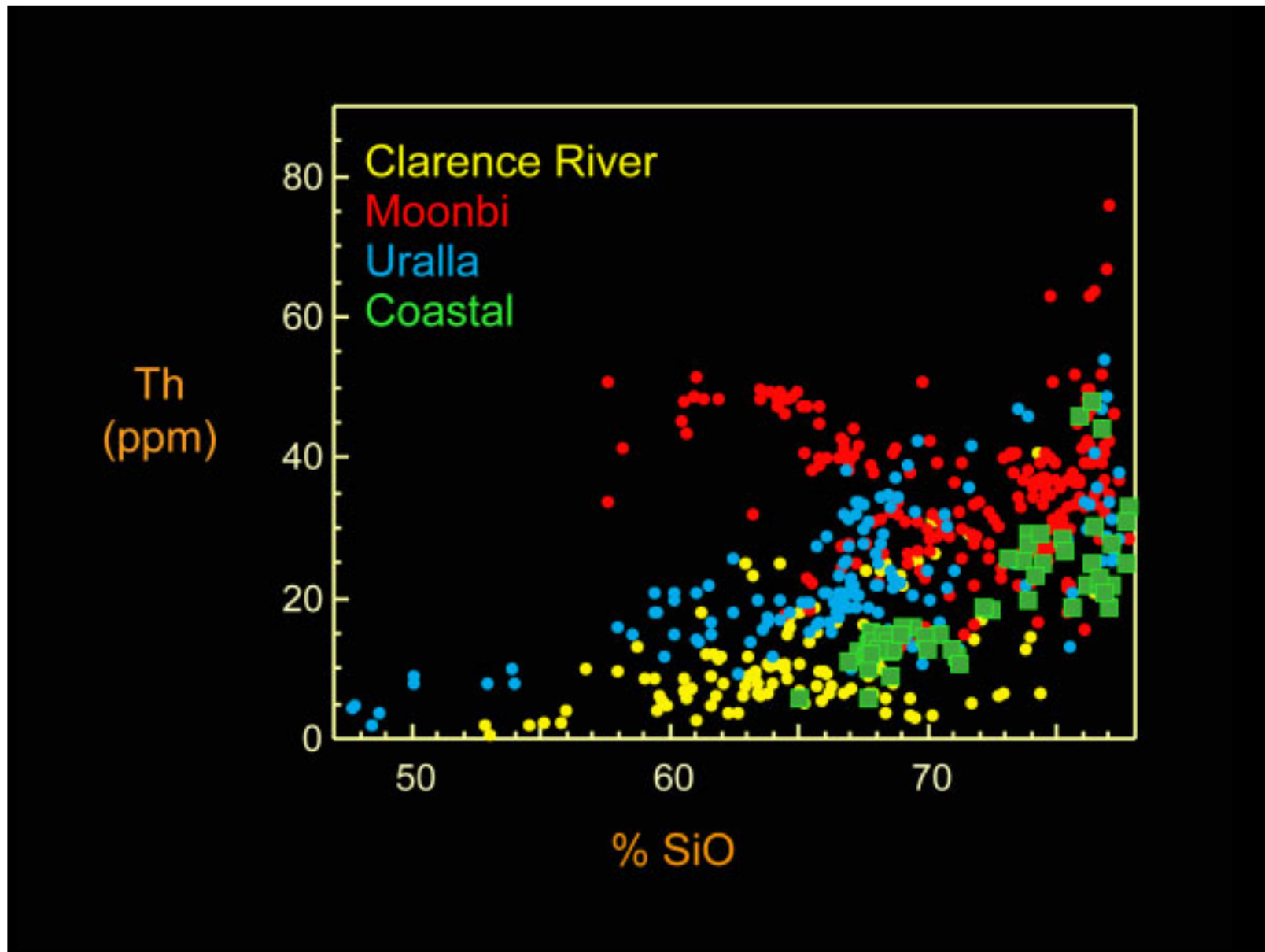
- Several different groups :

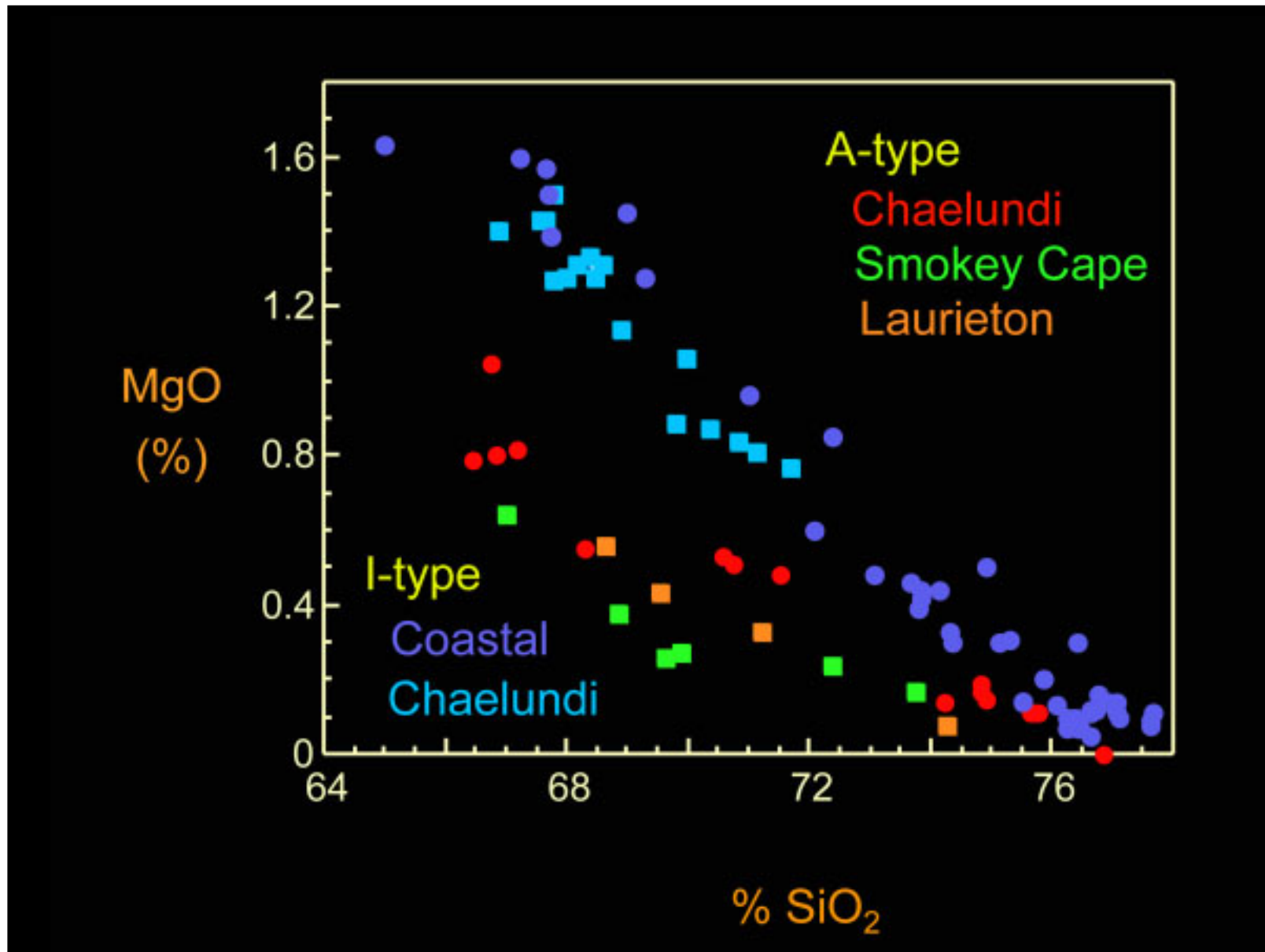
- Primitive CRSS Plutons* – opx and cpx bearing; lower SiO<sub>2</sub>; high CaO, FeO, MgO; low K, Rb, Ba, Sr, P, Ti, Th, U, LREE; very low  $^{87}\text{Sr}/^{86}\text{Sr}_{\text{initial}}$  and high  $\epsilon_{\text{Nd}}$  of +5.3 to +2.1

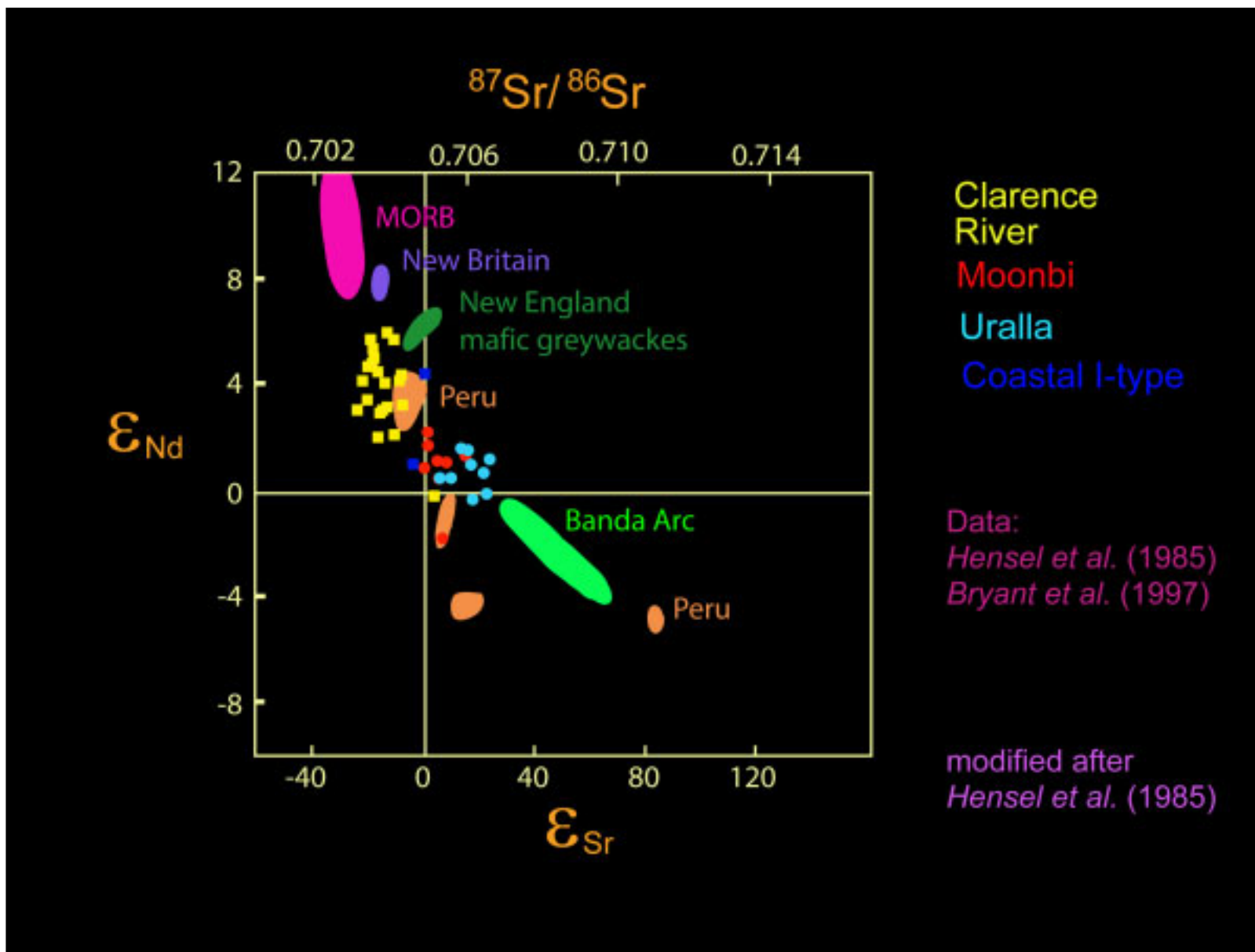
- Tonalite-Trondhjemite granites*; higher SiO<sub>2</sub>; more compositionally restricted; high Al<sub>2</sub>O<sub>3</sub>; Na<sub>2</sub>O, Sr; low FeO, Sc, V, Y and the HREE; with and without garnet signature; similar to adakites

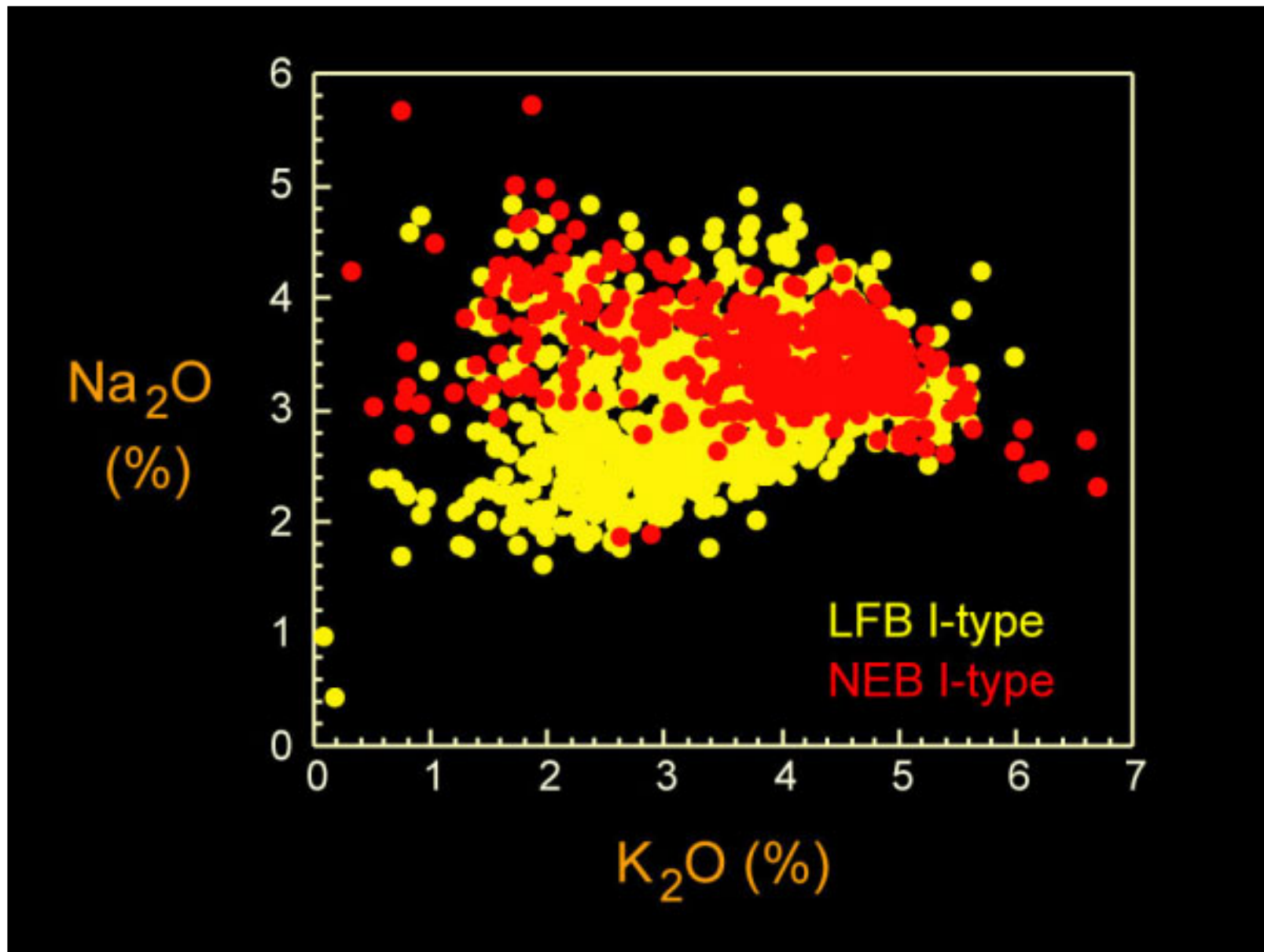
- Other*; include higher-K, higher HFSE intrusions

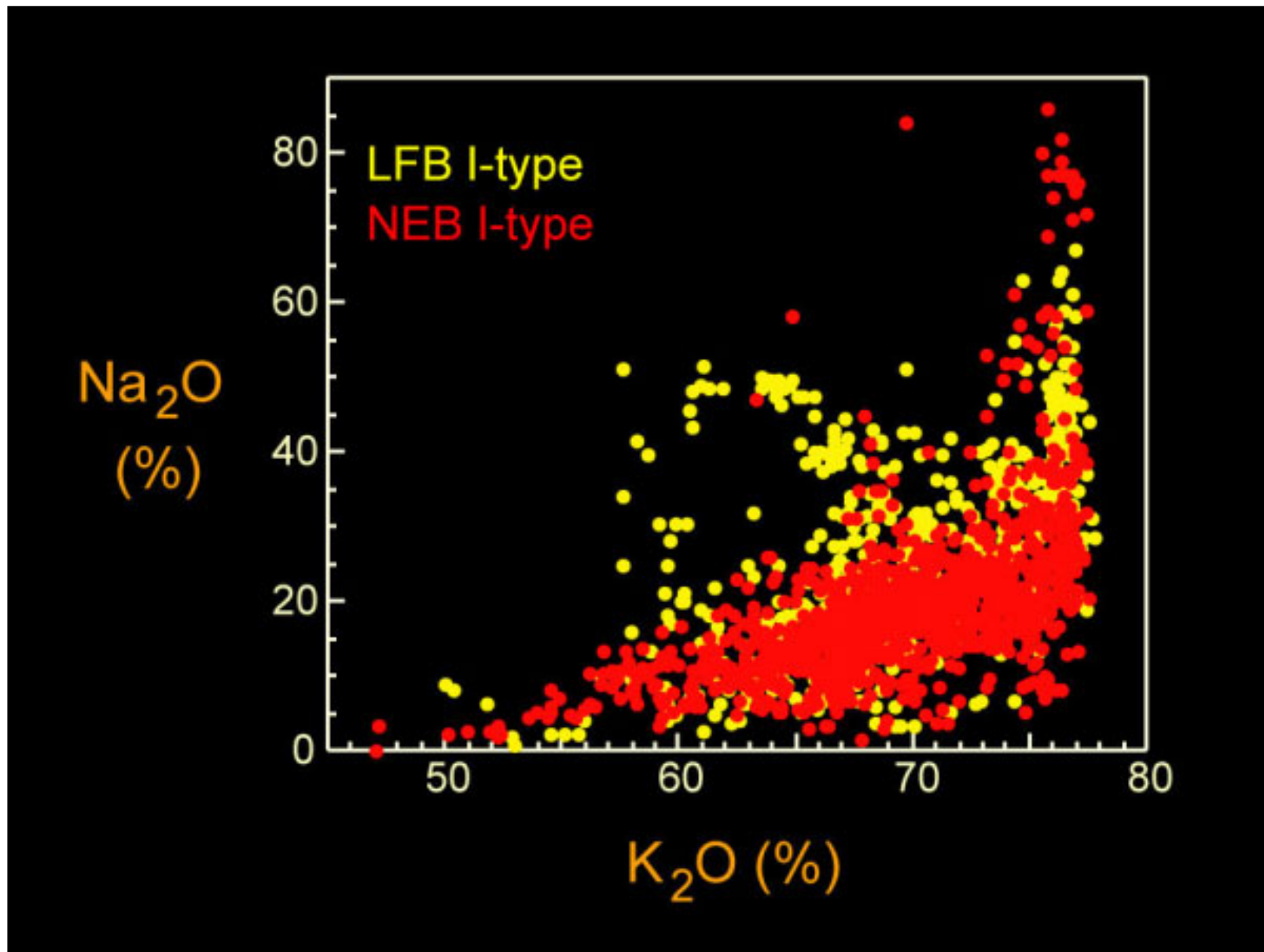












## NEB I-type – Source Rocks

### Clarence River

- relatively mafic, isotopically juvenile, low-K granites
- crystallised from high-temperature melt
- mantle-derived magmas – partial melting of juvenile crust

### Moonbi

- high-K granites,
- most mafic rocks are saturated in apatite, zircon, K-feldspar
- garnet in the source of southern Moonbi Supersuite
- shononitic parental material

### Uralla

- highly diverse group – strong regional zonation
- reduced I-type supersuite
- considerable contribution from sedimentary component
- some geochemical overlap with Moonbi Supersuite – northern portion of batholith, Mt Duval Group

Coastal I-type granites sodic, low-Sr, low K, Rb, Th; isotopically juvenile

## **New England Batholith**

- **both I- and S-types are sodic relative to the LFB**
- **both I- and S-type are isotopically very juvenile in comparison to their LFB counterparts – definite arc signature**
- **fewer S-type granites – these are less differentiated**
- **tonalitic I-type granites of the Clarence River Supersuite are a distinctive feature of juvenile crust generated in young arc settings**
- **NEB granites heterogeneous over short distances – fewer suites**
- **I-type suites are chemically more diverse – diversity of arc rock types initially incorporated into the crust; less homogenisation of the crust**
- **significant intra- and inter-supersuite zonation**
- **chemical and isotopic characteristics reflect granite magmatism in a juvenile crustal environment**