HIGH- AND LOW-TEMPERATURE GRANITES

Bruce Chappell
GEMOC, Macquarie University, NSW 2010

I-type granites of the Palaeozoic fold belts of Eastern Australia fall into two groups, formed at high and low magmatic temperatures. The distinction is made on the absence or presence, respectively, of zircon with inherited ages in the more mafic rocks determined using an ion probe (Williams, 1995), and related differences in Zr variation patterns with SiO_2. The high-temperature I-type granites formed from a magma that was completely or largely molten, and in which crystals of zircon were not initially present because the melt was undersaturated in zircon. In contrast with the low-temperature I-type granites, the compositions extend to lower SiO_2 contents and the abundances of Ba, Zr and the rare earth elements initially increase with increasing SiO_2 in the more mafic rocks. While the high-temperature granite magmas were produced by the partial melting of mafic source rocks and represent a comparatively primitive addition to the upper crust, the low-temperature I-type granites resulted from the partial melting of quartzofeldspathic rocks such as older tonalites. In that second case the melt produced was felsic and the more mafic low-temperature granites have that character because of the presence of entrained and magmatically equilibrated restite which includes older zircon crystals. These low-temperature granites may occur in close association with S-type granites since both are products of the magmatic recycling of older crust. There are also broad differences in composition between the I-type groups, with the low-temperature granites being more typically granodiorites and monzogranites. In contrast, tonalites and low-K granodiorites characterise the high-temperature granites, which have inherited that and associated features from their less evolved source materials. S-type granites, at least in the Lachlan Fold Belt, appear to always contain inherited zircon, and are therefore of low-temperature character.

The use of zircon saturation temperatures verifies the restite model for what we term the low-temperature I-type granites, and for the S-type granites (Chappell, 2003a). Those saturation temperatures, the presence of zircon with age inheritance, and the patterns of Zr variation show that the bulk of I-type granites of the Lachlan Fold Belt evolved by restite fractionation, and confirm that some did not, notably the Boggy Plain Supersuite, as we have long advocated (Wyborn, 1983; Chappell *et al.* 1987). Use of zircon saturation based on age-inheritance, and with its distinctive bulk rock chemical fingerprint, at least at more mafic compositions, provides a definitive test of whether a particular suite evolved either by fractionation of restite or in some other way.

Clemens (2003) has challenged the use of zircon saturation temperatures to estimate the temperature of S-type granite melts. He states that the behaviours of zircon and Zr are controlled by disequilibrium and kinetics, so that magma temperatures can rarely be calculated. Clemens (2003) argues that the rate of ascent of magma is far too rapid for equilibrium, which may be so. However the time of partial melting during which the minerals in the source rocks are melting or being transformed to other minerals by melt-forming reactions, would be quite long, so that kinetics should not be a problem. Also, the patterns of Zr variation observed in granite suites, that is Zr generally decreasing with increasing SiO_2 contents throughout low-temperature suites, and increasing towards higher SiO_2 contents in the more mafic rocks of high-temperature suites, must be noted. These variations are consistent only with the former being saturated in zircon, and the latter being undersaturated. Clemens (2001) also argued that it is likely that the more mafic granites are cumulates, rather than former liquids, so the saturation temperature for such a composition is meaningless. Chappell (2003a) has noted that the more mafic S-type granites of the LFB cannot be cumulate or cumulative rocks, and must represent magma compositions.

That I-type granites occur as two distinct types, high- and low-temperature, based on the absence or presence respectively of inherited zircons, has many important implications. To an extent this has previously been discussed, in a different guise, by Chappell (1996) in considering the implications of the restite model. One important implication relates to the potential for association with mineral deposits. Because of both their higher temperatures, and a greater potential to undergo changes in composition, including a progressive increase in both the activity of H_2O and the concentrations of incompatible elements through the process of fractional crystallisation, the high-temperature granite types are more likely to be related to significant mineralisation. This is clearly seen in eastern Australia (Blevin & Chappell, 1992) where, for example, most of the Devonian- and Carboniferous-age I-type granites of the Lachlan Fold Belt, largely of low-temperature origin, are conspicuously lacking in associated mineralisation

Miller *et al*. (2003) have recognised two distinct classes of granite. Their "cold" granites are rich in inherited zircon and formed by melting at temperatures less than 800°C, while the "hot" inheritance-poor granites formed at higher temperatures. This is not precisely the same subdivision as that of Chappell *et al*. (1998), which is based on the presence or absence of inherited zircon determined by ion probe analysis, so the low-temperature granites of that earlier contribution would include the "cold" and some of the "hot" granites of the later authors. Also, in proposing their subdivision, Chappell e*t al*. (1998) pointed out that the patterns of Zr variation within low- and high-temperature suites of granites are distinctive and can be used as a secondary criterion. Also, Miller *et al*. (2003) have calculated zircon saturation temperatures for rocks which, in the view of this author, might not represent melt compositions. Miller e*t al*. (2003) suggest that their two types must have different mechanisms of melting, whereas Chappell (2003b) considers that the differences are related to source rock compositions, specifically to the fraction of minimum-temperature melt components in the source rocks.

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Clemens, J.D. 2001. S-type granites—models and evidence. *In*: Chappell, B.W. & Fleming, P.D. (eds). S-type Granites and Related Rocks. Abstract volume. *Australian Geological Survey Organisation. Record* **2001/02**, 31-32.

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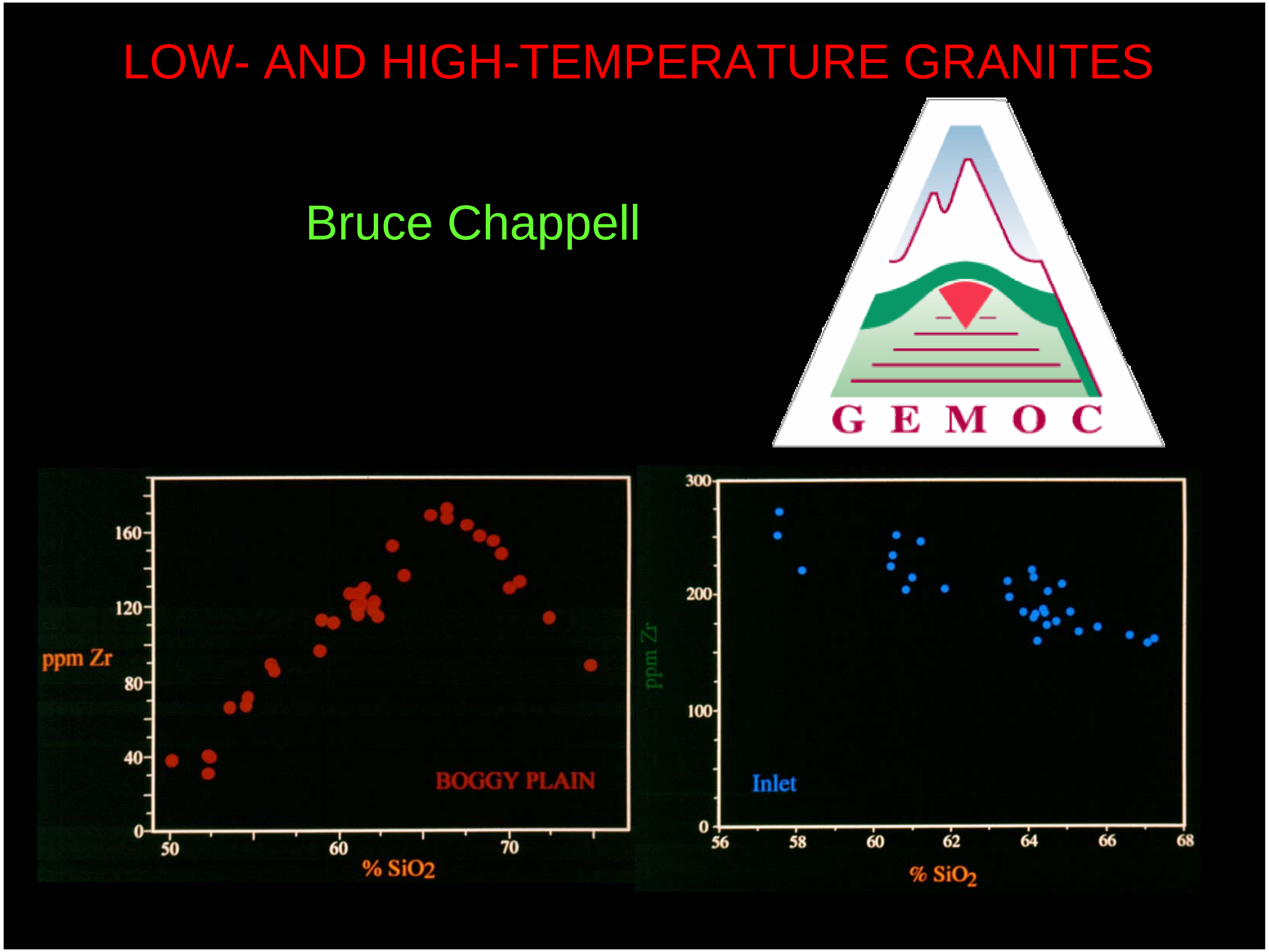

LOW- AND HIGH-TEMPERATURE GRANITES

Bruce Chappell

PROBLEMS WITH THE FRACTIONAL CRYSTALLISATION MODEL

The *fractional crystallisation model* is soundly based for some granite suites. But it encounters difficulties if it is applied to many of the granite suites of the LFB and elsewhere.

In particular, the common occurrence of “linear” variations within rocks suites is very difficult, if not completely impossible in most cases, to account for by using that model. We have also seen that magma mixing/mingling, which theoretically would produce such variations, is not feasible on a large scale. Some other mechanism seems to have produced the variations within many granite suites.

Also, in some cases, particularly for S-type suites, the direction of the variation for some elements is not compatible with the fractional crystallisation model.

These and other problems lead White *et al*. (1977) to propose a *restite model,* in which variations are accounted for on the basis of varying degrees of separation of solid material (restite) from melt, the restite being residual from the partial melting of the source rocks which produced that melt.

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Some references on the restite model:

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White, A.J.R. & Chappell, B.W. 1977. Ultrametamorphism and granitoid genesis. *Tectonophysics* **43**, 7-22.

Griffin, T.J., White, A.J.R. & Chappell, B.W. 1978. The Moruya Batholith and geochemical contrasts between the Moruya and Jindabyne suites. *Journal of the Geological Society of Australia* **25**, 235-247.

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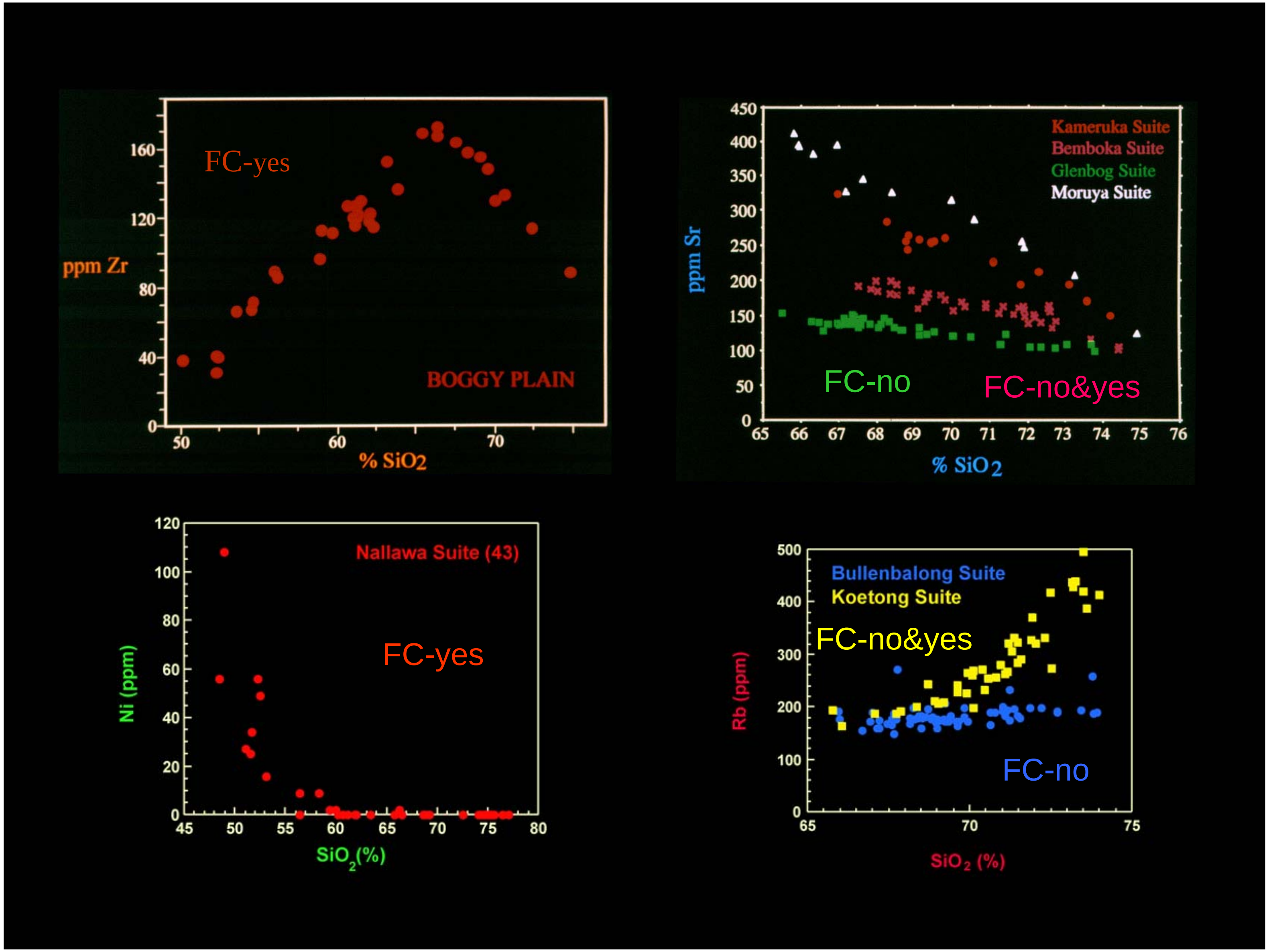
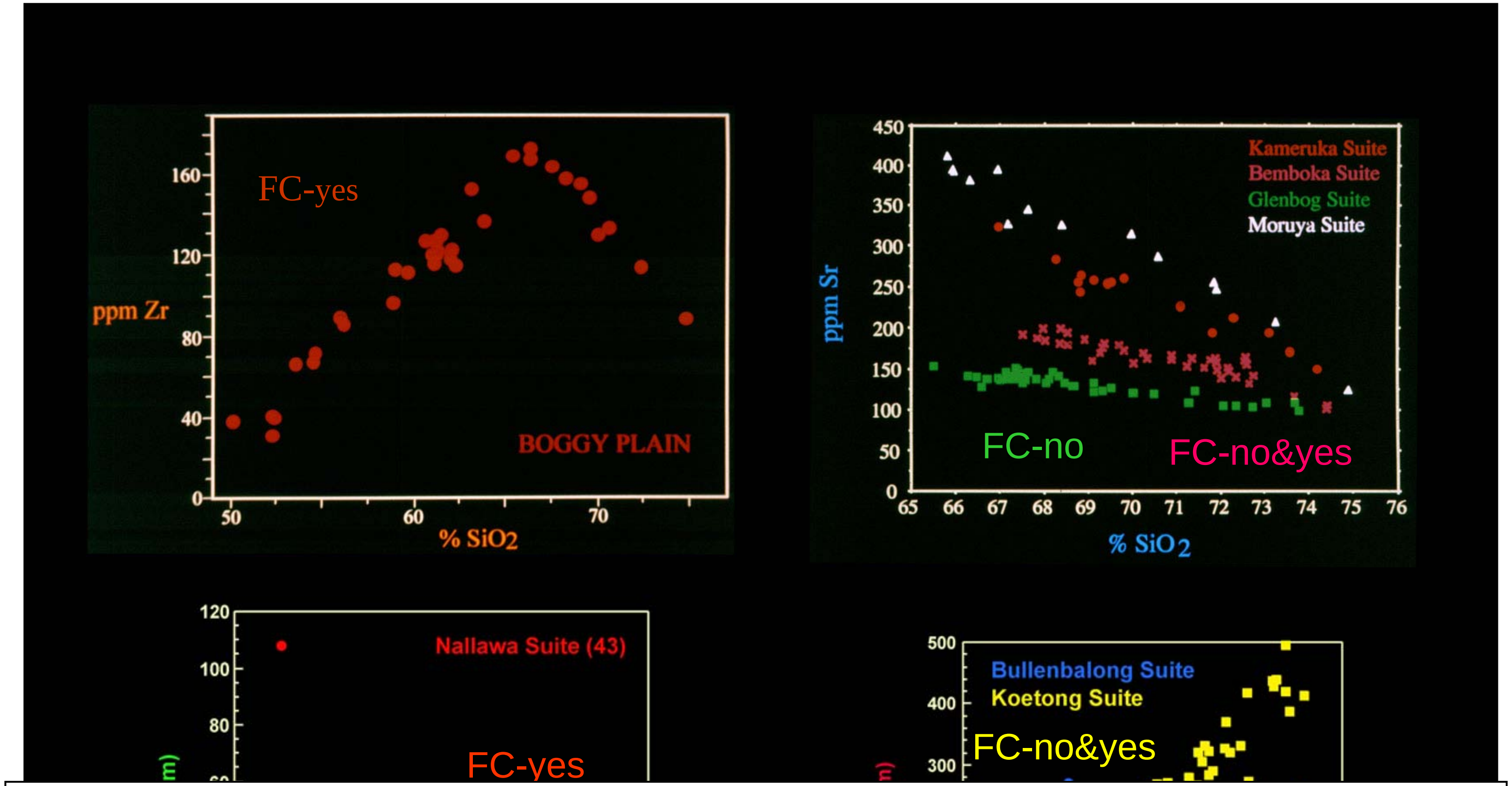
White, A.J.R., Chappell, B.W. & Wyborn, D. 1999. Application of the restite model to the Deddick Grano-diorite and its enclaves: a re-interpretation of the observations and data of Maas *et al*. (1998). *Journal of Petrology* **40**, 413-421.


FC-yes
ppm Zr
160
120
80
40
0
50
60
70
% SiO2
BOGGY PLAIN
ppm Sr
450
400
350
300
250
200
150
100
50
0
65
66
67
68
69
70
71
72
73
74
75
76
% SiO2
Kameruka Suite
Bemboka Suite
Glenbog Suite
Moruya Suite
FC-no
FC-no&yes
Ni (ppm)
120
100
80
60
40
20
0
45
50
55
60
65
70
75
80
SiO2(%)
Nallawa Suite (43)
FC-yes
Rb (ppm)
500
400
300
200
100
0
65
70
75
SiO2 (%)
Bullenbalong Suite
Koetong Suite
FC-no&yes
FC-no



Variation in the Bemboka Suite is dominated by restite separation, with the three most felsic samples being further modified by fractional crystallisation of the primary melt.

For the Koetong Suite, it is thought that below about 69% SiO_2, the compositions evolved by restite separation, and by fractional crystallisation at higher SiO_2 values. For the Bullenbalong Suite, one sample at the felsic end was modiified by fractional crystallisation.

7. RESTITE FRACTIONATION

The *restite model* was developed to account for features of many granite suites that cannot be readily accounted for using other models such as magma mixing and fractional crystallisation (Chappell, 1966; White & Chappell, 1977; Griffin et al., 1978; Chappell *et al*., 1987; Chappell & White, 2001). Among the LFB granites, powerful support for the restite model comes simply from the contrast in petrological and compositional features between most suites and those that clearly did evolve through fractional crystallisation, such as the Boggy Plain Supersuite of Wyborn *et al*. (1987).

The high correlations between element abundances that are observed for many granite suites, giving “linear” variations on Harker Diagrams, are interpreted using this model as resulting from the separation of varying amounts of a restite component from the magma. The composition of the partial melt lies at the felsic end of these trends, or their extrapolations, while the composition of the original source rock is located near the mafic end of the trends. This accounts for the correlation in abundances at either end of the variation within suites, with each element being partitioned into the melt and restite phases during partial melting, e.g. for Sr in the Bega Batholith suites shown in the previous slide. Among other features of many granites that the restite model can readily account for are the older zircon cores and the relatively uniform cores of plagioclase crystals.

The restite model has been controversial. For example, Collins (1998) stated “... the restite model as outlined by White & Chappell (1977) and Chappell *et al*. (1987) is regarded as generally inapplicable for Lachlan Fold Belt granitoid petrogenesis”. Wall *et al*. (1987) suggested that the model be left to ***R***est ***I***n ***P***eace. The alternative view is that it represents a ***R***evolution ***I***n ***P***etrogenesis.

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The high correlations between element abundances that are observed for many granite suites, giving "linear" variations on Harker Diagrams, are interpreted using this

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Collins, W.J. 1998. Evaluation of petrogenetic models for Lachlan Fold Belt granitoids: implications for crustal architecture and tectonic models. *Australian Journal of Earth Sciences* **45**, 483-500.

Griffin, T.J., White, A.J.R. & Chappell, B.W. 1978. The Moruya Batholith and geochemical contrasts between the Moruya and Jindabyne suites. *Journal of the Geological Society of Australia* **25**, 235-247.

Wall, V.J., Clemens, J.D. & Clarke, D.B. 1987. Models for granitoid evolution and source compositions. *Journal of Geology* **95**, 731-749.

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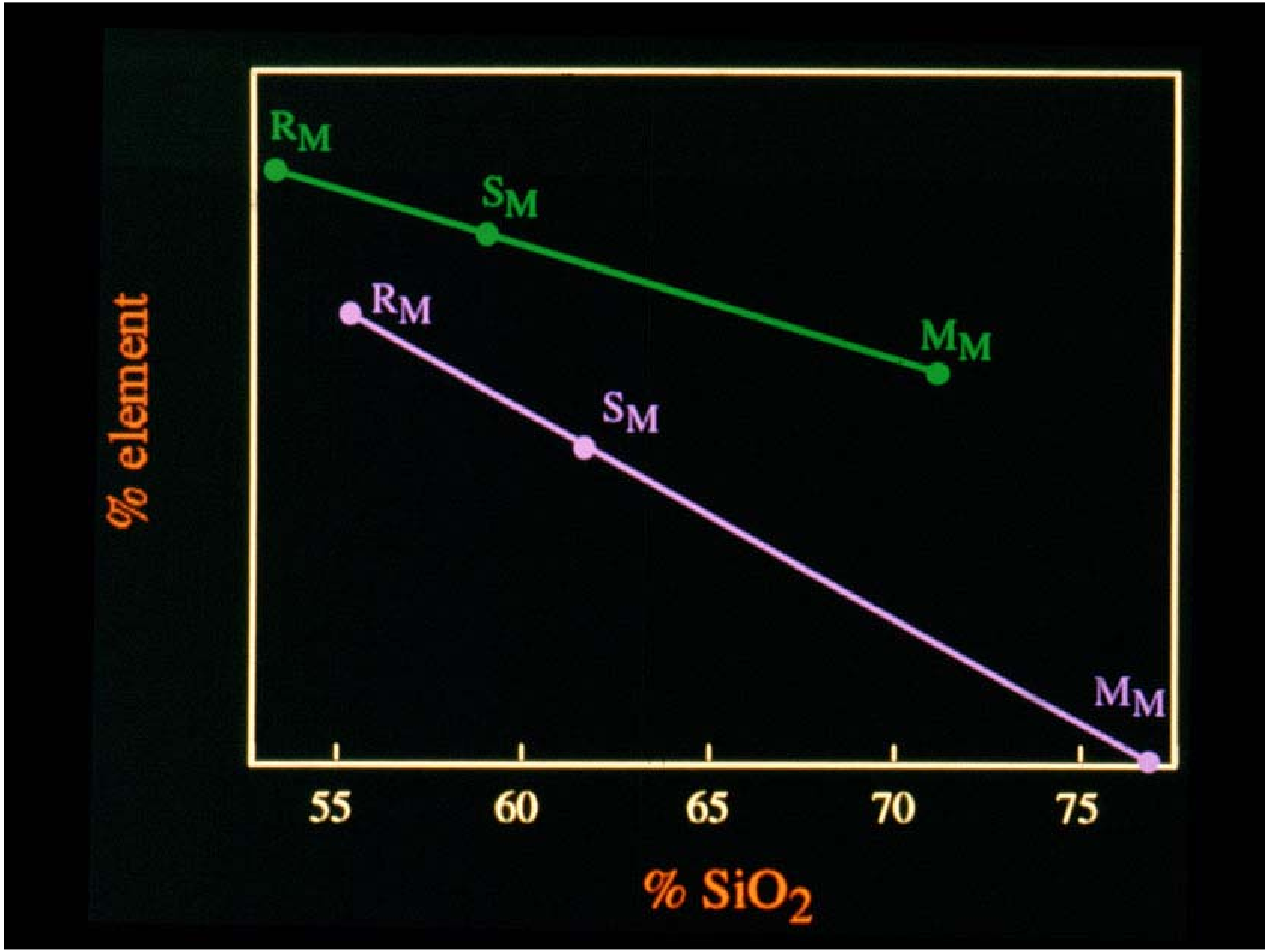
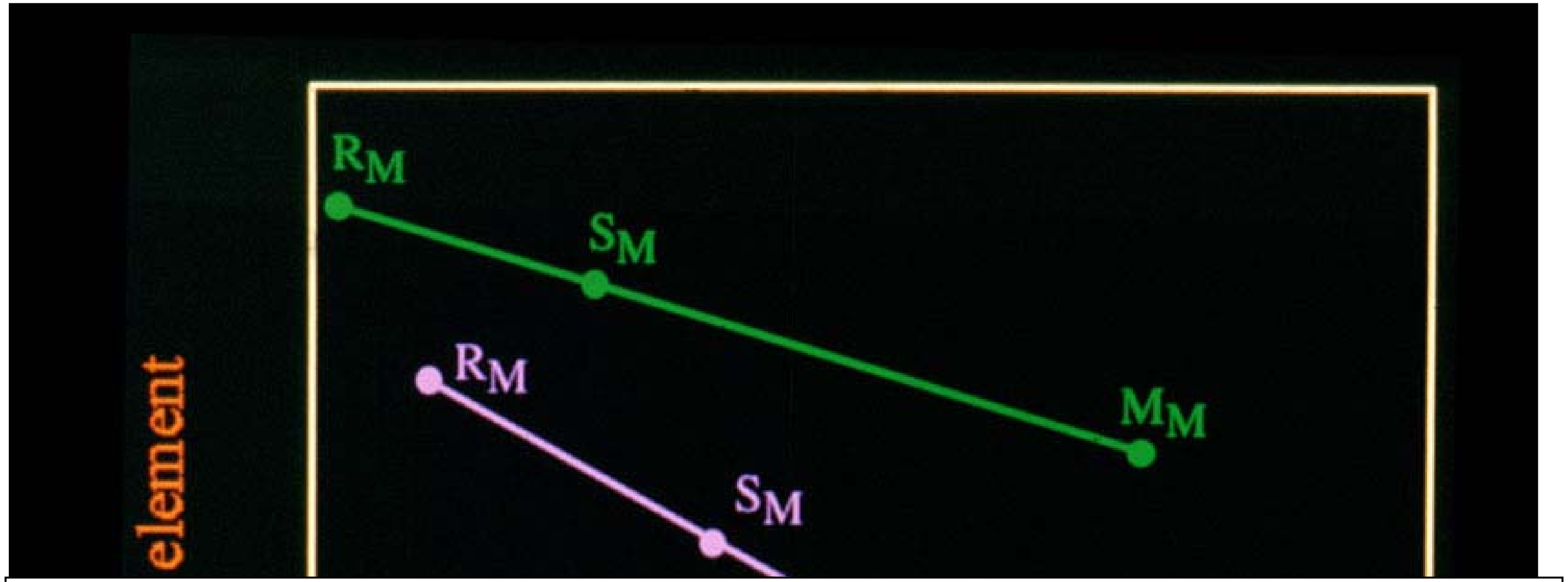
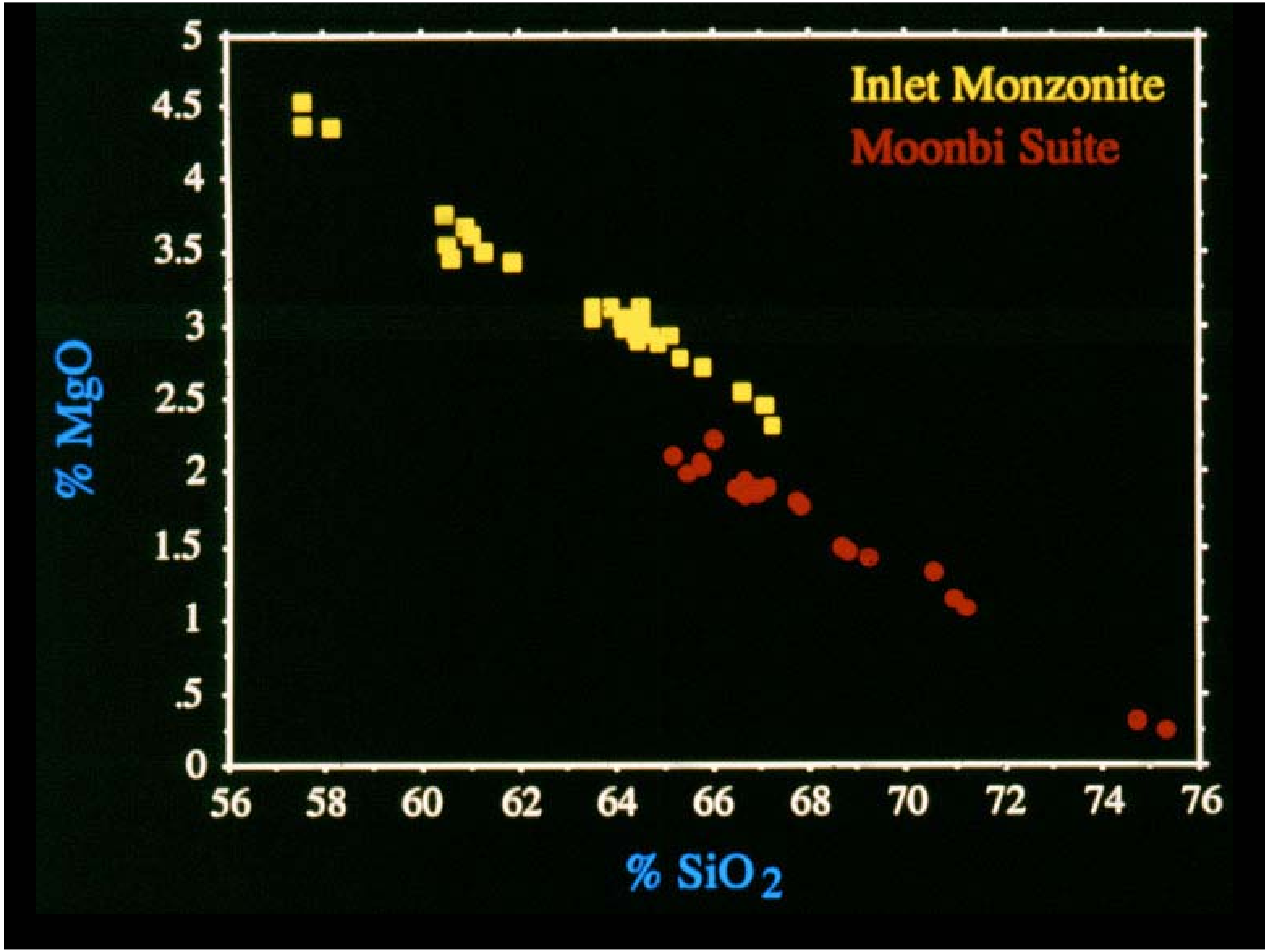
Wyborn, D., Turner, B.S. & Chappell, B.W. 1987. The Boggy Plain Supersuite: a distinctive belt of I-type igneous rocks of potential economic significance in the Lachlan Fold Belt. *Australian Journal of Earth Sciences* **34**, 21-43.


R_M
S_M
M_M
R_M
S_M
M_M
% element
55
60
65
70
75
% SiO_2



According to the restite model, source rocks of composition S_M split into melt (M_M) and restite (R_M) components during partial melting. Those two components comprise a magma once the fraction of melt exceeds the critical melt fraction. That magma initially has the bulk composition S_M. Fractionation between melt and restite may produce compositions lying along the line joining the melt and restite compositions. In granite suites that evolved in this way, and which have a wide range of compositions, the source rock compositions will lie on the restite-unmixing line and are thought to be close to those of the most mafic rock in a suite. This was taken as a *model source composition* by Chappell (1984). In the extreme case, there may be no fractionation between melt and restite and the composition of the granite (or volcanic rock) will precisely match that of the source rocks.

Chappell, B.W. 1984. Source rocks of I- and S-type granites in the Lachlan Fold Belt, southeastern Australia. *Philosophical Transactions of the Royal Society of London* A **310**, 693-707.


Inlet Monzonite
Moonbi Suite
% MgO
% SiO2
5
4.5
4
3.5
3
2.5
2
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.5
0
56
58
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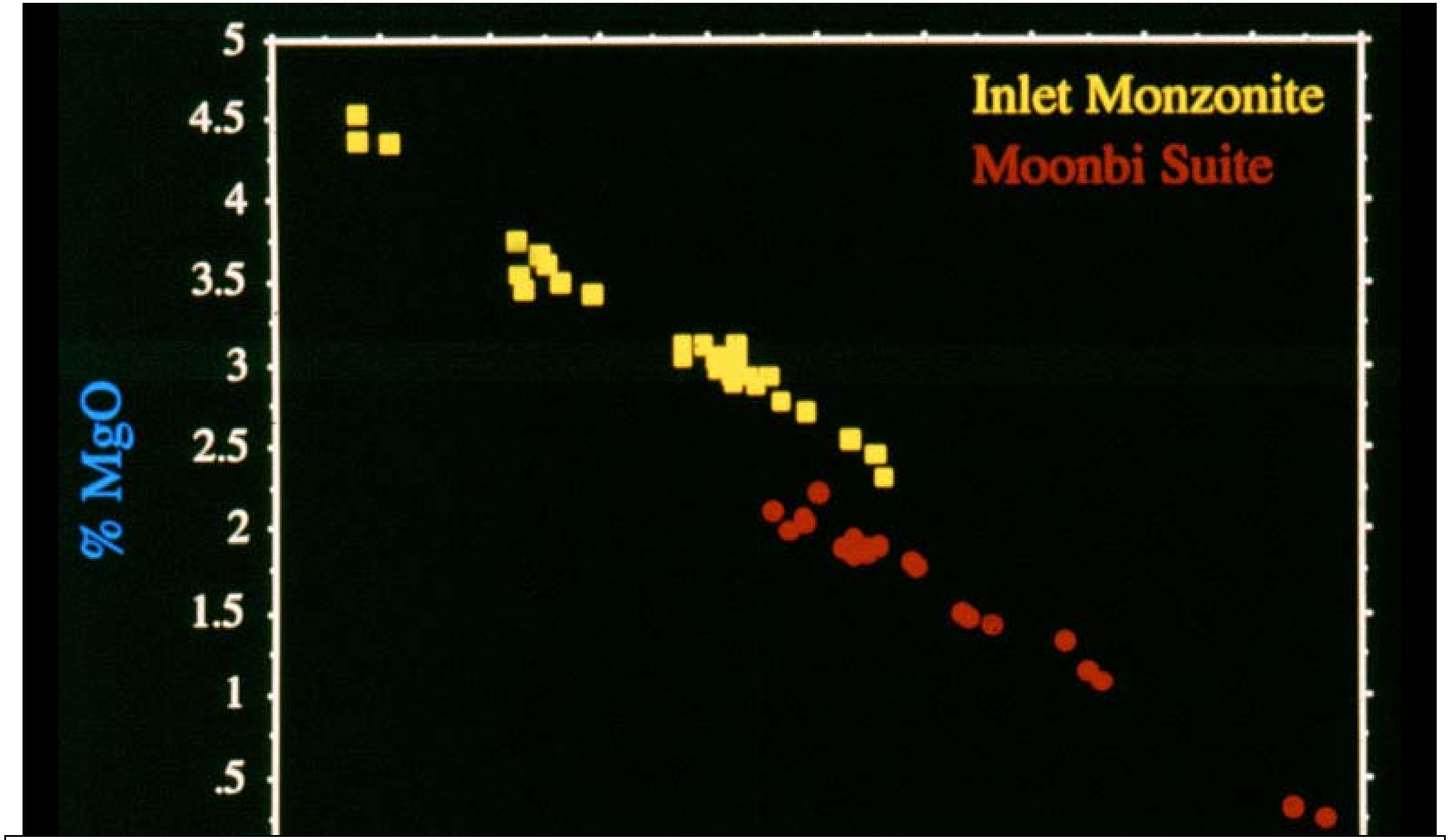
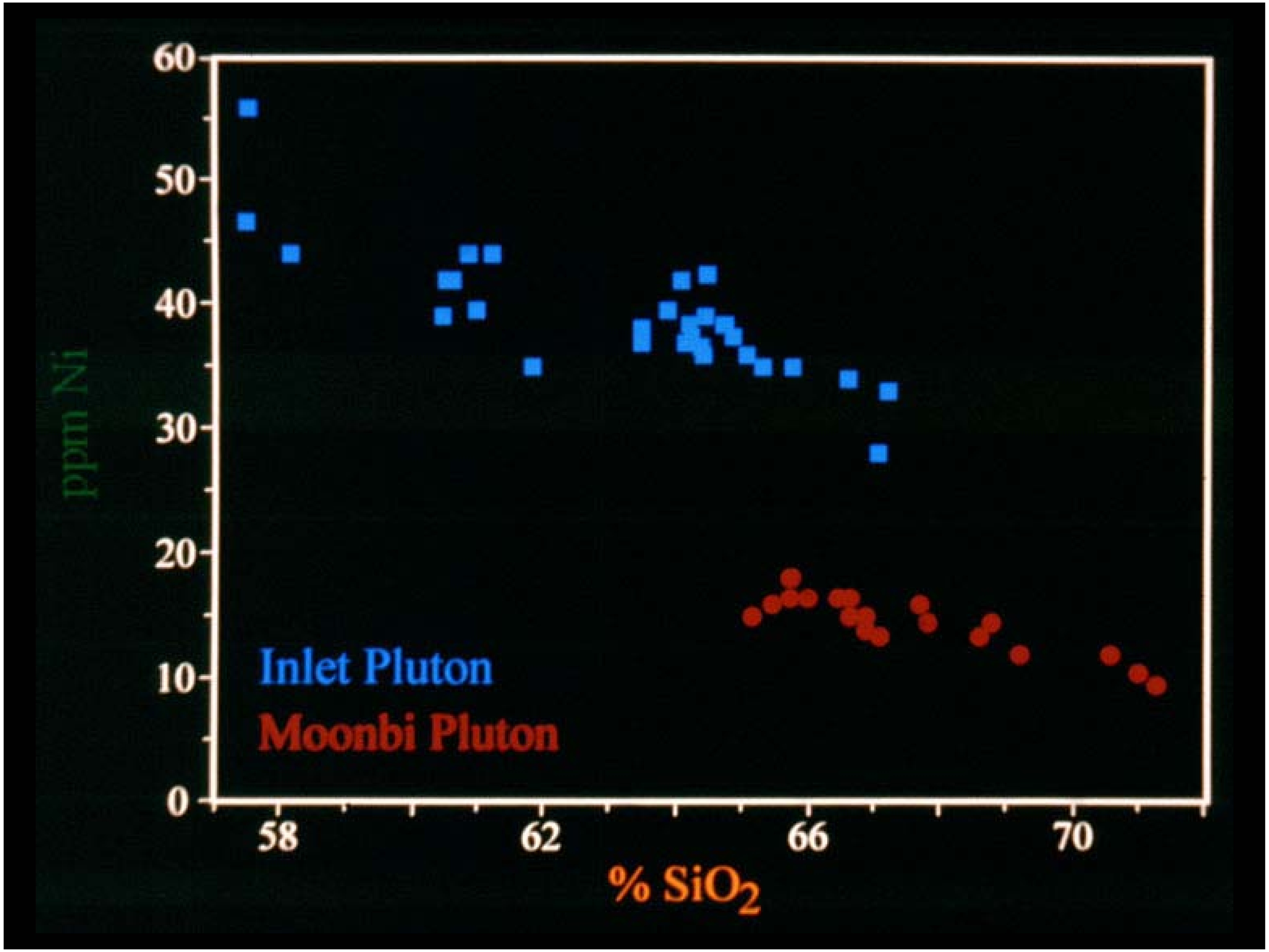


For the Inlet Monzonite, the melting went to higher temperatures, although it is not a “high-temperature” granite. The melt composition was about 68% SiO_2 and it contained a significant amount of MgO.


ppm Ni
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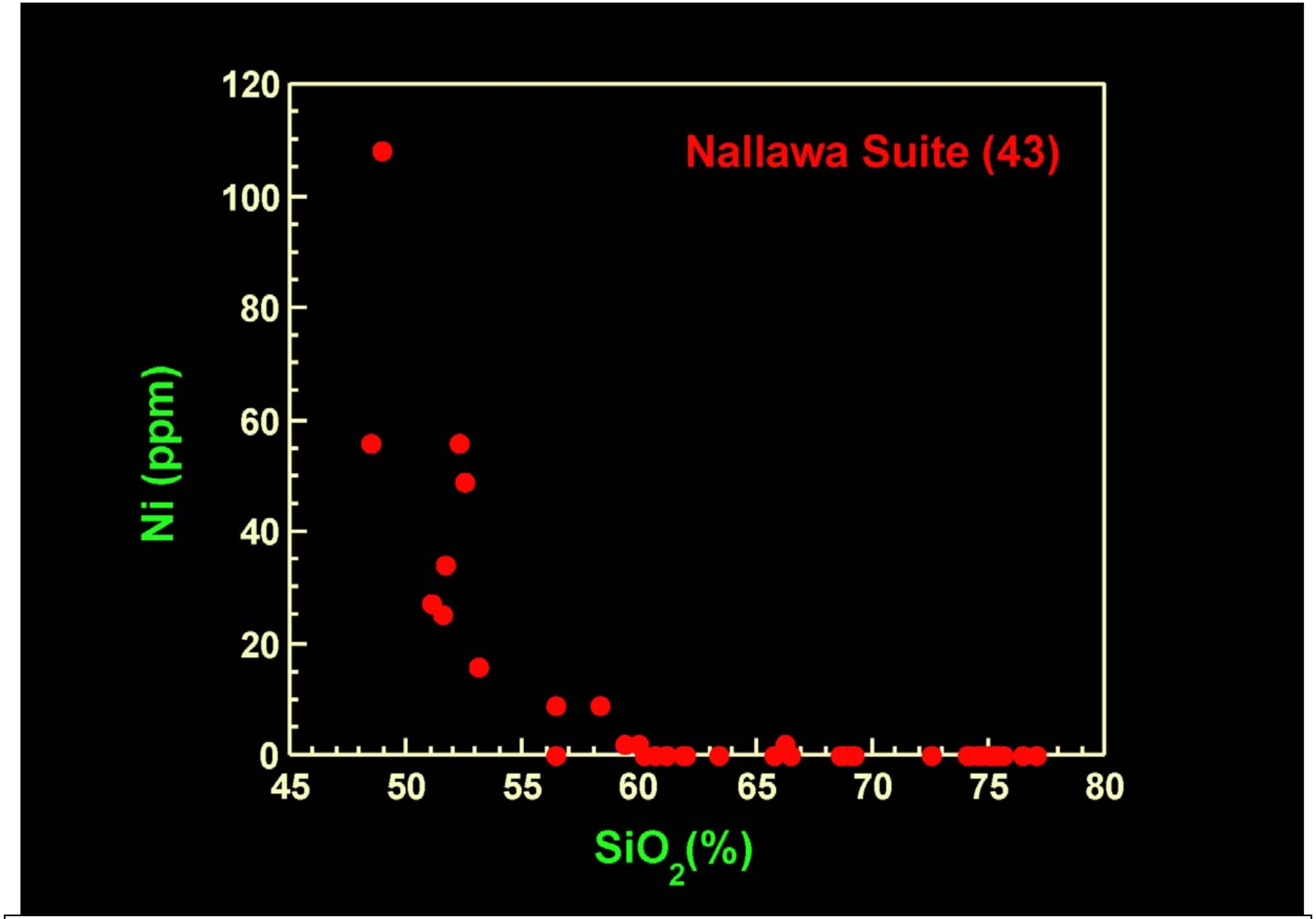
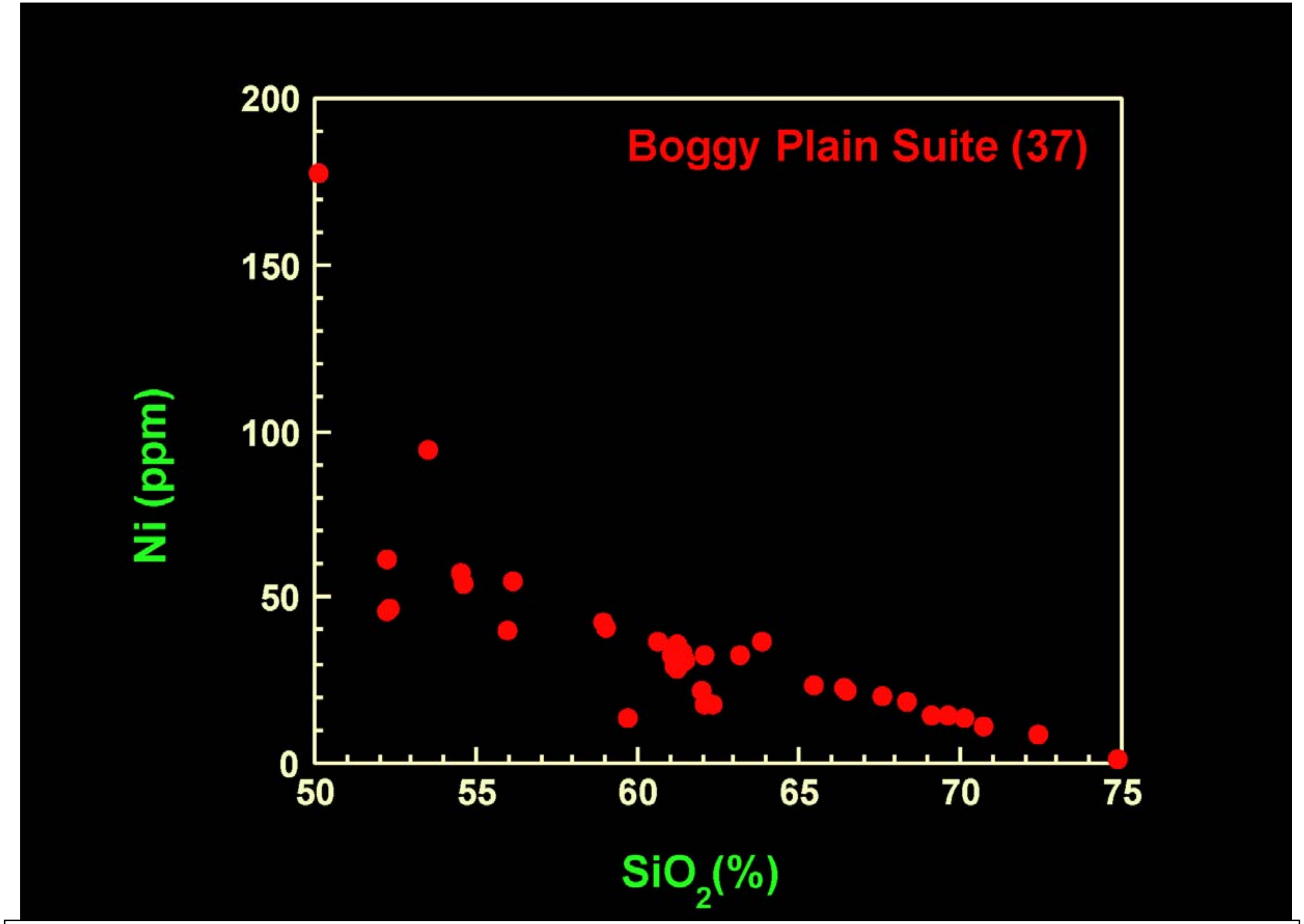
% SiO$_2$
Inlet Pluton
Moonbi Pluton

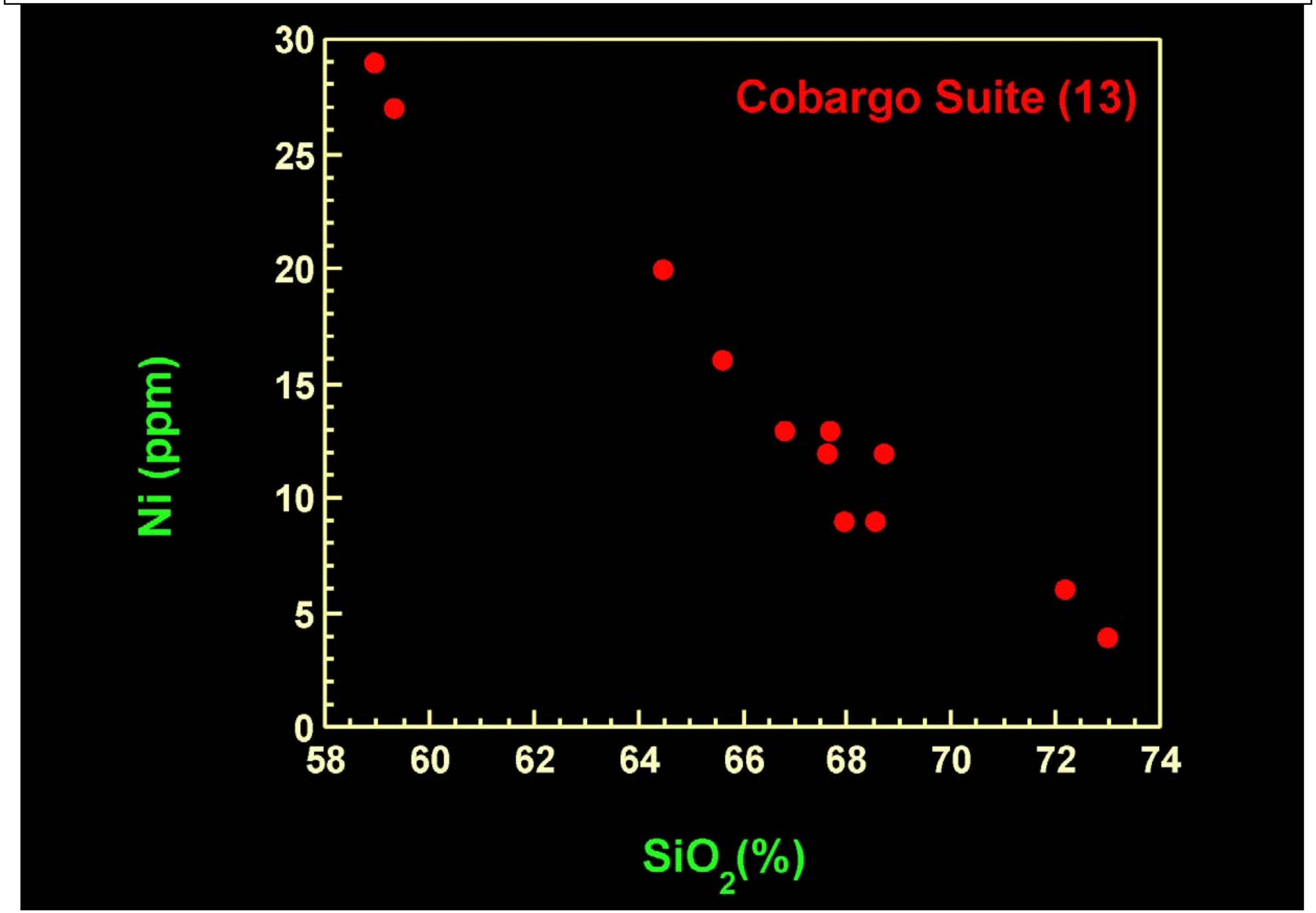


This shows the contrasting behaviour that results from fractional crystallisation.



Fractional crystallisation can generate straight lines, at least over part of the compositional range.

This is a classic case of restite unmixing.

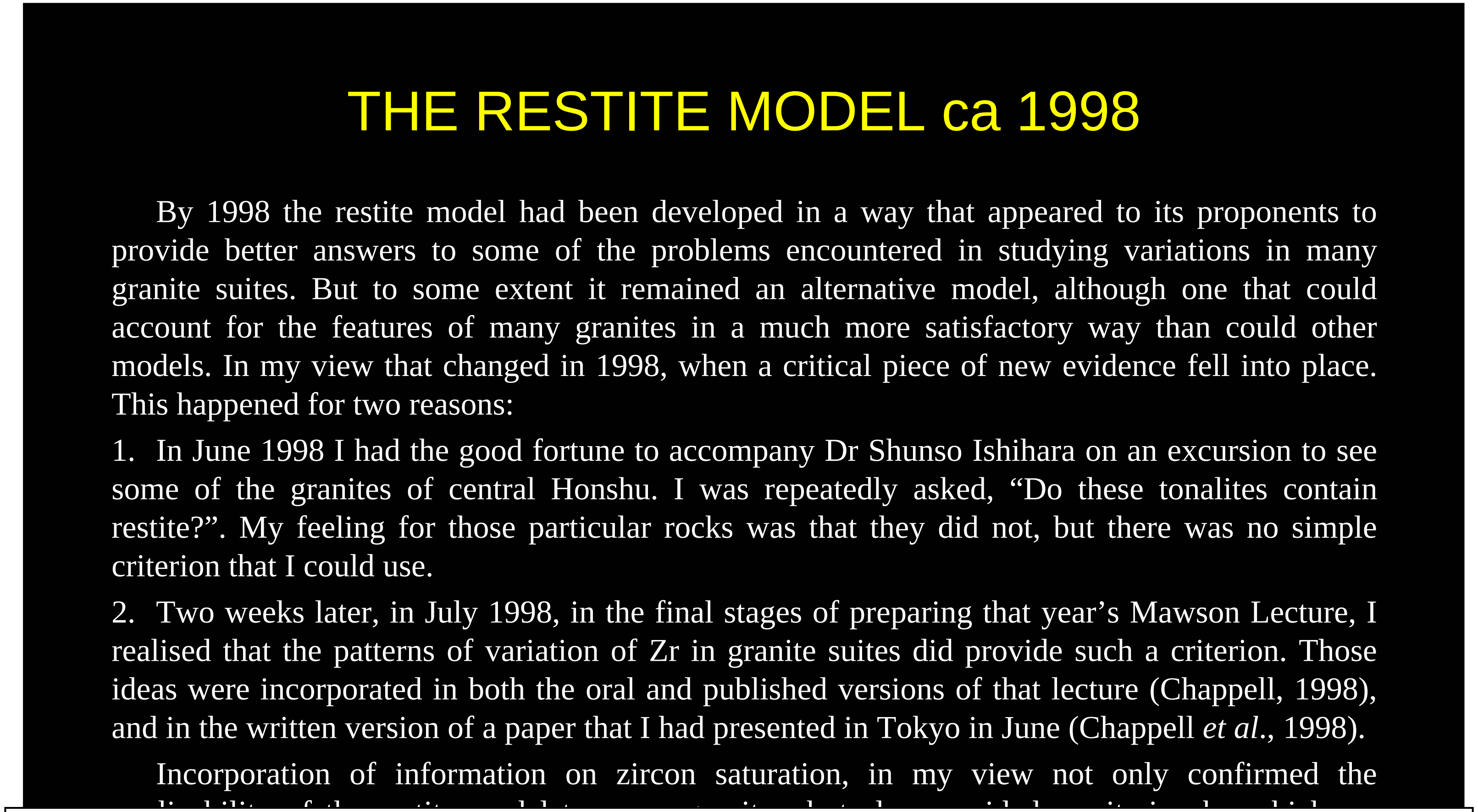


THE RESTITE MODEL ca 1998

By 1998 the restite model had been developed in a way that appeared to its proponents to provide better answers to some of the problems encountered in studying variations in many granite suites. But to some extent it remained an alternative model, although one that could account for the features of many granites in a much more satisfactory way than could other models. In my view that changed in 1998, when a critical piece of new evidence fell into place. This happened for two reasons:

1. In June 1998 I had the good fortune to accompany Dr Shunso Ishihara on an excursion to see some of the granites of central Honshu. I was repeatedly asked, “Do these tonalites contain restite?”. My feeling for those particular rocks was that they did not, but there was no simple criterion that I could use.
2. Two weeks later, in July 1998, in the final stages of preparing that year’s Mawson Lecture, I realised that the patterns of variation of Zr in granite suites did provide such a criterion. Those ideas were incorporated in both the oral and published versions of that lecture (Chappell, 1998), and in the written version of a paper that I had presented in Tokyo in June (Chappell *et al*., 1998).

Incorporation of information on zircon saturation, in my view not only confirmed the applicability of the restite model to many granites, but also provided a criterion by which we could say to which granites it applies, and to which it does not. We now know that it is, overall, the most common process by which granites evolve. It is the only completely new mechanism for the evolution of the igneous rocks that has been developed since the classic book of that name by Bowen in 1928. Which presumably largely accounts for the extreme opposition that the model has encountered!



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Chappell, B.W. 1998. Tectonic evolution of the eastern Australian fold belts from a granite-based perspective: 1998 Mawson Lecture. *The Australian Geologist* **109**, 24-30.

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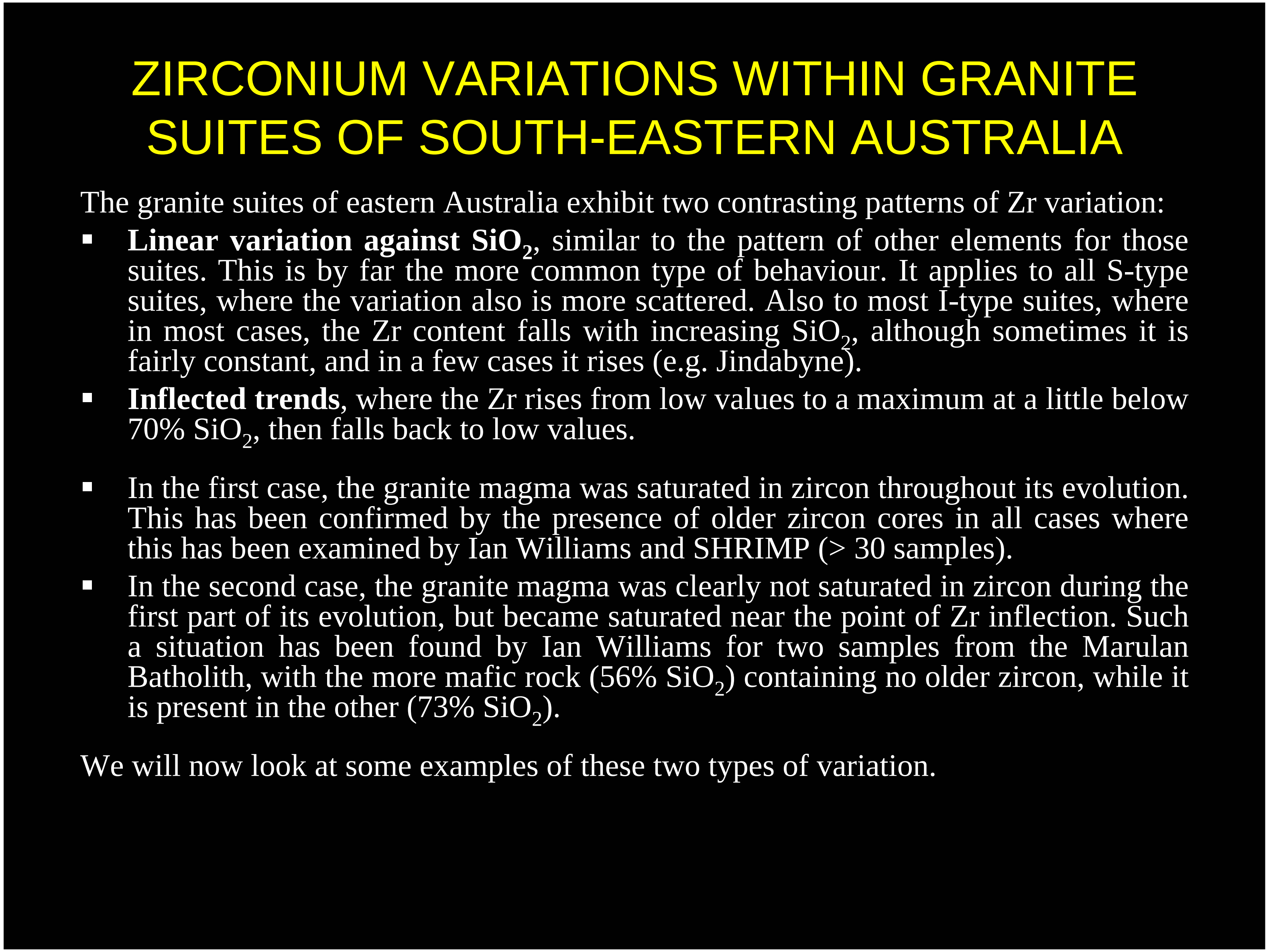


ZIRCONIUM VARIATIONS WITHIN GRANITE SUITES OF SOUTH-EASTERN AUSTRALIA

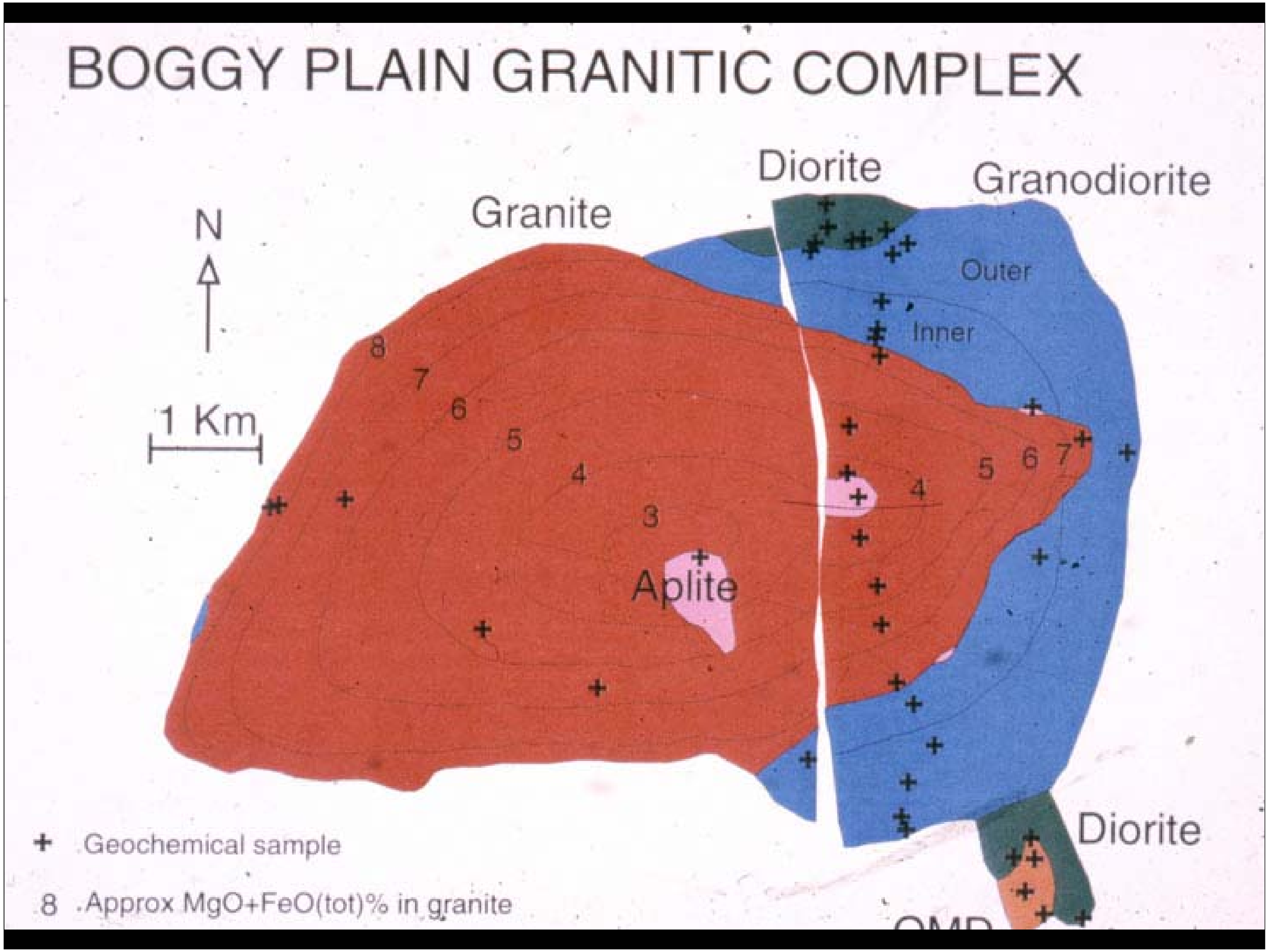
The granite suites of eastern Australia exhibit two contrasting patterns of Zr variation:

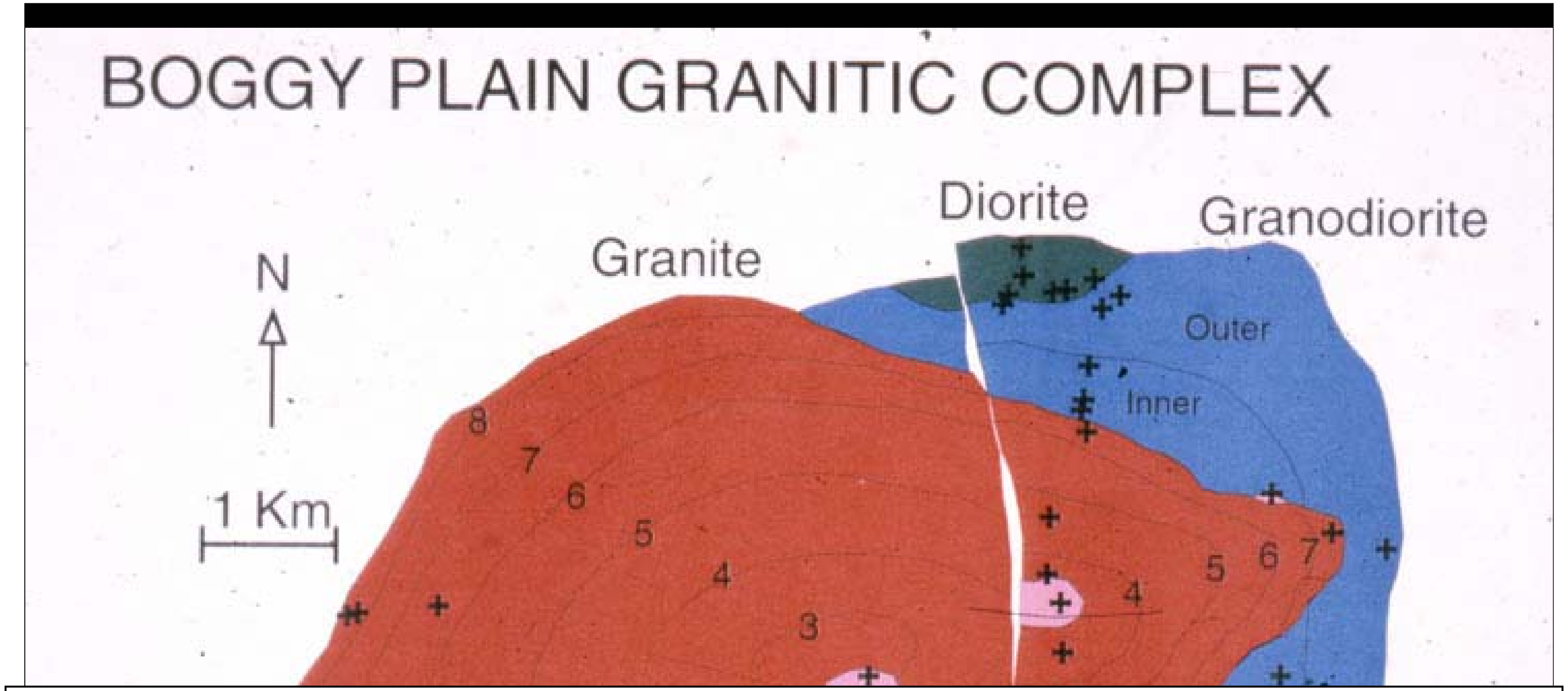
- **Linear variation against SiO_2**, similar to the pattern of other elements for those suites. This is by far the more common type of behaviour. It applies to all S-type suites, where the variation also is more scattered. Also to most I-type suites, where in most cases, the Zr content falls with increasing SiO_2, although sometimes it is fairly constant, and in a few cases it rises (e.g. Jindabyne).
- **Inflected trends**, where the Zr rises from low values to a maximum at a little below 70% SiO_2, then falls back to low values.

- In the first case, the granite magma was saturated in zircon throughout its evolution. This has been confirmed by the presence of older zircon cores in all cases where this has been examined by Ian Williams and SHRIMP (> 30 samples).
- In the second case, the granite magma was clearly not saturated in zircon during the first part of its evolution, but became saturated near the point of Zr inflection. Such a situation has been found by Ian Williams for two samples from the Marulan Batholith, with the more mafic rock (56% SiO_2) containing no older zircon, while it is present in the other (73% SiO_2).

We will now look at some examples of these two types of variation.

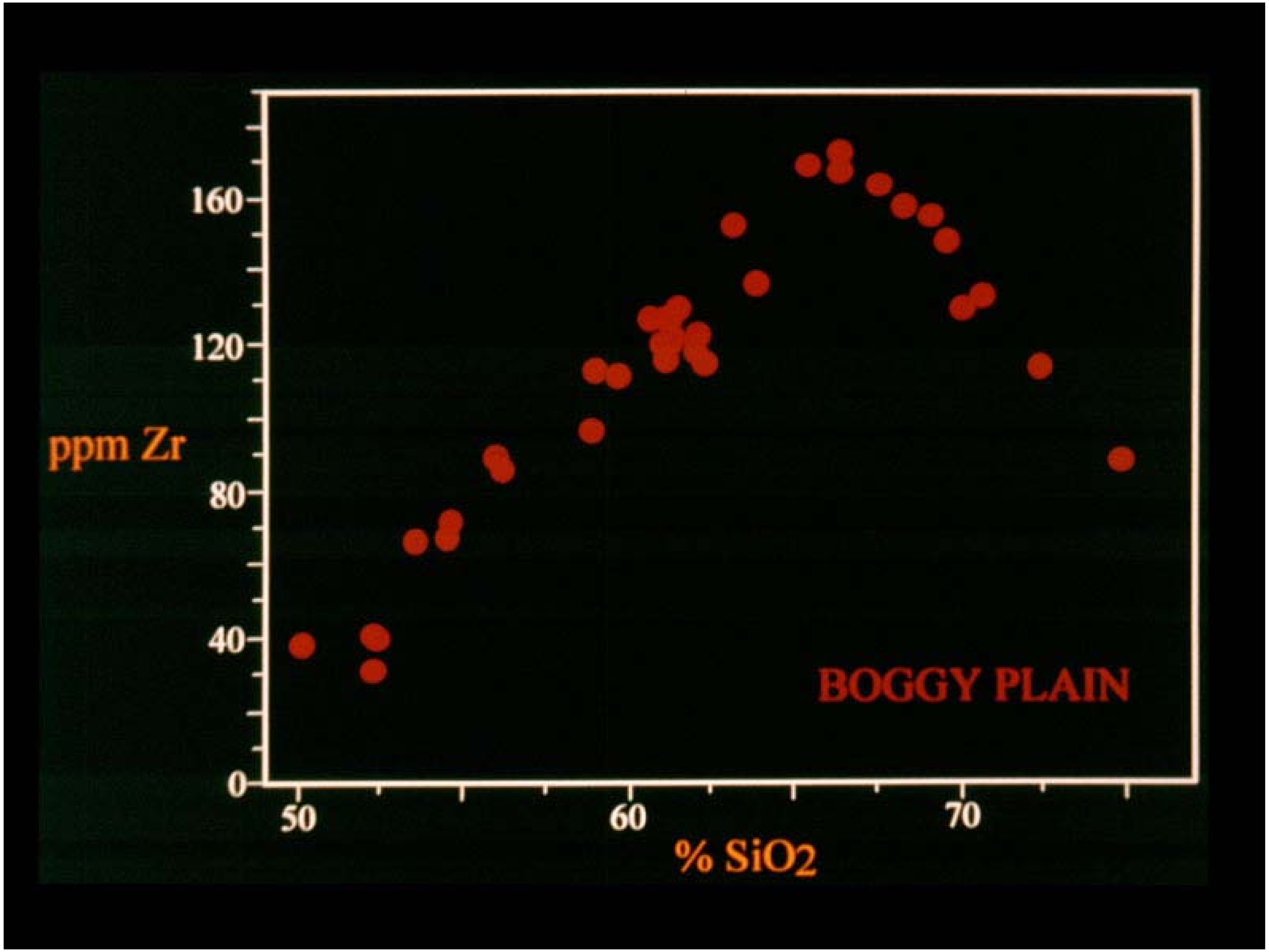
BOGGY PLAIN GRANITIC COMPLEX

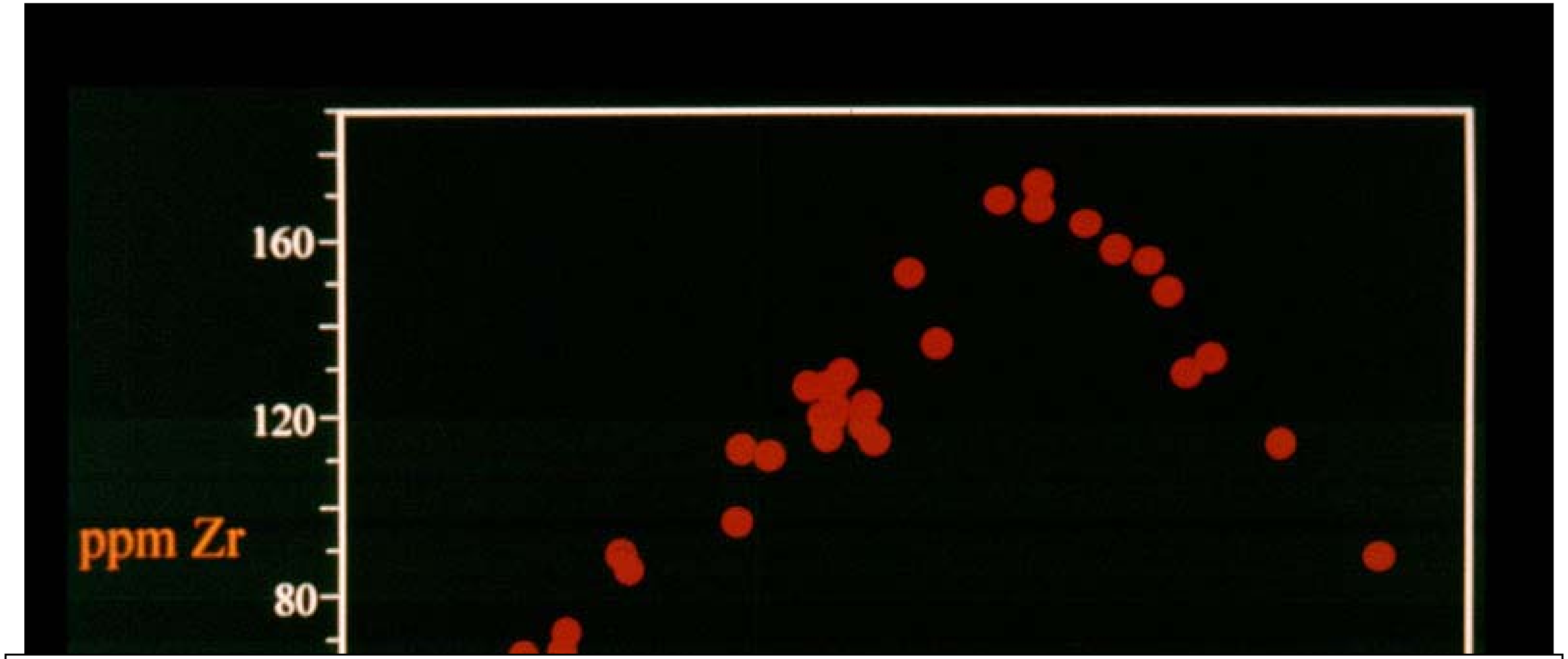




The Boggy Plain granitic complex (Wyborn, 1984) is zoned from more mafic rocks at the margins to more felsic rocks, including some aplite, at the centre. Apart from one internal contact, the zoning is cryptic and progressive. It resulted from newly-formed crystals nucleating and growing on the walls of the pluton as cumulate rocks. Some melt was trapped interstitially to those crystals, and some was displace back into the more central molten part of the pluton. Hence the melt from which the rocks were forming became more felsic with time.

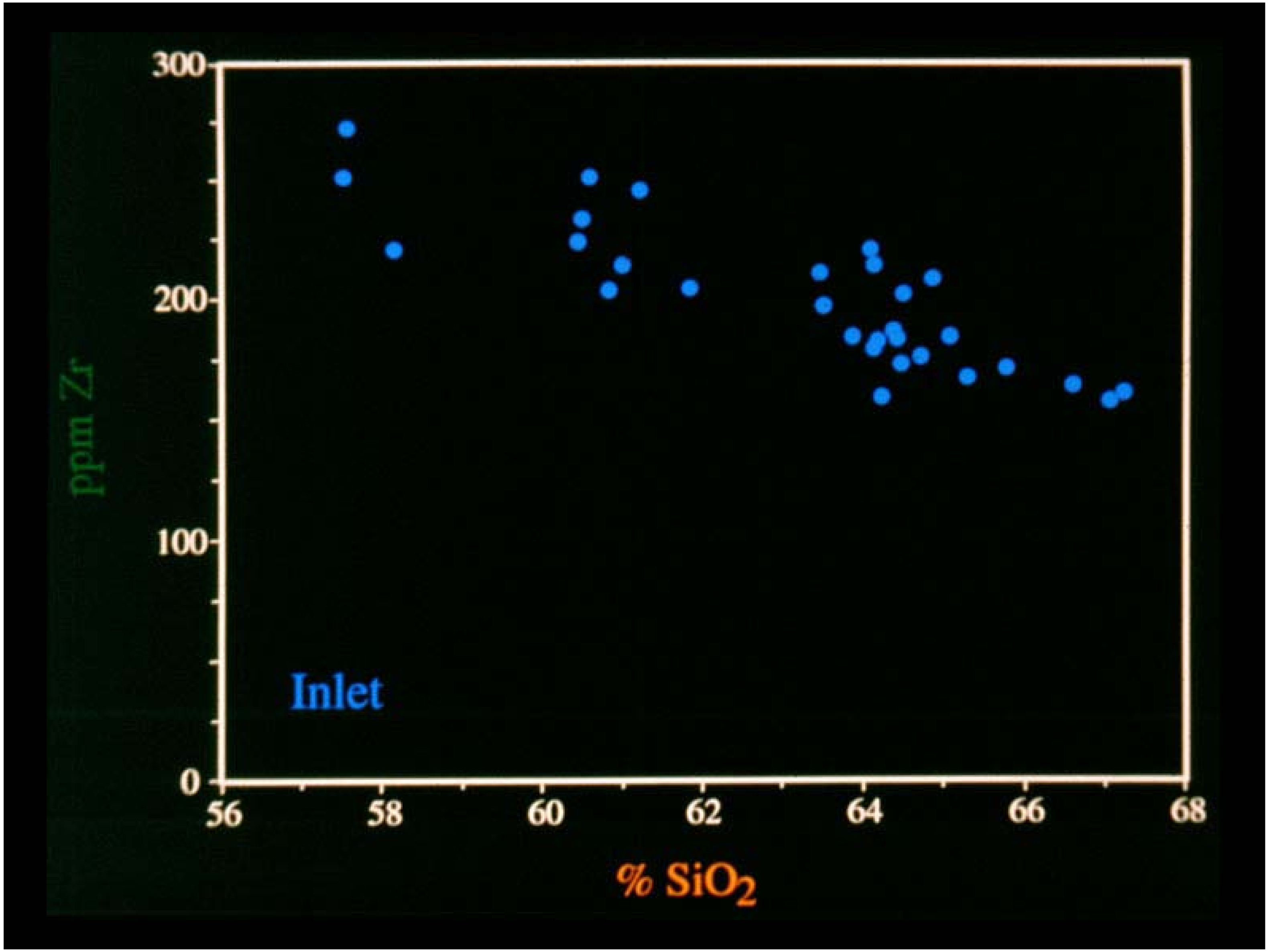
Wyborn, D. 1984. Fractionation processes in the Boggy Plain zoned pluton. PhD Thesis, The Australian National University (*unpublished*).

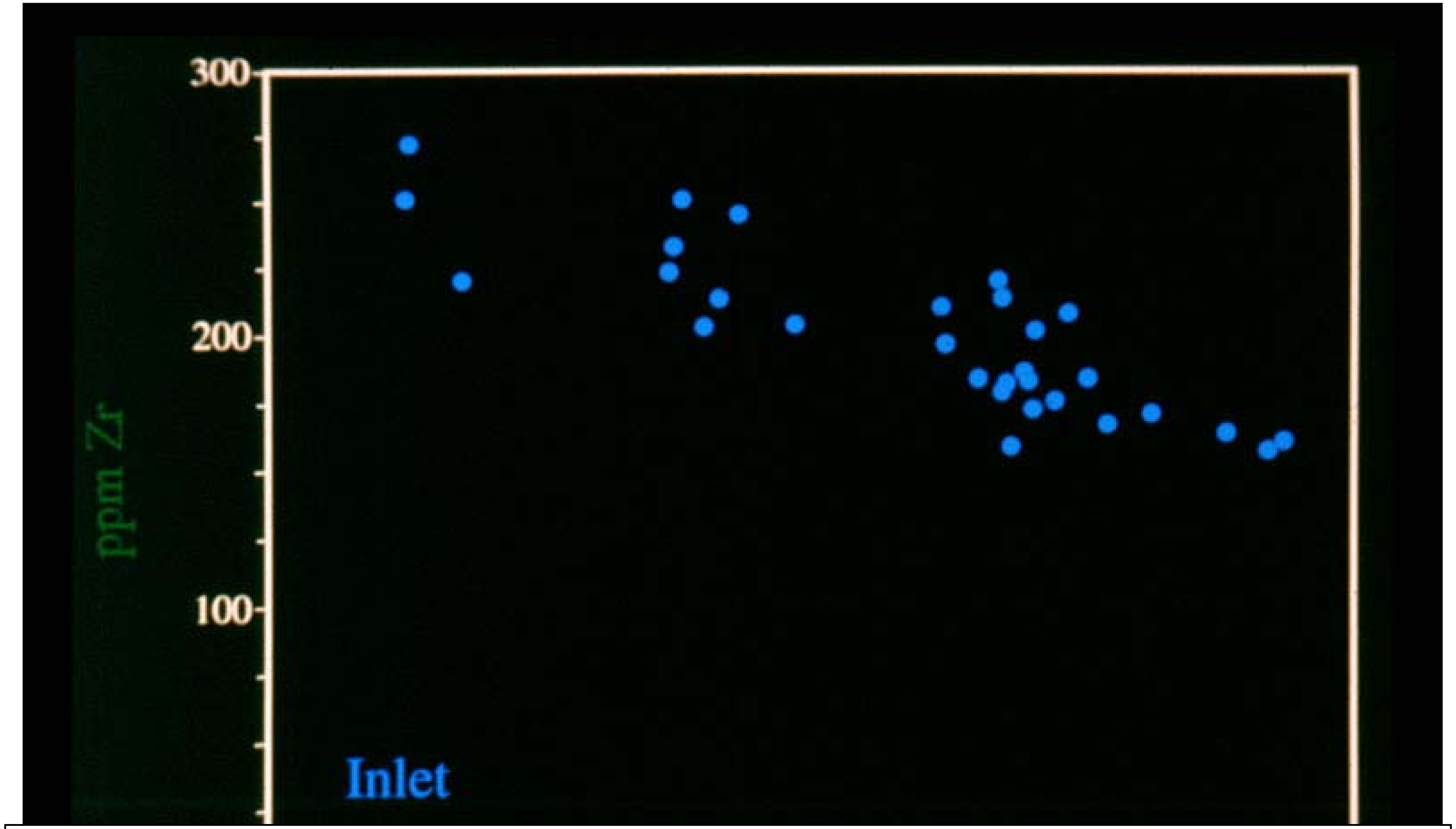

ppm Zr
160
120
80
40
0
50
60
70
% SiO2
BOGGY PLAIN



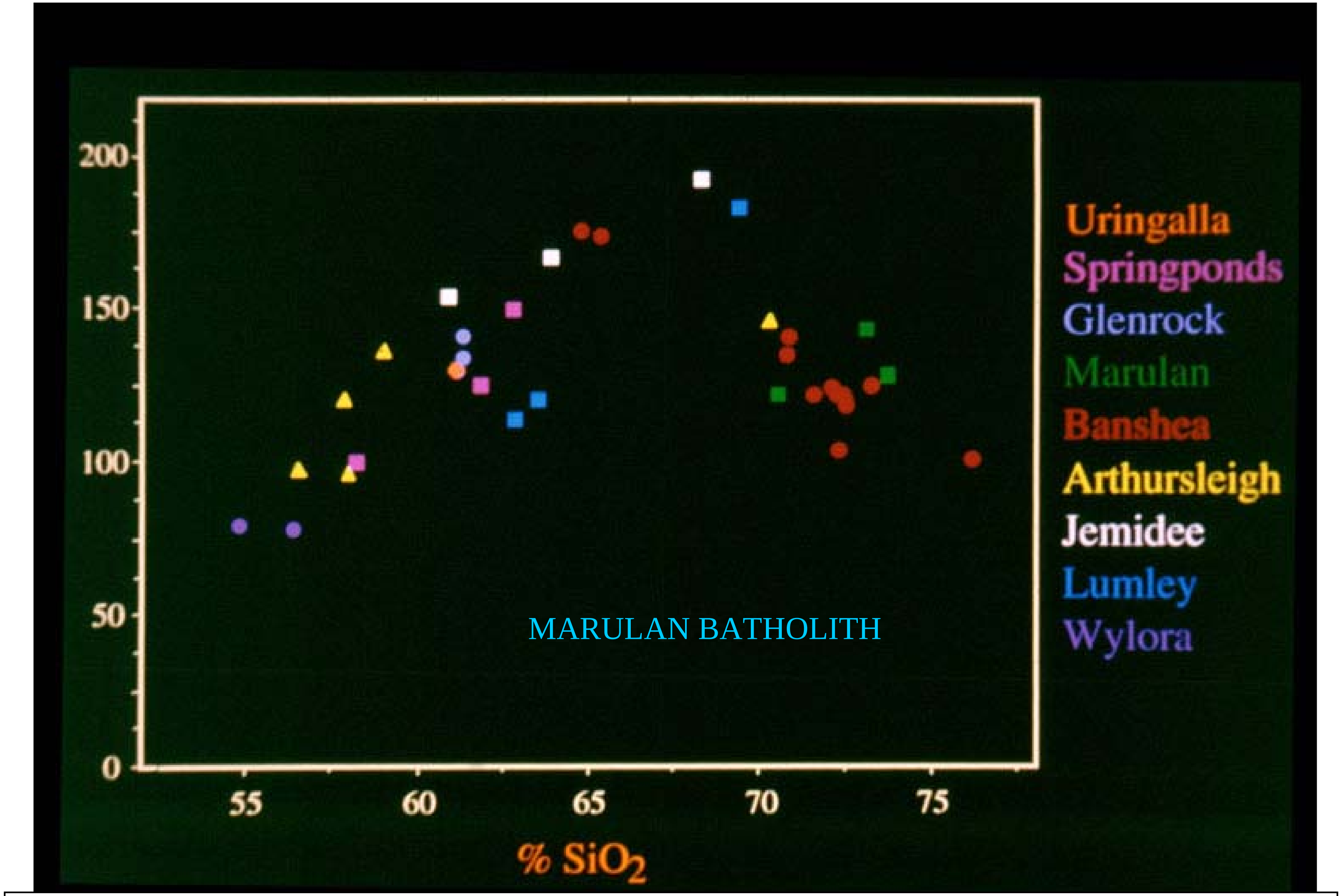
Zircon was not saturated in the melts from which the early rocks were formed, principally because of the high temperatures. Some poorly-shaped zircons grew from the trapped interstitial melt, but much of the Zr was displaced back into the main body of melt. At about the point where rocks containing 68% SiO_2 were forming, zircon became saturated, mainly because of falling temperatures. Zr was then extracted from the melt, in which consequently its abundance fell (see Wyborn *et al*., 2001, p. 537).

Wyborn, D., Chappell, B.W. & James, M. 2001. Examples of convective fractionation in high-temperature granites from the Lachlan Fold Belt. *Australian Journal of Earth Sciences* **48**, 531-541.

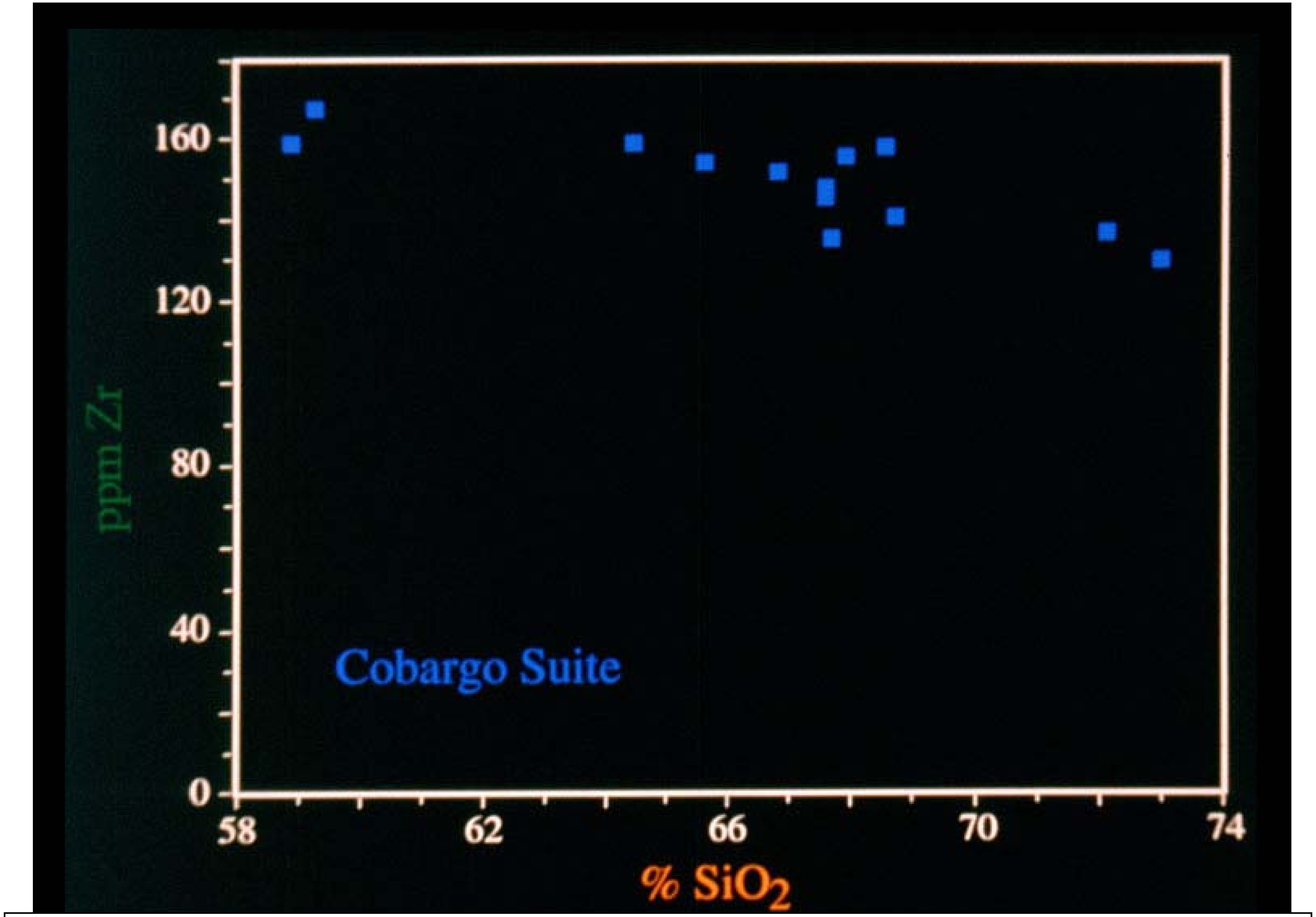

300
200
100
0
ppm Zr
56
58
60
62
64
66
68
% SiO$_2$
Inlet



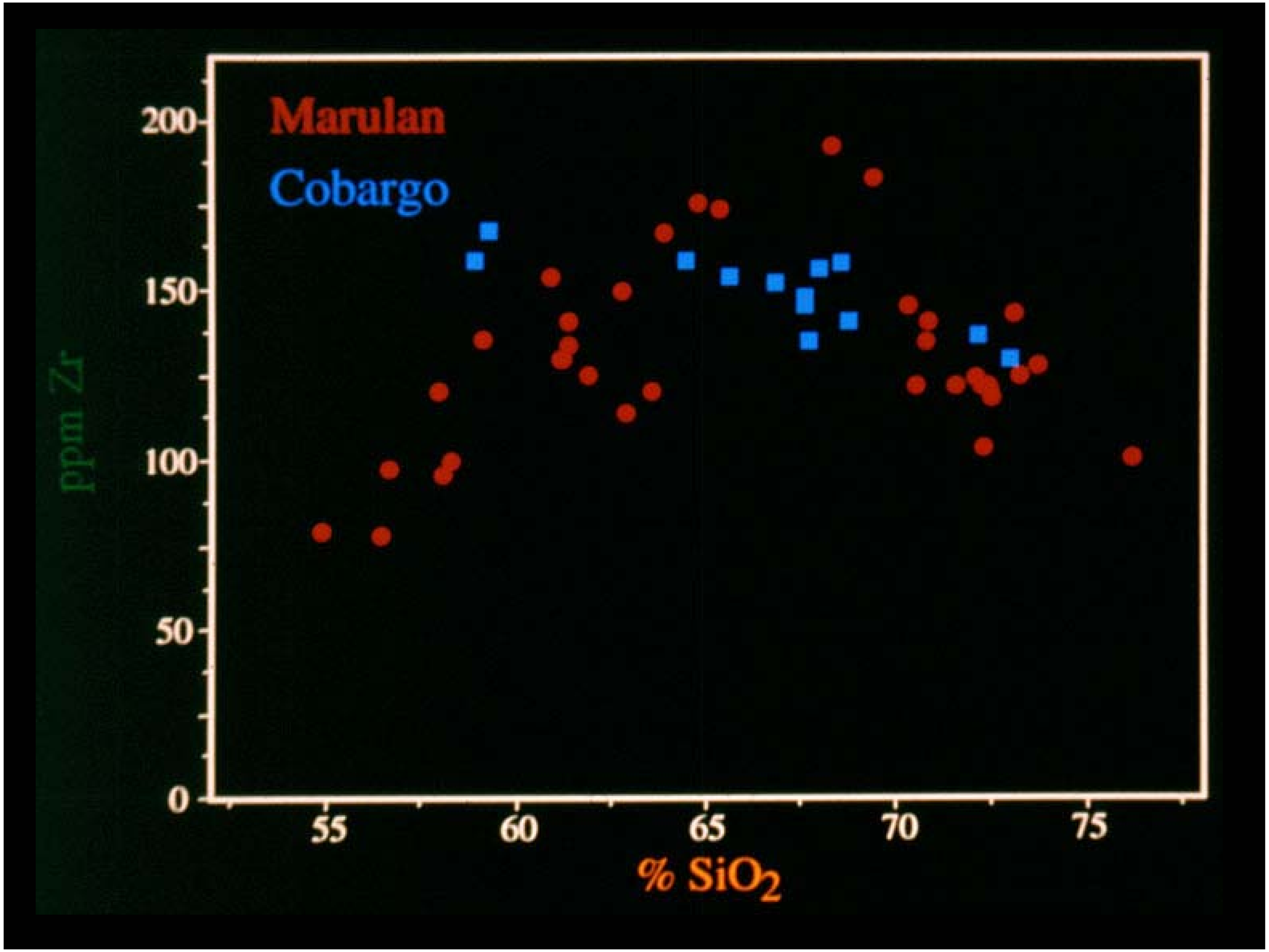
The Inlet Monzodiorite is much more weakly zoned than Boggy Plain. It is also a high-K, Ba, Sr granite, so it has compositional affinities with that other granite. However it formed at lower temperatures and evolved quite differently. Zircon was always saturated and the variation is dominantly the result of restite fractionation.

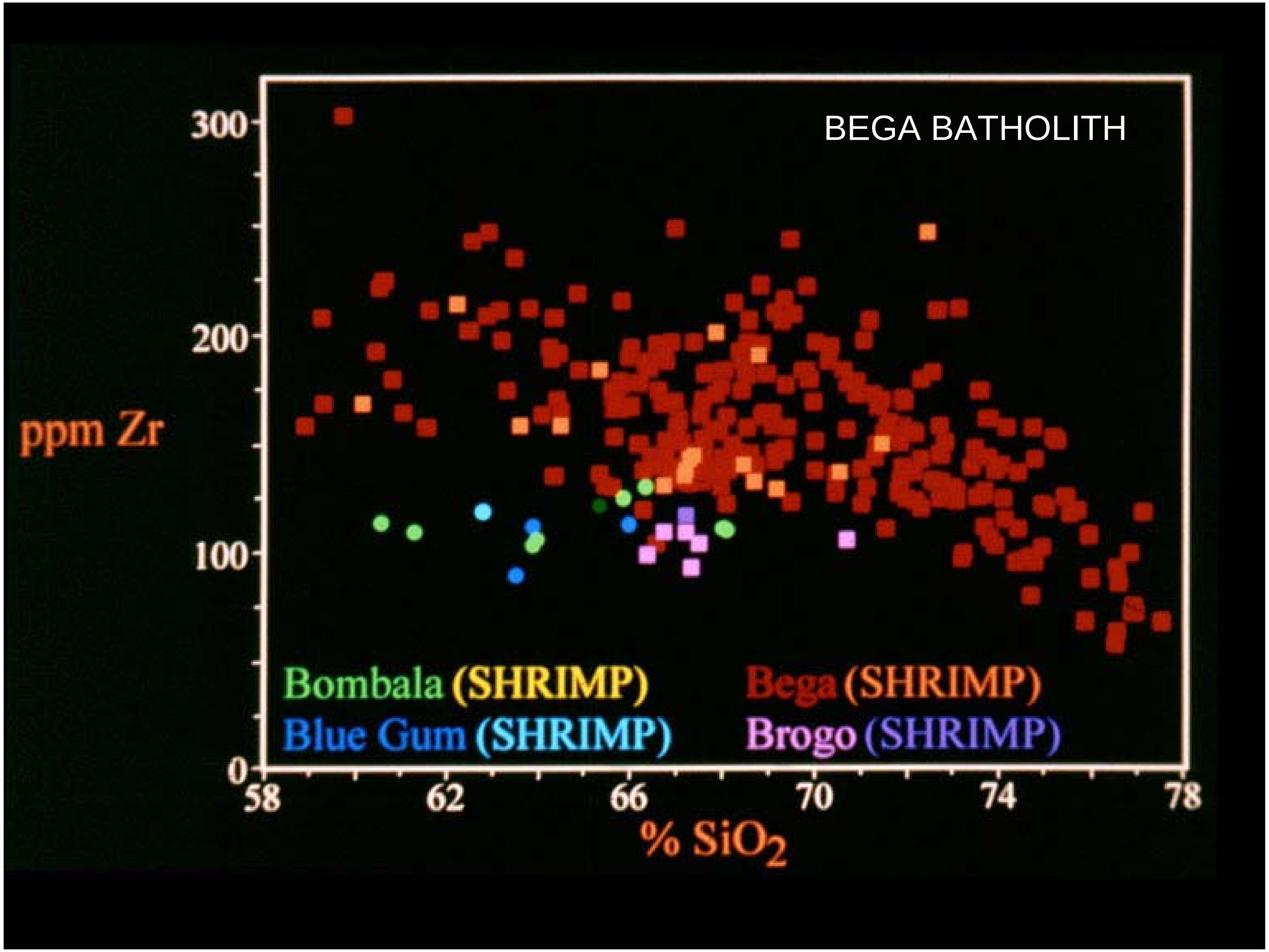


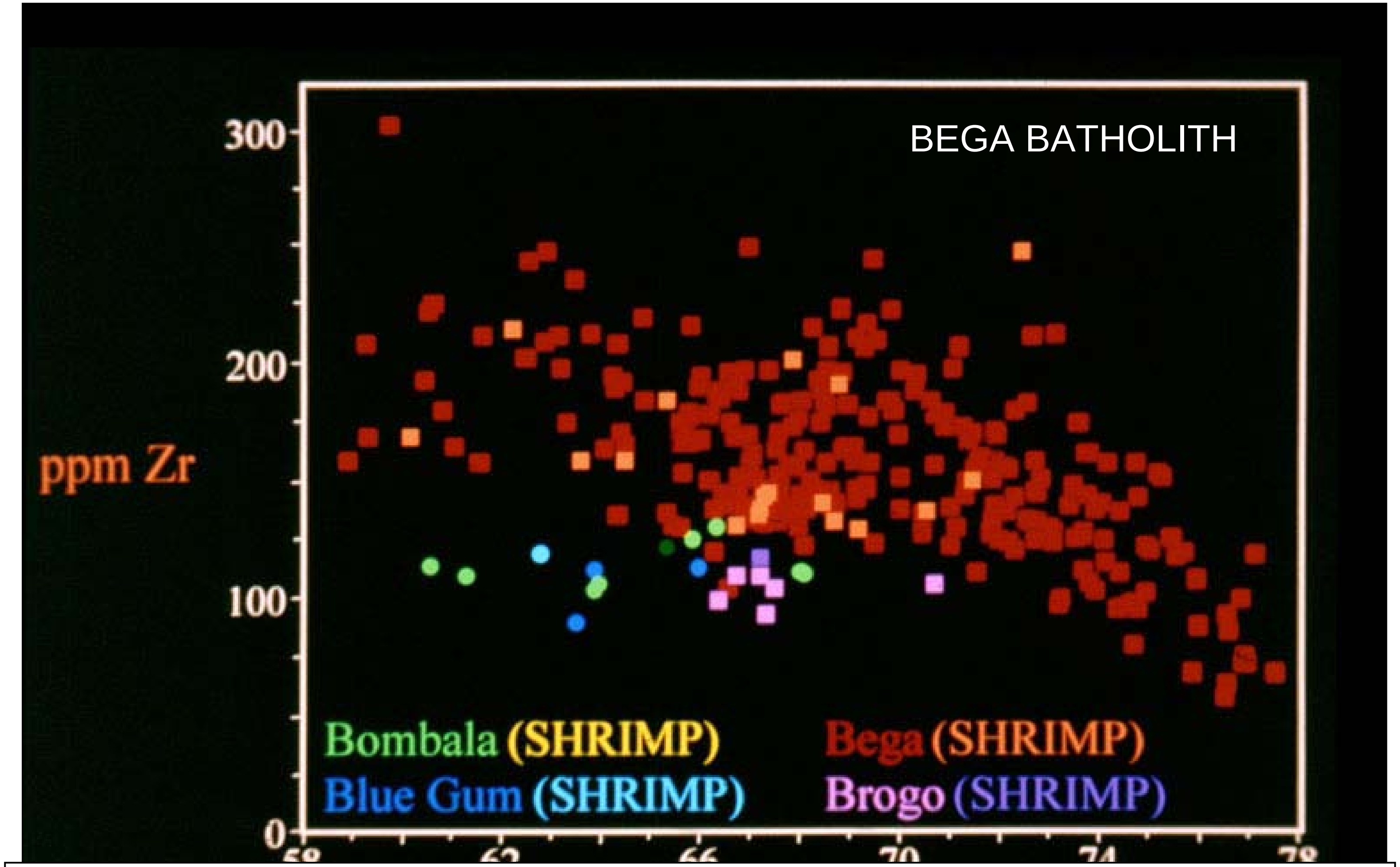
Zr in the Marulan Batholith behaves like Boggy Plain. This is a lower-K system and comprises several plutons of different compositions, rather than a single zoned body.



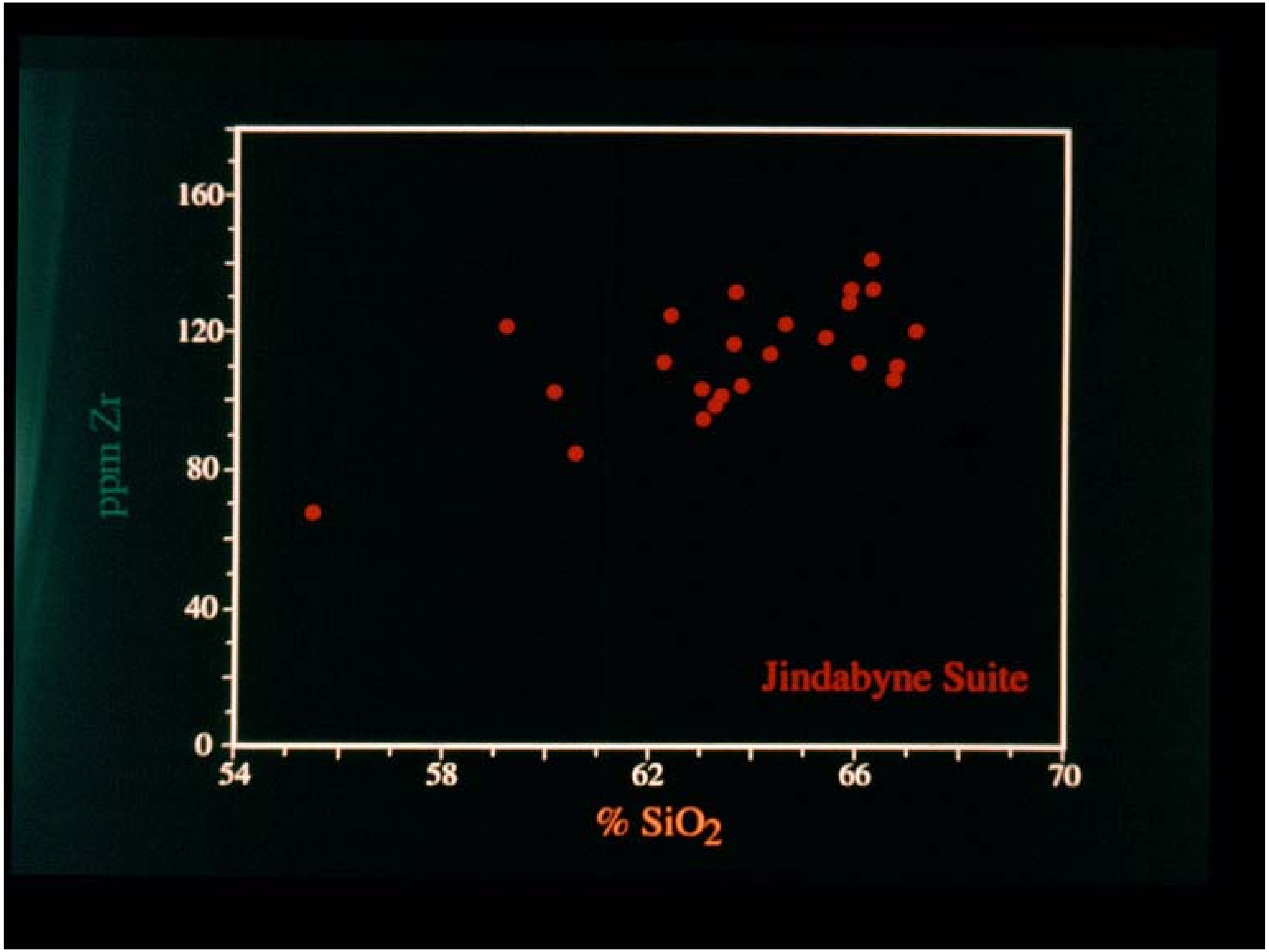
Cobargo, like Marulan, is a lower-K system, but evolved at lower temperature by restite separation.

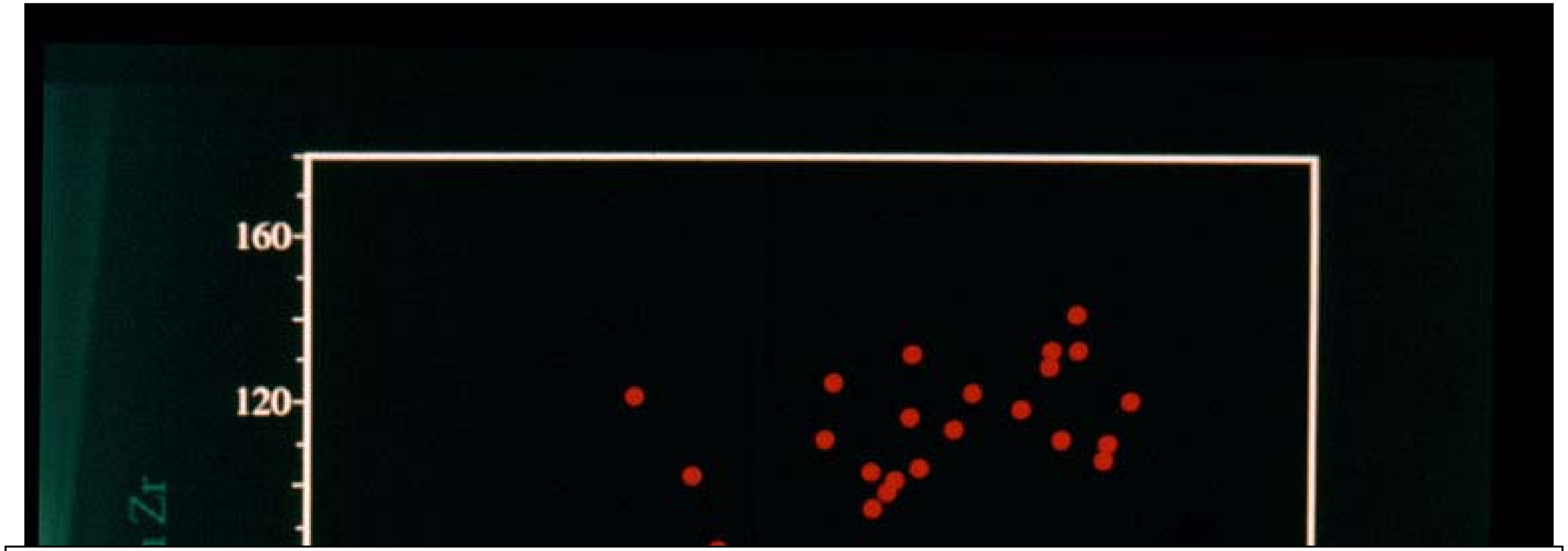

Marulan
Cobargo
ppm Zr
200
150
100
50
0
55
60
65
70
75
% SiO2


BEGA BATHOLITH
ppm Zr
300
200
100
0
58
62
66
70
74
78
% SiO2
Bombala (SHRIMP)
Blue Gum (SHRIMP)
Bega (SHRIMP)
Brogo (SHRIMP)



These are the Zr data for analysed rocks of the Bega Batholith. Rocks that have been studied by Ian Williams using SHRIMP are shown. In all cases, older cores have been found. In the Bombala, Blue Gum and Brogo Suites, the variations of Zr is flat or increases slightly with increasing SiO_2.


160
120
80
40
0
ppm Zr
54
58
62
66
70
% SiO_2
Jindabyne Suite



Zr in rocks of the Jindabyne Suite increases with increasing SiO_2, despite the fact that zircon age-inheritance is widespread in this rock. Apparently, in this case a higher temperature melt dissolved more Zr, so that the melt contained more Zr than the restite.

It would be very difficult to explain this variation by fractional crystallisation, given that old zircon is present and the magma was therefore saturated in that mineral.

This is all consistent with an early observation that suites such as Jindabyne which have most felsic compositions ~ 70% SiO_2, formed at higher temperatures than those suites that continue to ~ 75% SiO_2. These were referred to as “non-minimum temperature” and “minimum temperature” suites, respectively.

Hine, R., Williams, I.S., Chappell, B.W. & White, A.J.R. 1978. Contrasts between I- and S-type granitoids of the Kosciusko Batholith. *Journal of the Geological Society of Australia* **25**, 219-234.

SOLUBLITY OF ZIRCON IN GRANITE MELTS

- Many granites contain some zircon that is older than the rock – this was known from multi-grain zircon U-Pb analyses and has been brilliantly confirmed by the SHRIMP ion probe
- Zircon was always saturated in magma from which that rock formed
- Saturation is confirmed in most cases by the decreasing Zr with increasing SiO_2
- Saturation is a function of melt composition, Zr content and temperature
- The temperature at which a melt of known composition and Zr content is just saturated in zircon, the *zircon saturation temperature* can be calculated (Watson & Harrison, 1983)
- Above that temperature, zircon cannot exist in a melt for any length of time

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Watson, E.B. & Harrison, T.M. 1983. Zircon saturation revisited: temperature and composition effects in a variety of crustal magma types. *Earth and Planetary Science Letters* **64**, 295-304.

Watson, E.B. 1996. Dissolution, growth and survival of zircons during crustal fusion: kinetic principles, geological models and implications for isotopic inheritance. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 87, 43-56.

Clemens, J. D. 2003. S-type granitic magmas—petrogenetic issues, models and evidence. *Earth-Science Reviews* **61**, 1-18.

TWO QUESTIONS REGARDING ZIRCON SATURATION TEMPERATURES

1. THE QUESTION OF EQUILIBRIUM

The use of calculated zircon saturation temperatures in this way to examine granite origins, has been questioned, e.g. by Clemens (2003).

But Watson (1996) has concluded that only the largest protolith zircons (> 120 µm) are likely to survive magmatic events that exceeded a temperature of 850°C. The old zircon cores in the LFB granites are more typically < 50 µm in diameter. Also, if these suites evolved by fractional crystallisation, temperatures much higher than 850°C would have been involved.

2. ARE THE MORE MAFIC GRANITES CUMULATIVE?

Clemens (2001) has stated that “it is likely that the more mafic granites are cumulates, rather than former liquids”. If that were so, of course, the calculation of zircon saturation temperatures would be invalid, so this must be considered.

TWO QUESTIONS REGARDING ZIRCON SATURATION TEMPERATURES

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Clemens, J.D. 2001. S-type granites—models and evidence. *In*: Chappell, B.W. & Fleming, P.D. (eds). S-type Granites and Related Rocks. Abstract volume. *Australian Geological Survey Organisation. Record* **2001/02**, 31-32.

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ARE THE MORE MAFIC GRANITES CUMULATIVE?

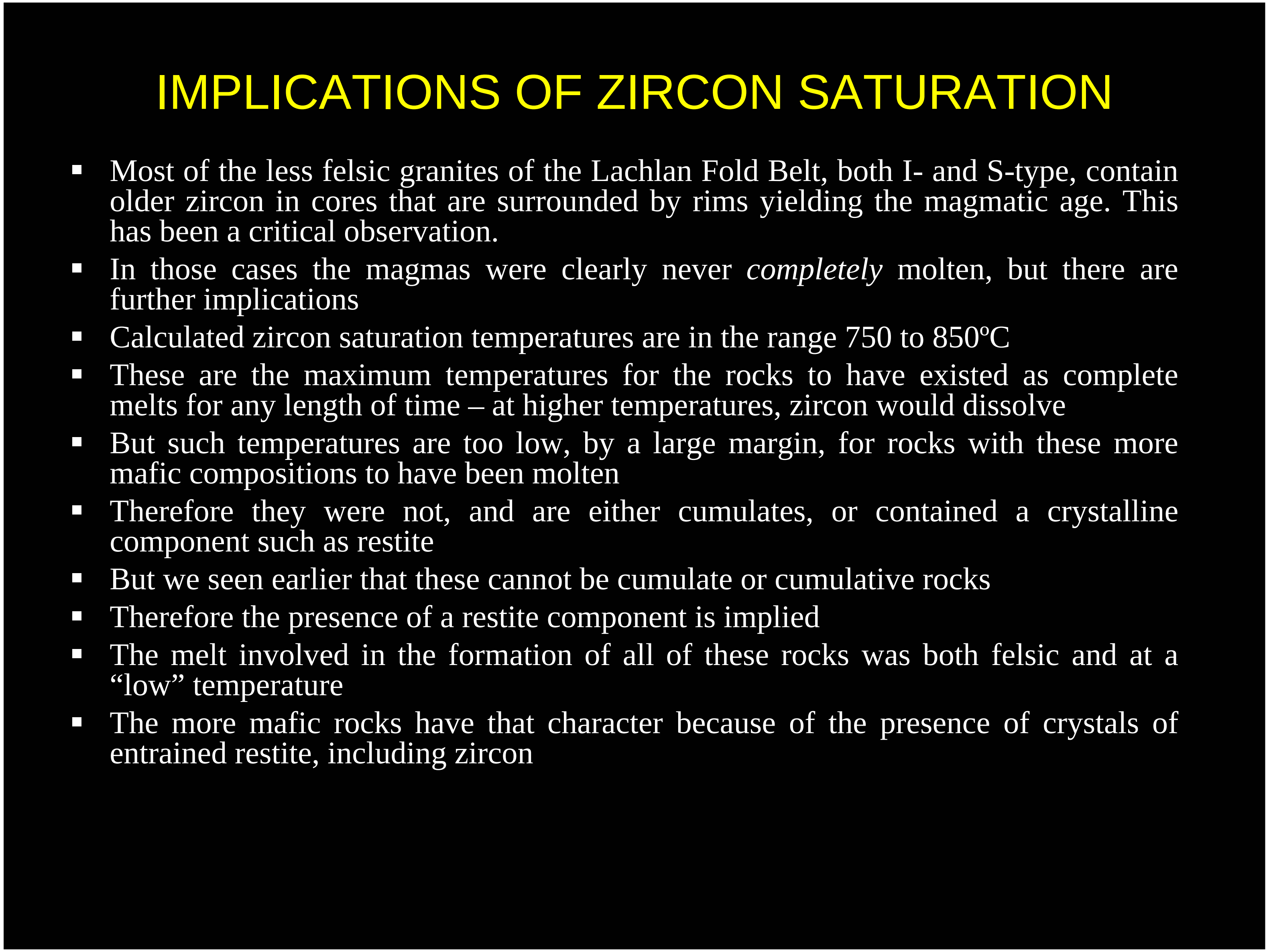
Clemens (2001) takes the view that the more mafic granites of the LFB are products of crystal accumulation. While that is the case for mafic rocks of high-temperature granite suites (Chappell *et al*., 1998), which are always I-type, it does not seem to be the case for the much more abundant low-temperature I-type suites of the LFB, for four reasons:

1. Low-silica rocks have a very low abundance
2. Chemical equivalence of plutonic and volcanic rocks
3. Variations within suites are inconsistent with a cumulative origin
4. Rock suites extend from felsic melt compositions to mafic compositions without hiatus

For a more detailed discussion of these features see pp. 30-31 of the abstracts volume, *Geoscience Australia Record* 2003/14.

Clemens, J.D. 2001. S-type granites—models and evidence. *In*: Chappell, B.W. & Fleming, P.D. (eds). S-type Granites and Related Rocks. Abstract volume. *Australian Geological Survey Organisation. Record* **2001/02**, 31-32.

Chappell, B.W. 1998. Tectonic evolution of the eastern Australian fold belts from a granite-based perspective: 1998 Mawson Lecture. *The Australian Geologist* **109**, 24-30.



IMPLICATIONS OF ZIRCON SATURATION

- Most of the less felsic granites of the Lachlan Fold Belt, both I- and S-type, contain older zircon in cores that are surrounded by rims yielding the magmatic age. This has been a critical observation.
- In those cases the magmas were clearly never *completely* molten, but there are further implications
- Calculated zircon saturation temperatures are in the range 750 to 850°C
- These are the maximum temperatures for the rocks to have existed as complete melts for any length of time – at higher temperatures, zircon would dissolve
- But such temperatures are too low, by a large margin, for rocks with these more mafic compositions to have been molten
- Therefore they were not, and are either cumulates, or contained a crystalline component such as restite
- But we seen earlier that these cannot be cumulate or cumulative rocks
- Therefore the presence of a restite component is implied
- The melt involved in the formation of all of these rocks was both felsic and at a “low” temperature
- The more mafic rocks have that character because of the presence of crystals of entrained restite, including zircon

HIGH-TEMPERATURE GRANITES (I-TYPE)

- Defined on the absence of inherited zircon in more mafic rocks (< 65% SiO_2)
- Zircon was not saturated in the melts from which those mafic rocks formed
- Zircon became saturated in the more felsic melts
  - seen from inflections in Zr abundances, and for some other elements
- Formed from total melts, which for mafic rocks have temperatures higher than 1000°C
- Such melts may evolve through fractional crystallisation or alternatively may result from varying degrees of partial melting of the source rocks
- Characteristic among the dominantly tonalites of the Cordilleran-like fold belts
- Produced by the partial melting of more mafic source rocks
- The rocks represent a relatively new addition to the crust

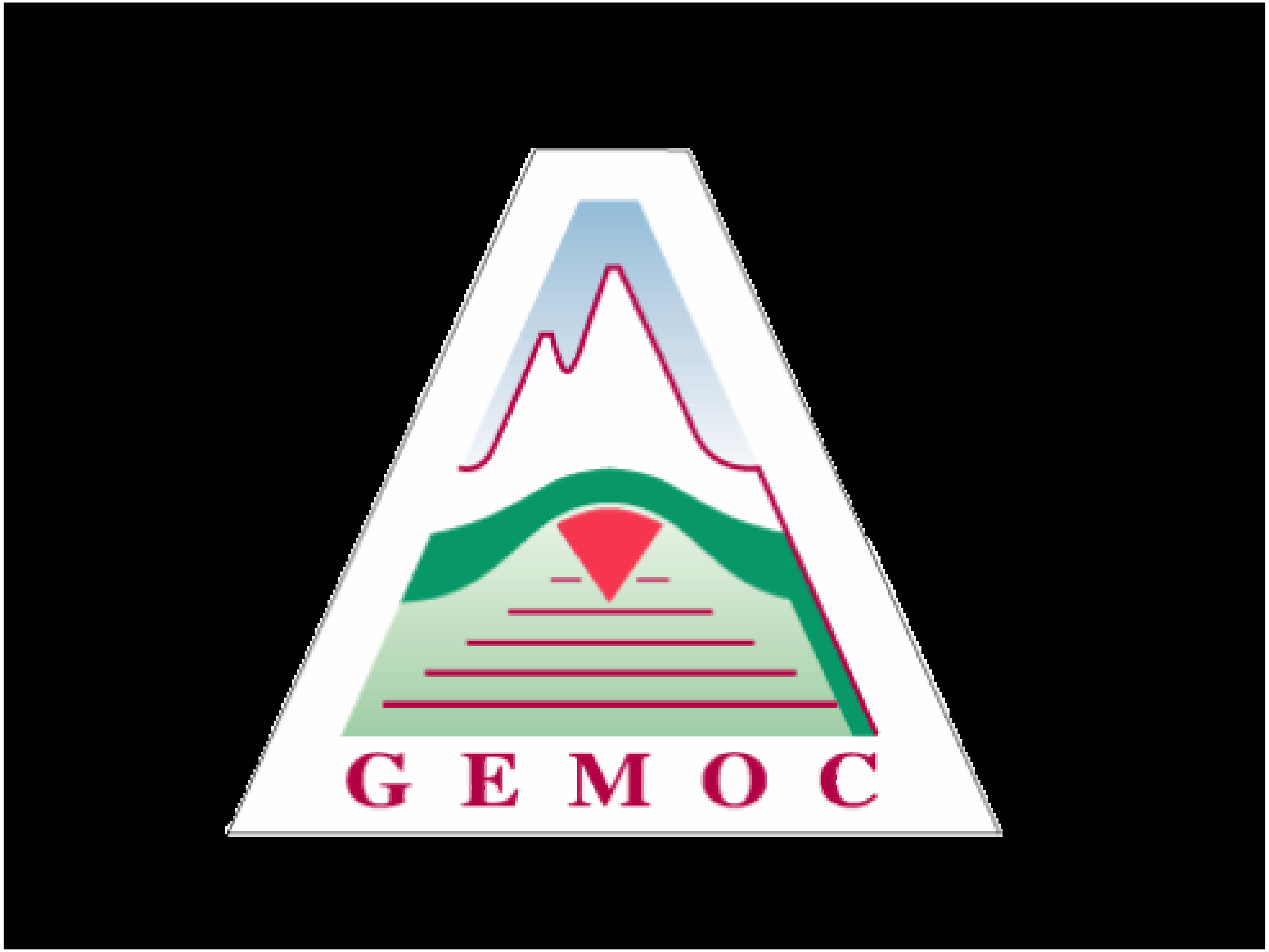
LOW-TEMPERATURE I-TYPE GRANITES

- Defined on the presence of inherited zircon in the more mafic rocks (<65% SiO_2)
- Zircon was saturated in the melts & magmas from which all rocks formed
- Zr and other elements show “linear” variation
- Formed from magmas that were not completely molten, which for mafic rocks have temperatures ~ 700-800°C
- Such magmas may evolve through the fractionation of restite
- Characteristic among the dominantly granodiorites of the Caledonian-like fold belts
- Produced by partial melting of quartzofeldspathic source rocks
- The granites represent a recycling of older crust
- Are commonly associated with S-type granites, which apparently are always low-temperature

TWO COMPOSITIONS OF LOW- AND HIGH-TEMPERATURE TONALITES

	MAFIC COBARGO SUITE AB127	MEAN OF 17 PRB ANALYSES (58-60% SiO_2)
SiO_2	58.91	59.03
TiO_2	0.86	0.86
Al_2O_3	17.29	16.68
FeO_{total}	5.48	6.38
MnO	0.11	0.11
MgO	3.49	3.56
CaO	6.56	6.67
Na_2O	3.76	3.33
K_2O	1.46	1.56
P_2O_5	0.23	0.16

The SiO_2 range chosen for the analyses of the Peninsular Ranges Batholith (PRB) was chosen that rocks of broadly similar composition could be prepared.


GEMOC