Modelling the production of linear trends in granitoids using the Magma Chamber Simulator:

A case study of the Jindabyne Suite from the Lachlan Fold Belt, Australia

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vPICO presentation…

(the sneak peak at the conclusions)

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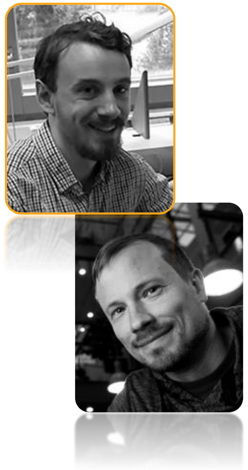

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Can fractional crystallisation drive the formation of linear geochemical trends in granitoids such as the Jindabyne Suite?

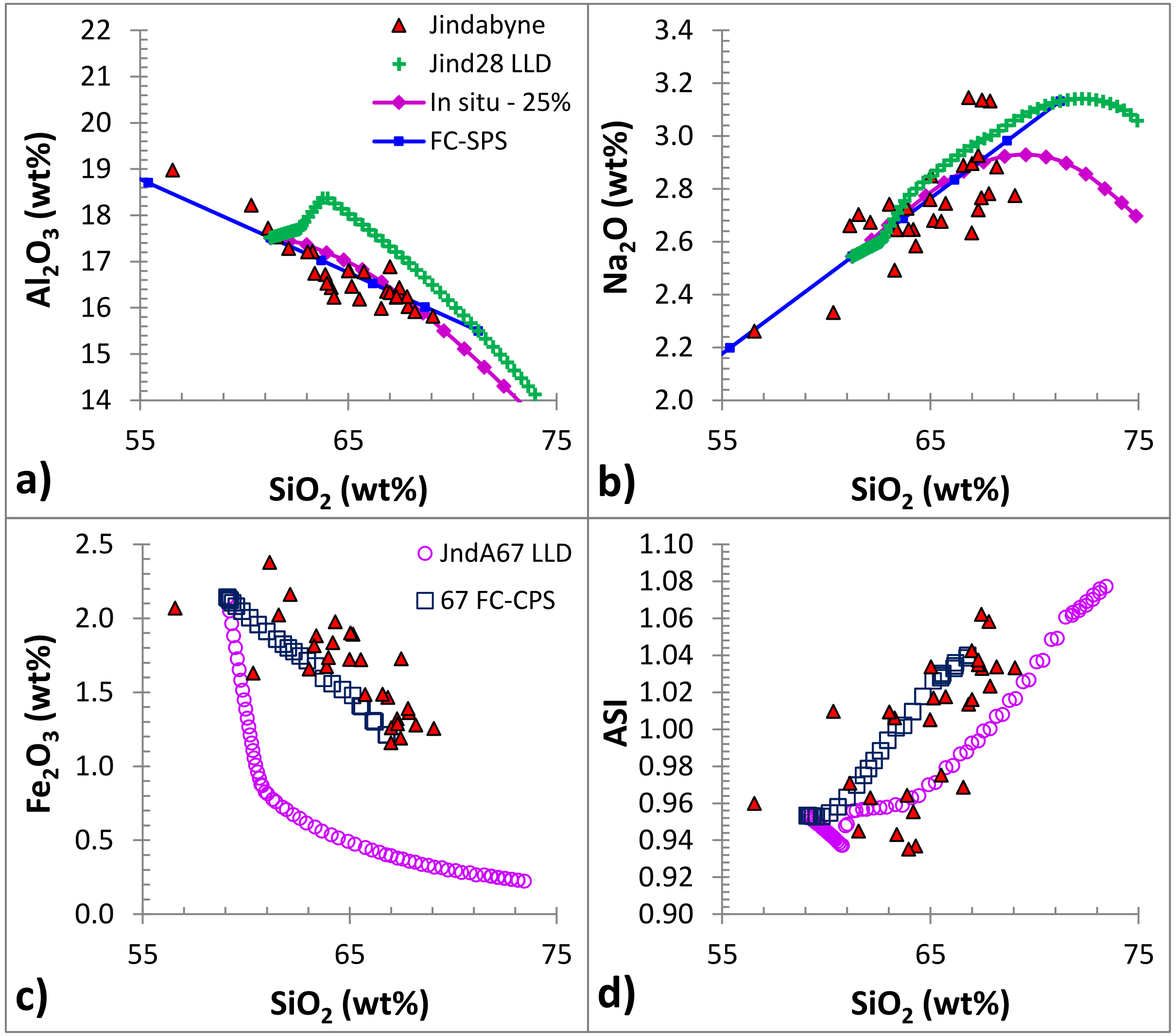
Thermodynamically-constrained modelling using the Magma Chamber Simulator: fractional crystallisation ± assimilation of melt ± stoping of wallrock

Major and trace element trends of Jindabyne compared to:

- Liquid lines of descent,
- Crystal bearing magma evolutions:
  - Partial segregation during crystallisation
  - Segregation after crystallisation
- In situ crystallization

Conclusions:

1. Three different regimes involving fractional crystallisation produce similarly close matches to the Jindabyne trends
2. Generally, the shape of the LLD of a parental magma is an important control on the trends of the more complex models



Introduction

Geological background & scientific question/framework

The Jindabyne Suite granitoids

Introduction:

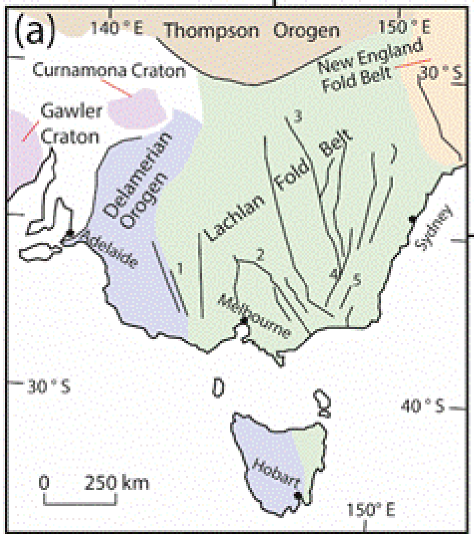
Jindabyne Suite Granitoids

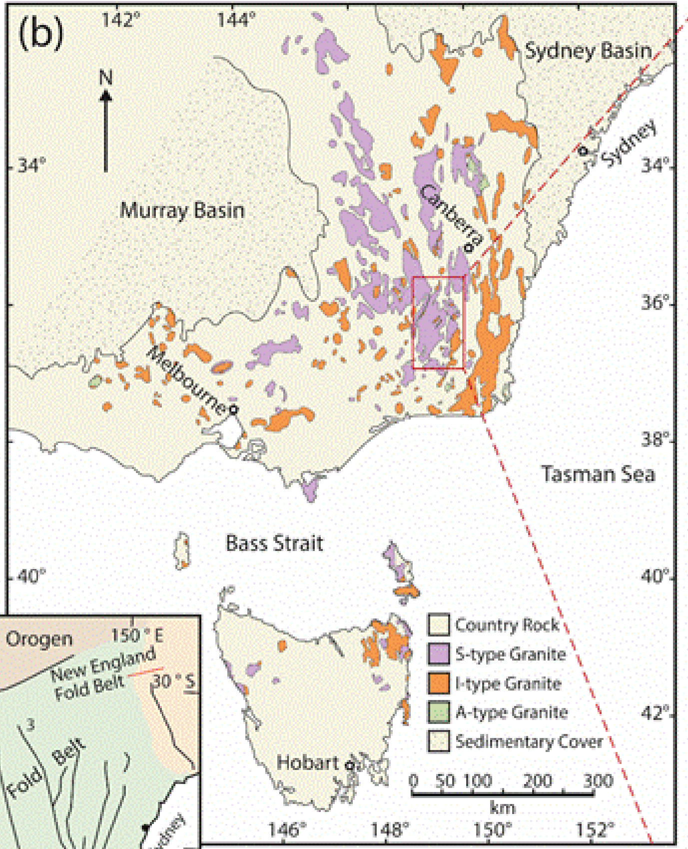
Granitoids with **consistent linear relationships between bulk-rock major and trace elements** contents are prevalent across the **Lachlan Fold Belt (LFB) of Australia**.

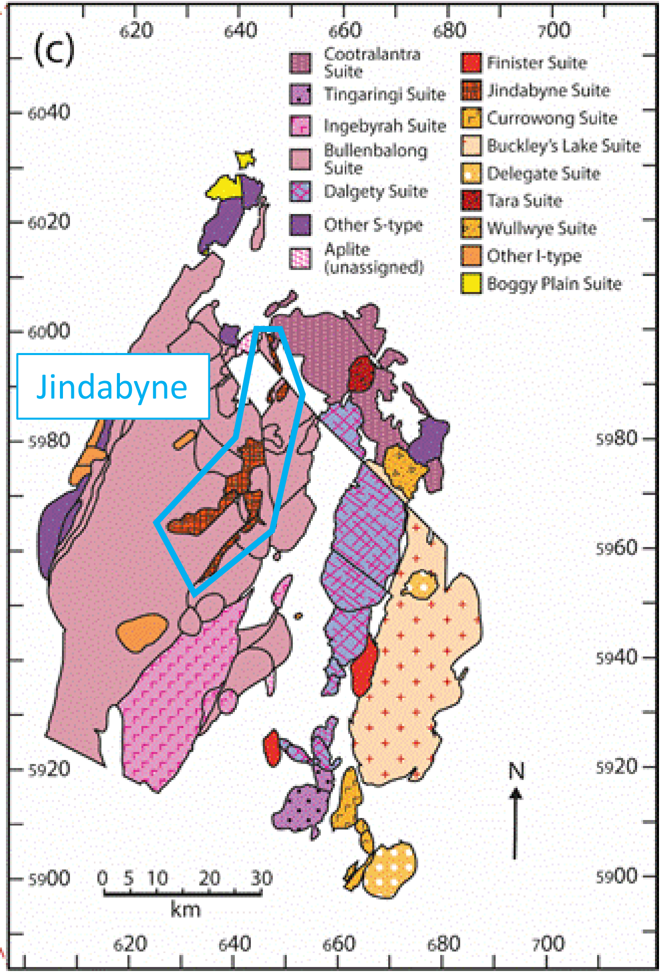
- Restite unmixing explains such geochemical variations
- Alternatively, magma mixing/assimilation models commonly invoke **fractional crystallisation**.

The **Jindabyne Suite** is an **I-type** example of such granitoids:

- **9 lithological units** that are geographically, petrographically and chemically associated
- **Hornblende tonalites** with accessory magnetite, apatite, zircon and allanite
- **Plagioclase grains with highly calcic cores**







The question:

Introduction:

The question

Can fractional crystallisation drive the formation of linear geochemical trends in granitoids such as the Jindabyne Suite?

Existing models suggesting a role for fractional crystallisation in Jindabyne and other LFB I-types are a problem because:

- The *quantitative* examples **lack thermodynamic constraints** to establish their physical plausibility
- Other examples are ***qualitative and incomplete*** (e.g., consider only a few elements)

But now we have sophisticated tools remedy these issues

The idea that fractional crystallisation is responsible is very broad, so we consider variants in two subdivision:

- Is **assimilation** of wallrock material involved? FC or AFC?
- What is the relationship between the melt, the crystals and the samples?

Forms of fractional crystallisation and related models:

Simple model → **More complex variants** | **A 'cousin' model**

Liquid lines of descent (LLDs)
- Granites = solidified liquids
- Melt evolves via:
  - Crystallisation
  - ± Assimilation of melt
  - ± Stoping

Crystallisation with **concurrent** partial segregation (FC-**C**PS/ AFC-**C**PS)
- Magma evolves due to LLD and degree of liquid-crystal segregation

Crystallisation with **subsequent** partial segregation (FC-**S**PS/ AFC-**S**PS)
- Magma evolves by unmixing the crystal cargo from the melt (on LLD)

- Granites = magma batches (melt+crystals)
- Zoning chemically isolates crystals after formation (FC without complete crystal settling)

In situ crystallisation
- Granites = solidified liquid resident magma
- Crystallisation zone produces fractionated liquid (on an LLD)
- Resident magma evolves via additions of fractionated liquid

Modelling

The Magma Chamber Simulator & results

MAGMA CHAMBER SIMULATOR

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Modelling:

The Magma Chamber Simulator

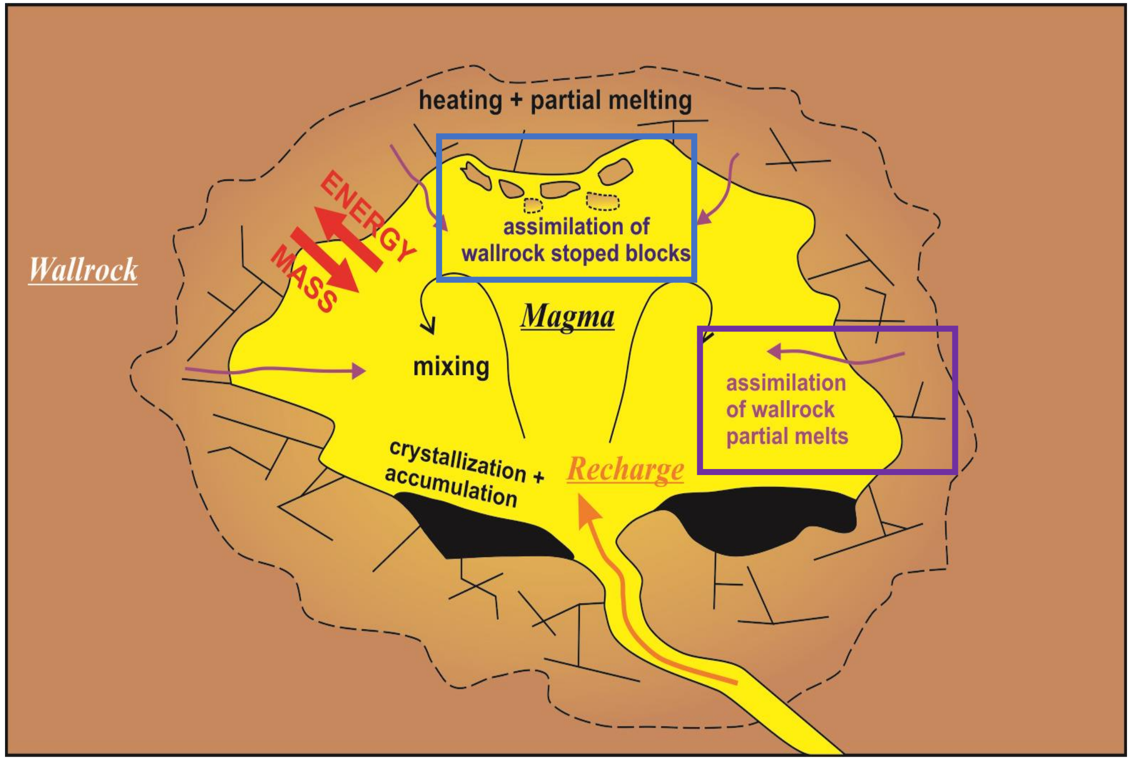
The Magma Chamber Simulator (**MCS**) is a numerical code that quantifies the **thermodynamic** and **geochemical** effects of magma **Recharge**, **Assimilation of partial melts** and/or **Stoped blocks**, and **Fractional Crystallization** (**RASFC**) on the evolution of a magma body and surrounding wallrock.

Simulates LLDs for a range of fractional crystallisation scenarios with and without assimilation:

- Variations in pressure (1.5-7.5 kbar)
- Variations in magma initial composition
  - H_2O content (1.5-8 wt%)
  - Different compositions along and nearby Jindabyne trend
- Diverse wallrock compositions
- Variations in wallrock mass and initial temperature
- Assimilation by stoping (bulk) vs. wallrock partial melting (selective)

MCS outputs magma and wallrock melt compositions, and masses of the subsystems, phases crystallised and wallrock phases.

- This information is used to build variant models



Liquid line of descent models

Modelling:

Liquid lines of descent

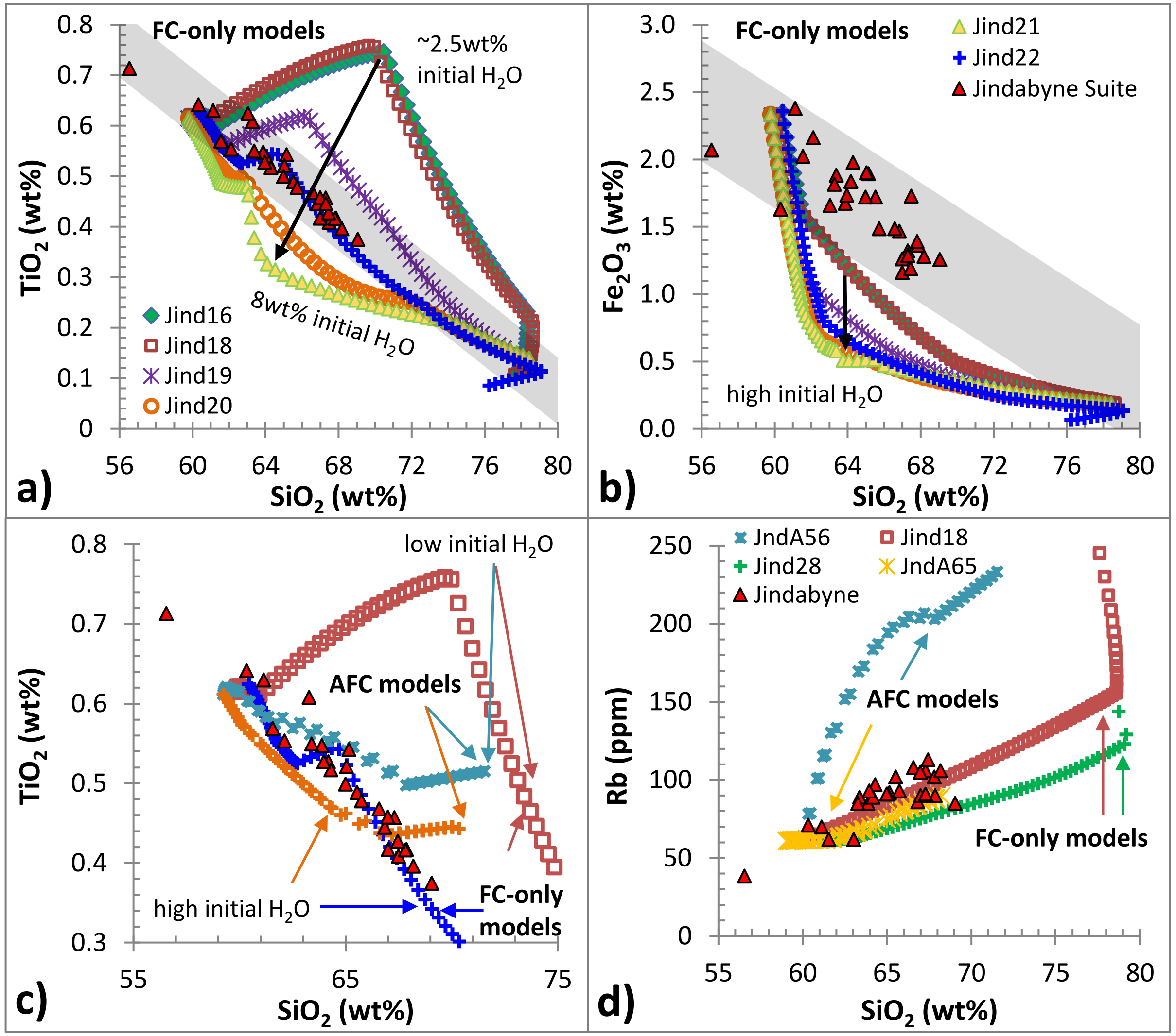
Some observations from **29 FC models** and **67 AFC models**:

- LLDs have **variable non-linear shapes**
- **Deviate from Jindabyne trend** in diverse ways, often markedly
- Strong pressure and H_2O dependence
- **Assimilation has a strong effect** on the shape of LLDs – Figure c)
- Even the best models match data for some elements but not others
  - Example Jind22 in Figures a) and b)
  - Some reasonable matches from major elements fail to match the traces – Figure d)

Models involving stoping were not viable matches

The linear trends in the granitoids are *not* consistent with LLDs formed by fractional crystallisation ± assimilation

- This is contrary to the suggestions of existing petrogenetic models



Fraction crystallisation with subsequent partial segregation

Modelling:

Subsequent partial segregation

Consider magma crystallising at depth but crystals do not segregate at all from melt:

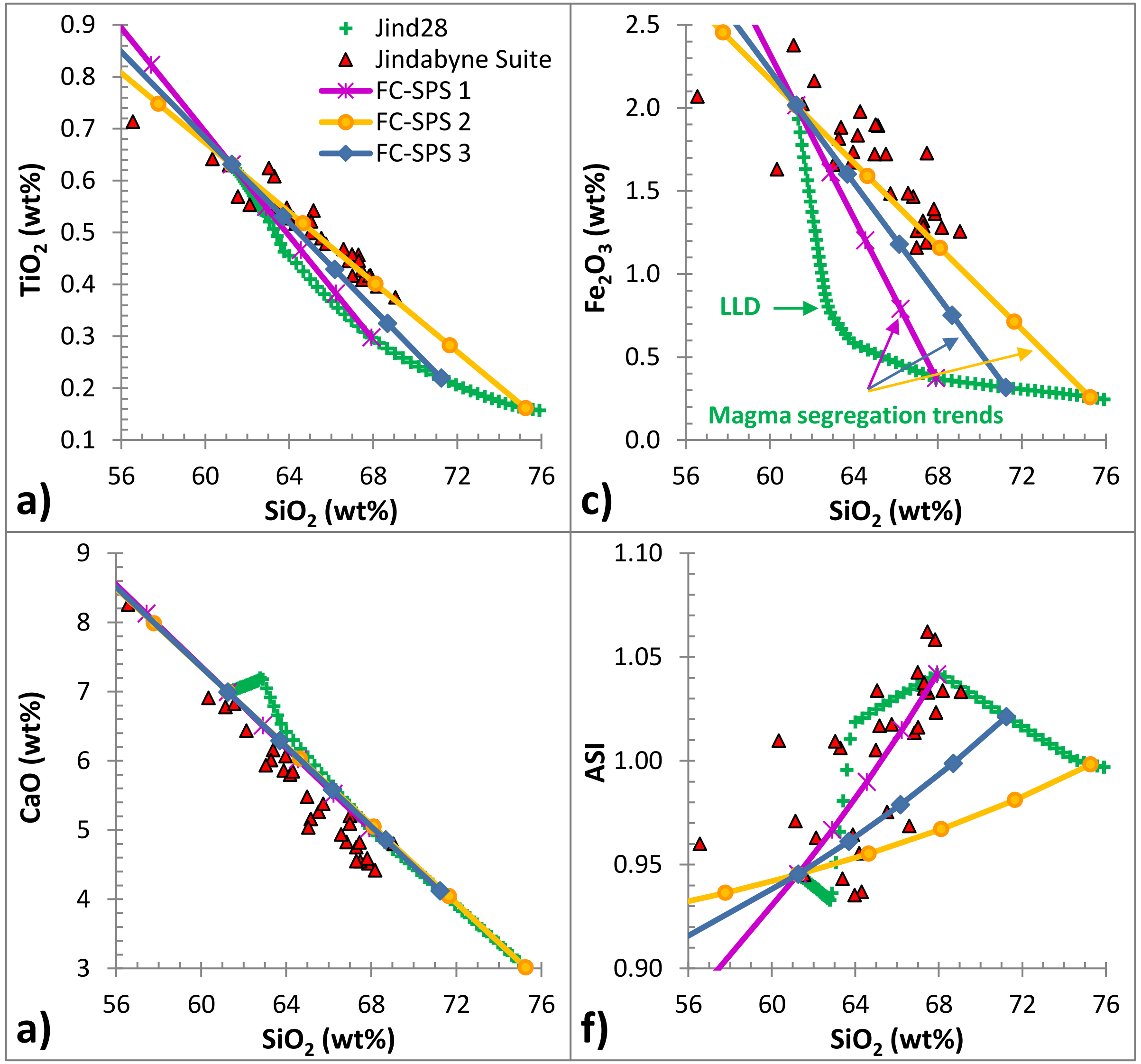
- Magma becomes increasingly crystal rich
- **New crystal growth zones shield earlier zones**, preventing equilibration with melt, thus:
  - **Melt evolution is fractional**
  - MCS models can be used to construct model
- Magma will have two basic components: melt + crystal cargo

After a certain degree of crystallisation, varying degrees of **segregation will create linear trends**

- Analogous to restite unmixing

Although the LLD in model Jind28 does not match the Jindabyne trend, it starts in the data and evolves to an extension of the linear trend.

By selecting an appropriate LLD and the right degree of crystallisation, a segregation trend (such as FC-SPS 3) can produce a reasonable match to the data.



Fractional crystallisation with concurrent partial segregation

Modelling:

Concurrent partial segregation

Consider magma at depth undergoing **fractional crystallisation with incomplete segregation of crystals from melt**:

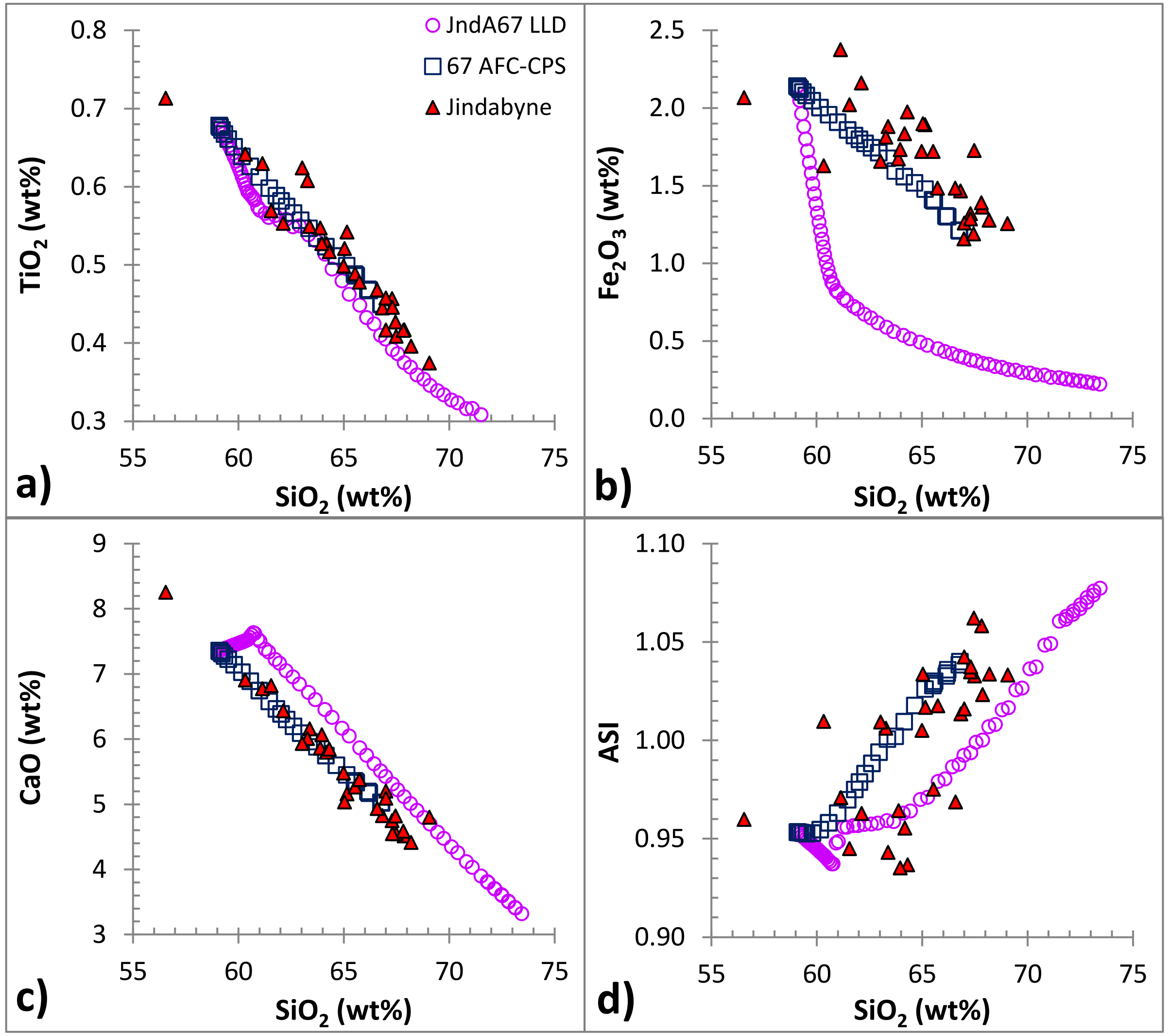
- Crystal-bearing magma will develop
- New crystal growth zones shield earlier zones, preventing equilibration with melt, thus:
  - Melt evolution is fractional
  - MCS models can be used to construct model

The **trends are curved** because the melt and crystal cargo components both change from step to step

- **A hybrid between LLD and subsequent crystallisation models**

Here a LLD derived through **assimilation and fractional crystallisation** (model JndA67) is used as the basis of an AFC-CPS model.

With a suitable degree of segregation, the magma compositional evolution (67 AFC-CPS) makes a reasonable match to the data.



Fraction crystallisation with concurrent partial segregation

Modelling:

***In situ* crystallisation**

Consider magma chamber at depth in which the **edges form a 'crystallisation zone' and the centre a 'resident magma'**

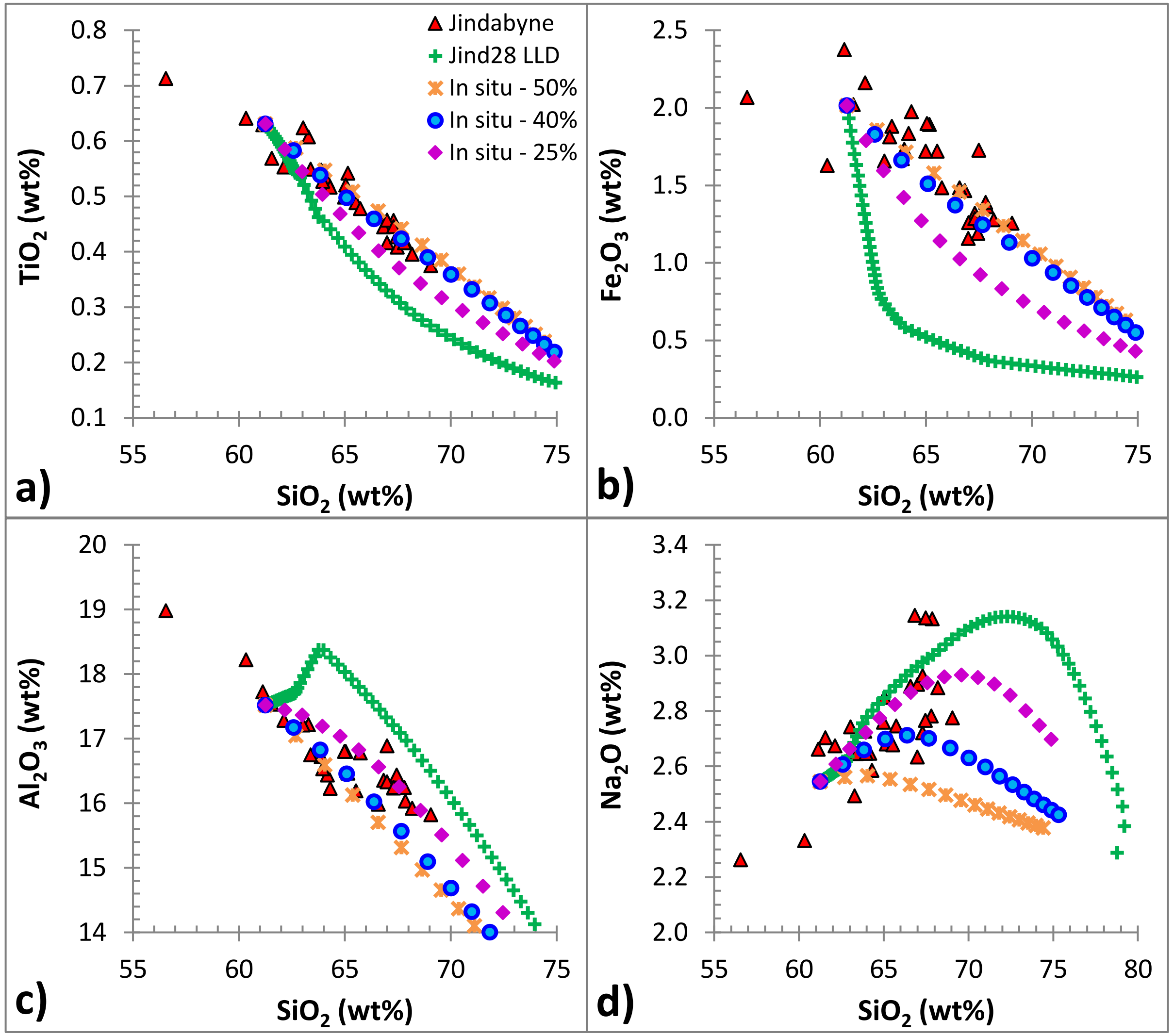
- Both zones have the same initial composition
- The magma in the **crystallisation zone evolves via fractional crystallisation** (with crystal zoning)
  - Eventually **some of the fractionated liquid is mixed back into the resident magma**
    - Thus, the resident magma evolves and a new portion of it becomes a new crystallisation zone

The **resident magma trends are curved** in accordance with the shape of the LLDs

- However, the curvature is usually subtle in comparison to LLD and equivalent FC-CPS

Here again the Jind28 LLD is the basis of the model.

With a suitable degree of crystallisation (25%) before each addition of fractionated melt, a resident magma trend can be a reasonable match to the data.



Conclusions

Is fractional crystallisation appropriate?

Conclusions

Can fractional crystallisation drive the formation of linear geochemical trends in granitoids such as the Jindabyne Suite?

Granites as compositions along a **liquid line of descent? No**

Magma compositions formed my **imperfect crystal-melt segregation? Yes, possibly**
- **Fractional crystallisation followed by variable degrees of segregation (FC-SPS, magma "unmixing")**
- **Assimilation + fractional crystallisation with concurrent partial segregation (AFC-CPS)**

Granites representing the resident magma evolution for ***in situ* crystallisation? Yes, possibly**

In each case, it is envisaged that differentiation takes place at depth, with the modelled magma evolutions tapped periodically to build the observed collection of related plutons that constitute the Jindabyne Suite.

Applying this modelling elsewhere:
The shapes of trends in the more complex models all depend to varying degrees upon the shape of the LLD
- For subsequent segregation trends are linear, but the LLD influences the slope
- For concurrent partial segregation, the magma trend is generally very sensitive to the shape of the LLD
    - Trend is like a "subdued" version of the LLD, depending on the degree of segregation
- For *in situ* crystallisation, the magma trend only vaguely capture the curvature of the LLDs involved

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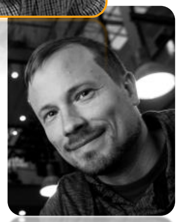

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MCS presentations in this conference:

SC5.20 EDI

Showcasing the Magma Chamber Simulator

Co-organized by GMPV

Convener: Jussi Heinonen | Co-conveners: Wendy Bohrson, Riikka Fred ECS, Frank Spera, Ville Virtanen ECS

Tue, 27 Apr, 16:00–17:00 (CEST)

Short course

EGU21-6922 | vPICO presentations

The Origin and Melt Evolution of Massif-type Anorthosite Parental Magmas: Thermodynamically Controlled Major Element Constraints

Riikka Fred, Aku Heinonen, and Jussi S. Heinonen

Mon, 26 Apr, 11:16–11:18

EGU 21-1251 | vPICO presentations

Thermodynamic constraints on assimilation of silicic crust by primitive magmas

Jussi S. Heinonen, Frank J. Spera, and Wendy A. Bohrson

Tue, 27 Apr, 09:10-09:12

EGU21-7903 | vPICO presentations

Modeling the sulfide saturation in continuously assimilating magmatic systems with the Magma Chamber Simulator

Ville Virtanen, Jussi Heinonen, Nicholas Barber, and Ferenc Molnár

Thu, 29 Apr, 15:35–15:37

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