Compositional attributes and geochronology of granite suites; implications to metallogenic processes

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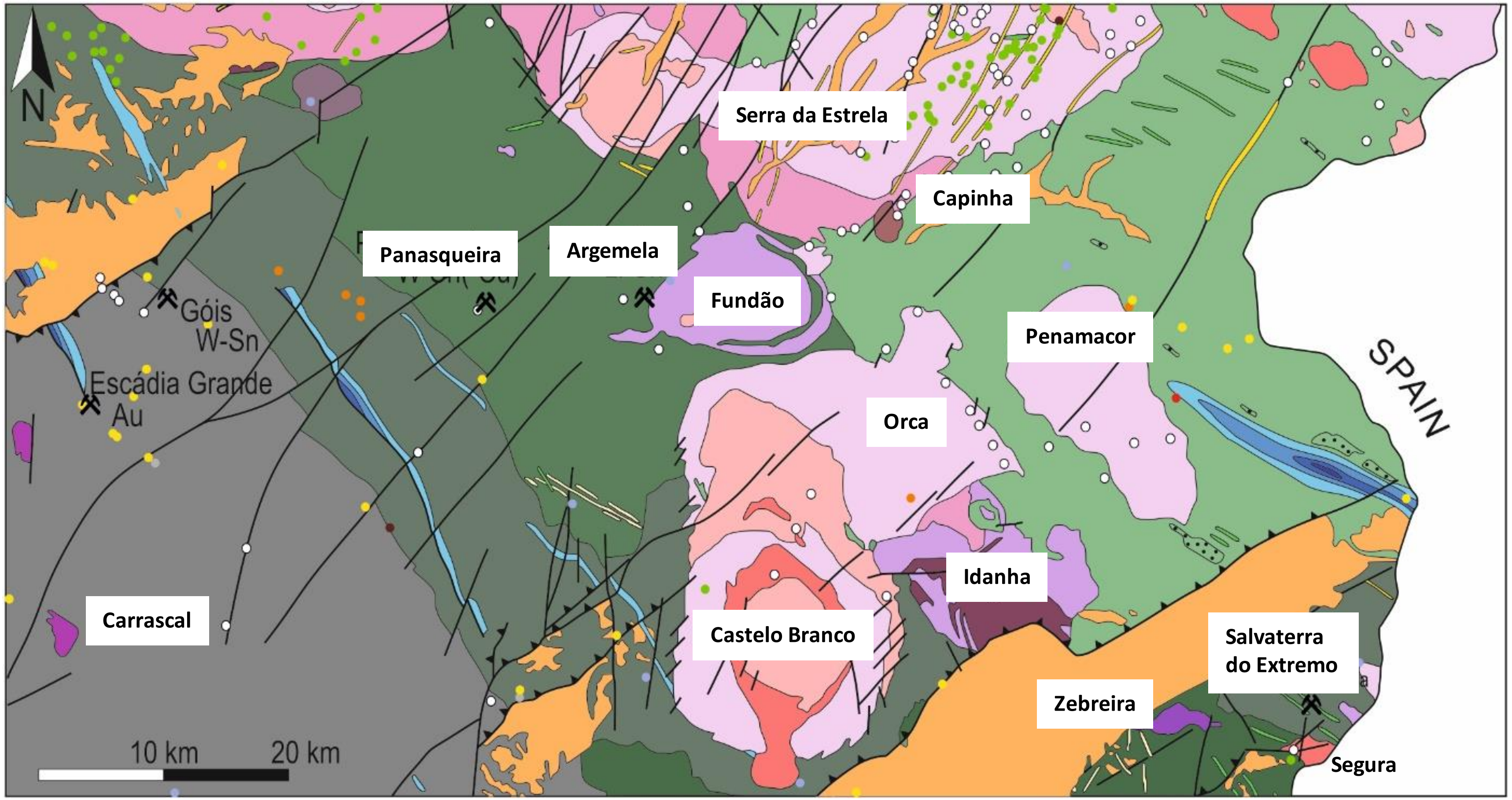
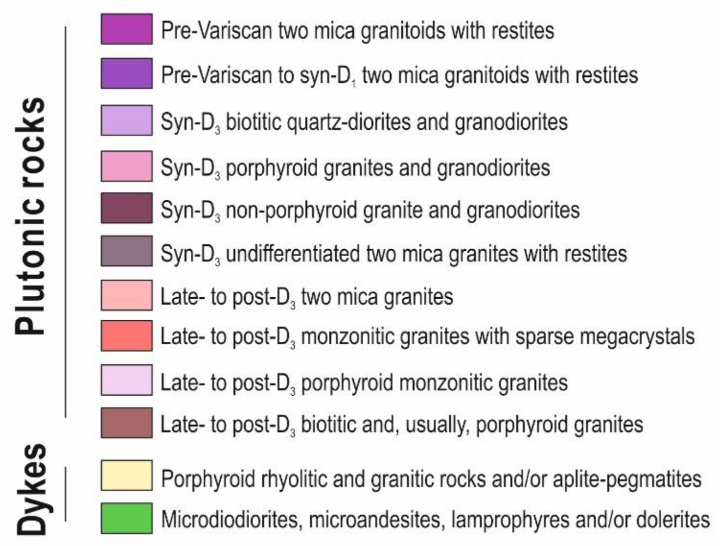
GEOCIÊNCIAS USP

Granitoid, aplite & pegmatite rocks





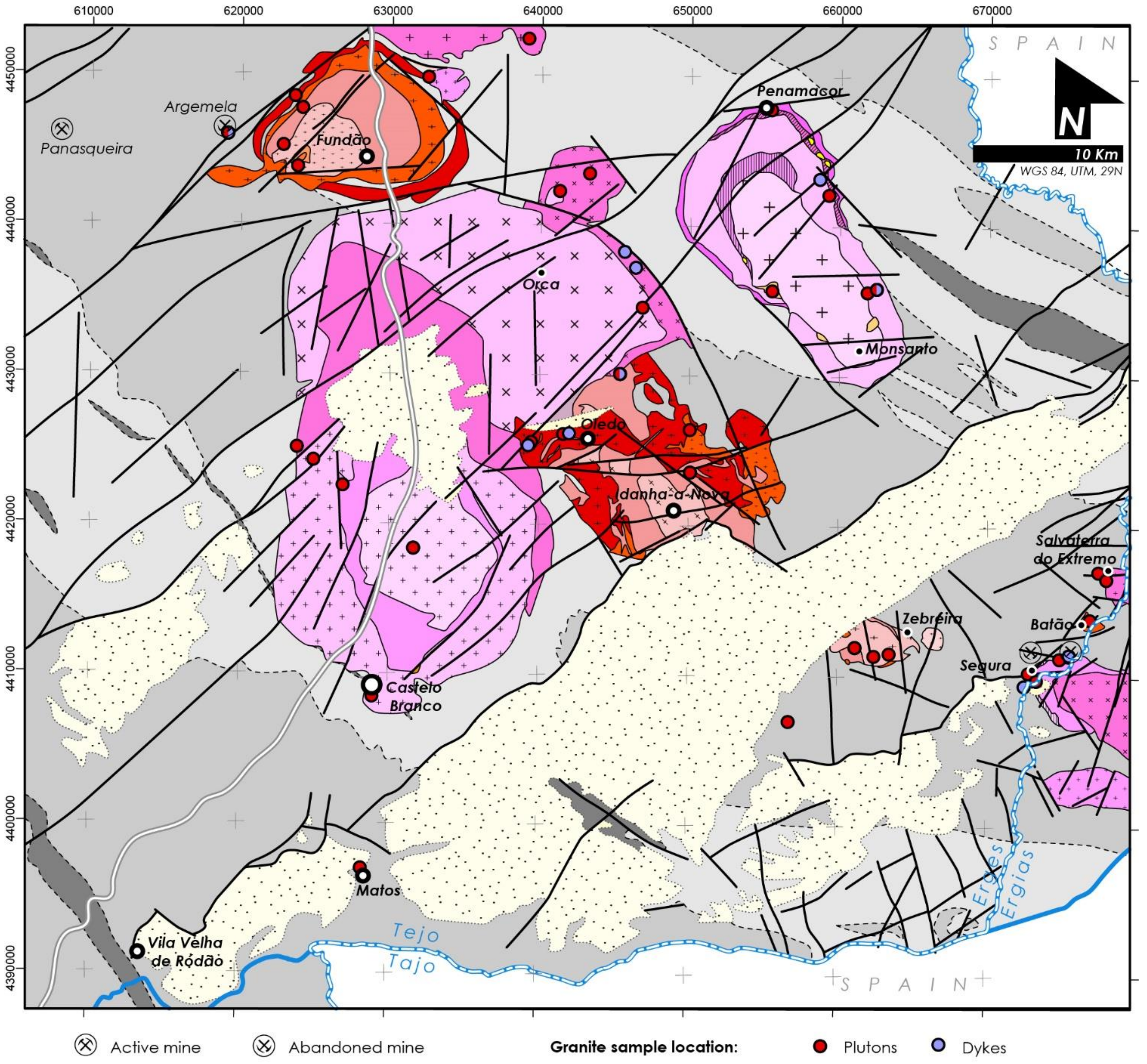
Starting point: results from many studies carried out throughout the past four decades

However:

- **Some data needing validation;**
- **Several gaps demanding further research (facies and elements analysed); and**
- **Limited information for aplite and pegmatite bodies.**

Sampling

- Focus on the Panasqueira-Segura area.
- 62 samples of granitoid rocks + 45 samples of aplite-pegmatite bodies and porphyry dykes.
- *23 extra samples from Fundão and Orca (Mata da Rainha) recently collected (Sept2023) and under study.*
- Compared with 192 whole-rock analyses compiled from published data.



Two main suites, documenting distinct magmatic events

- **Cambrian-Ordovician**

Early Ordovician plutons

Fundão

- G_{Fun}1: Biotite monzonitic granite
- G_{Fun}2: Biotite quartz-diorite
- G_{Fun}3: Biotite granodiorite
- G_{Fun}4: Biotite quartz-diorite
- G_{Fun}5: Transitional facies granite
- G_{Fun}6: Monzonitic granite

Oledo - Idanha-a-Nova

- G_{OIN}1: Medium-grained biotite granodiorite
- G_{OIN}2,3: Medium- to coarse-grained porphyritic biotite-muscovite granodiorite
- G_{OIN}4: Medium- to coarse-grained muscovite-biotite granite
- G_{OIN}5: Muscovite-biotite porphyroid granite

Zebreira

- Medium-coarse grained granodiorite
- Metassomatized granodiorite
- Porphiroid muscovite granite
- Medium-grained monzonitic granite

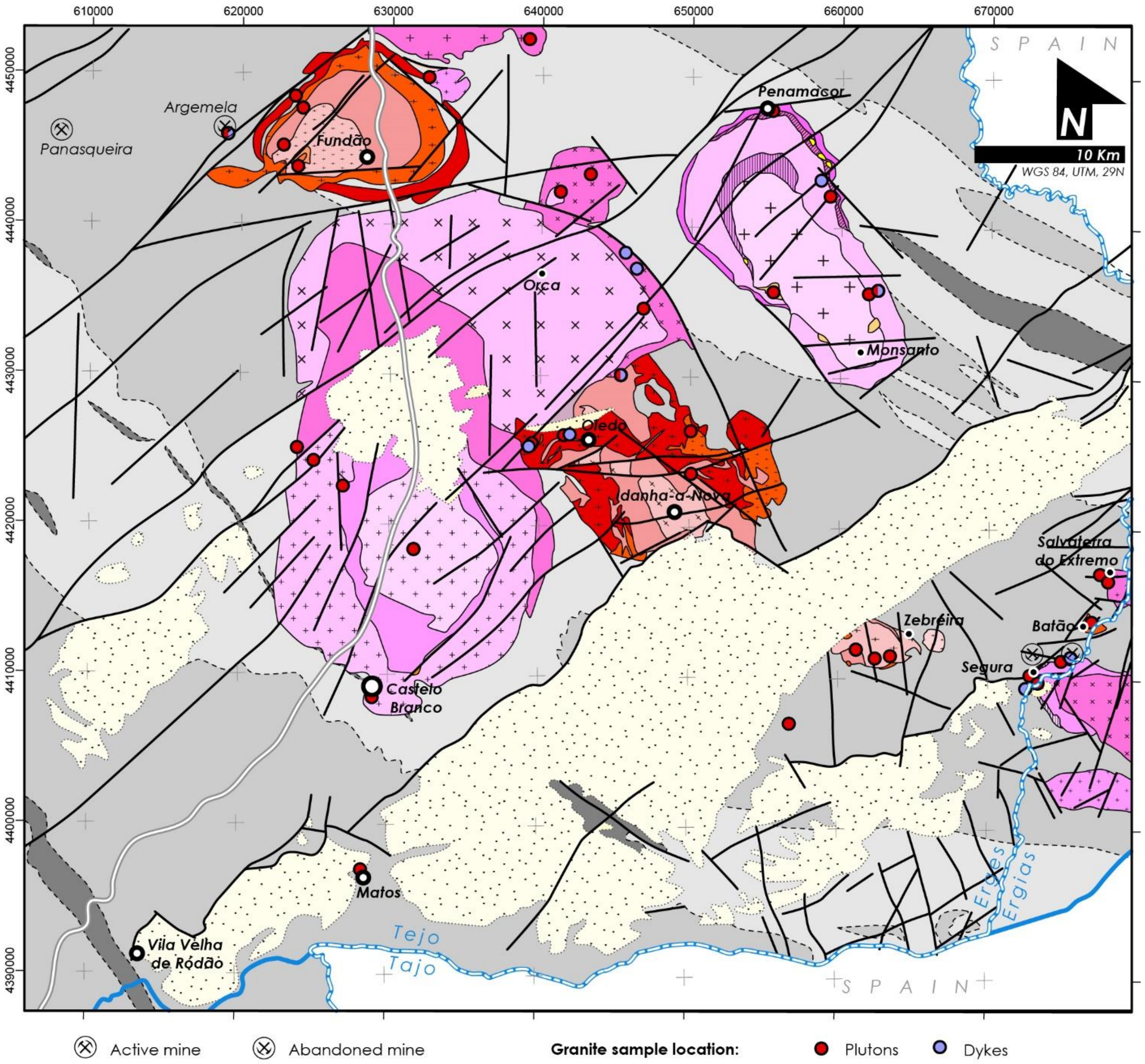
Batão

- Tonalite

- Cenozoic cover

- Ordovician-Silurian synclines
- Rosmaninhal Fm. (Ediacaran-lower Cambrian)
- Malpica do Tejo Fm. (Ediacaran)

- Stratigraphic boundary
- Intrusive contact
- Fault
- River
- Spanish-Portuguese border



Two main suites, documenting distinct magmatic events

- **Carboniferous-Permian**

Variscan (late Carboniferous) plutons

Pero-Viseu and Capinha
- Coarse- to very coarse-grained, porphyritic granite

Atalaia
- Albite-muscovite granite

Orca
- $G_{Orc}1$: Medium- to fine-grained muscovite granite
- $G_{Orc}2$: Porphyroid biotite-muscovite granite

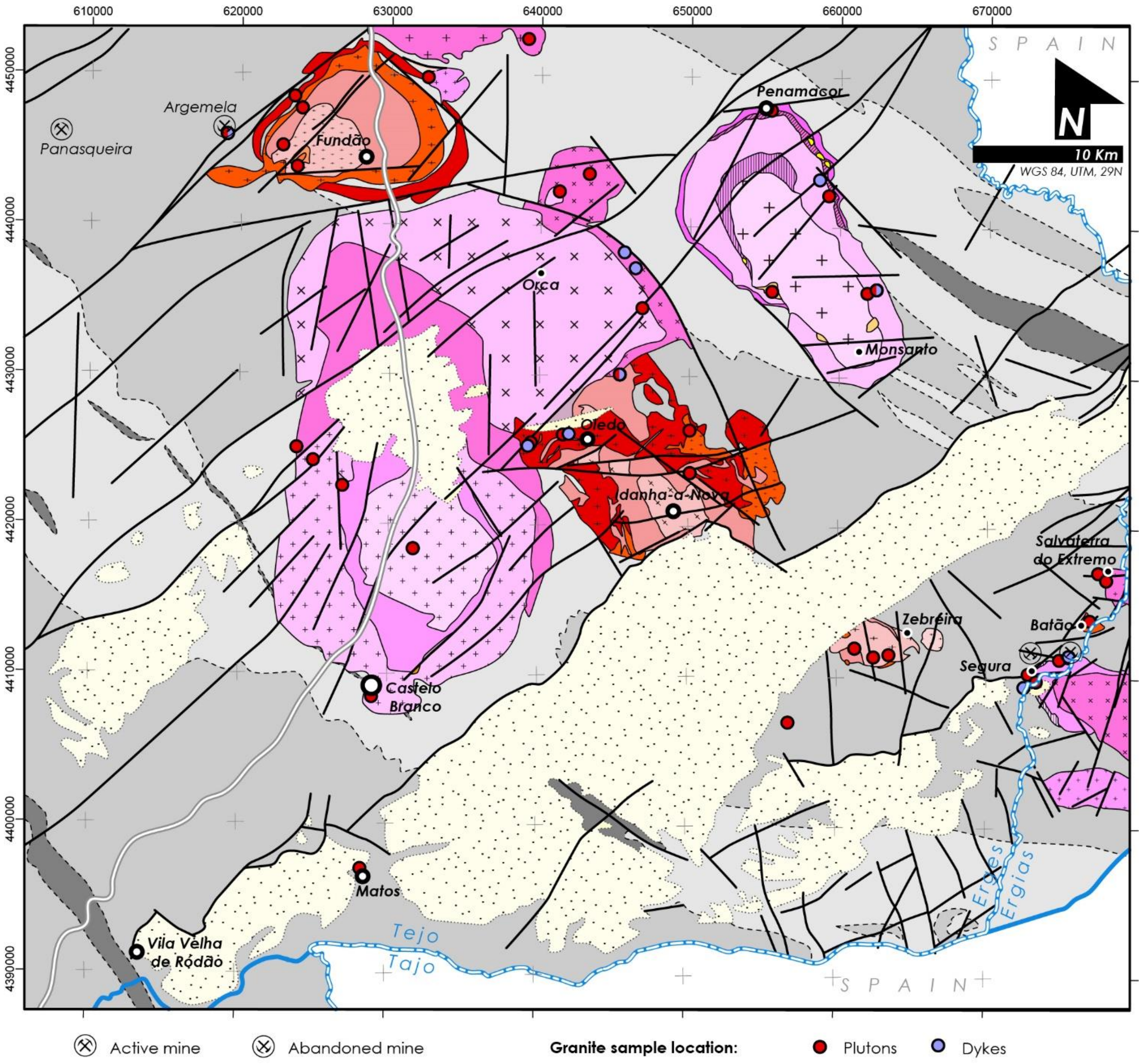
Castelo Branco
- $G_{CB}1$: Medium- to fine-grained muscovite-biotite granite
- $G_{CB}2$: Medium- to fine-grained porphyritic biotite-muscovite granodiorite
- $G_{CB}3,4$: Medium- to coarse-grained porphyritic biotite-muscovite granite
- $G_{CB}5$: Coarse-grained muscovite-biotite granite

Penamacor-Monsanto
- $G_{PM}1$: Medium- to coarse-grained muscovite-biotite granite
- $G_{PM}2$: Medium-grained muscovite-biotite granite
- $G_{PM}3$: Coarse- to medium-grained porphyritic biotite-muscovite granite
- $G_{PM}4$: Medium-grained porphyritic biotite-muscovite granite
- $G_{PM}5$: Coarse-grained porphyritic muscovite-biotite granite
- $G_{PM}6$: Medium- to coarse-grained porphyritic
- Pegmatite-Aplite dykes swarm

Salvaterra do Extremo
- Medium- to coarse-grained muscovite granite

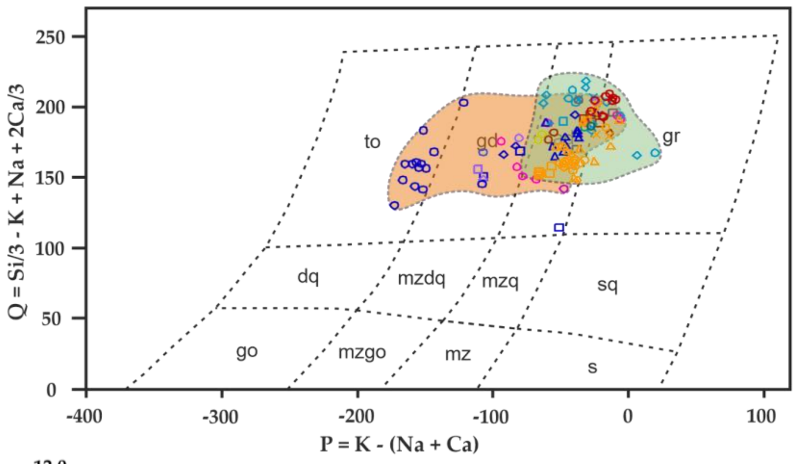
Segura-Cabeza de Araya
- $G_{SCA}1$: Coarse- to fine-grained muscovite-turmaline granite
- $G_{SCA}2$: Porphyroid two-mica granite
- $G_{SCA}3$: Porphyroid biotite-cordierite granite

Estorniños
- Two-mica porphyroid granite

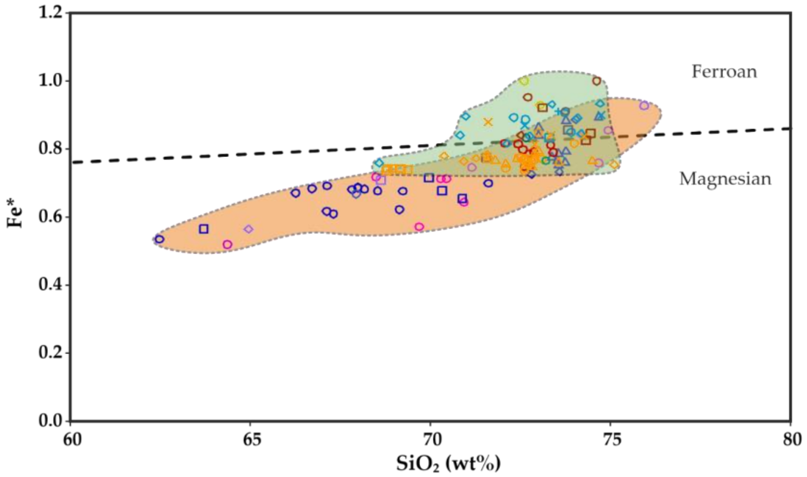


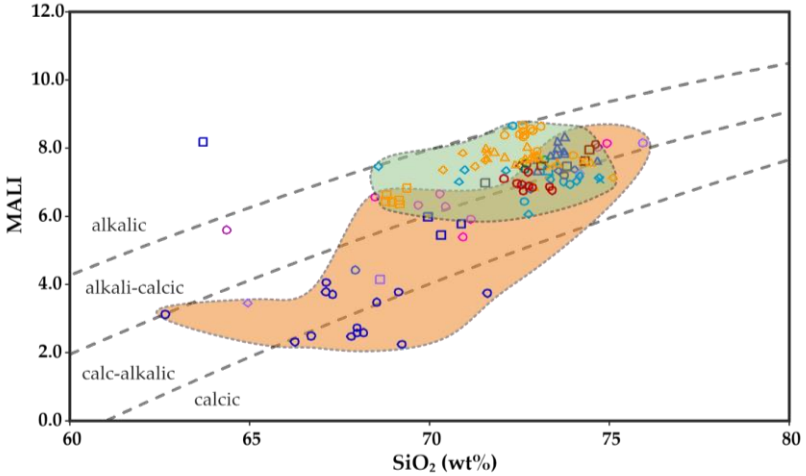
Compositional features

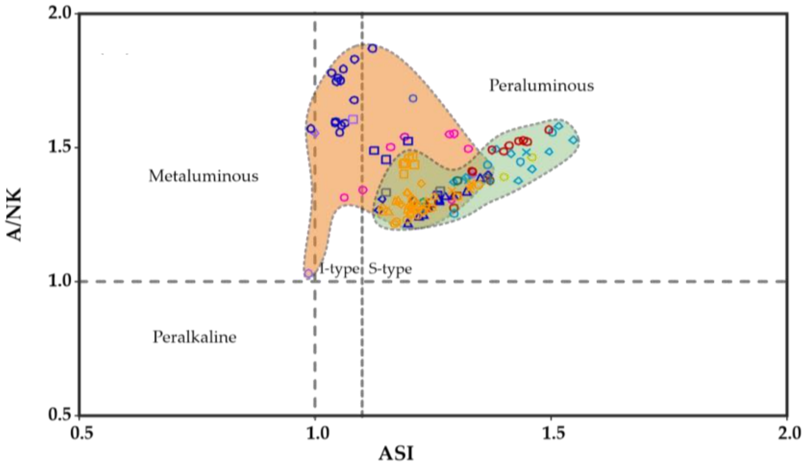
- **Cambrian-Ordovician magmatism:**
    - Weakly peraluminous I-type;
    - Bt/Bt>Ms tonalite to granodiorite;
    - Calcic to calc-alkalic series and magnesian granitoid rocks

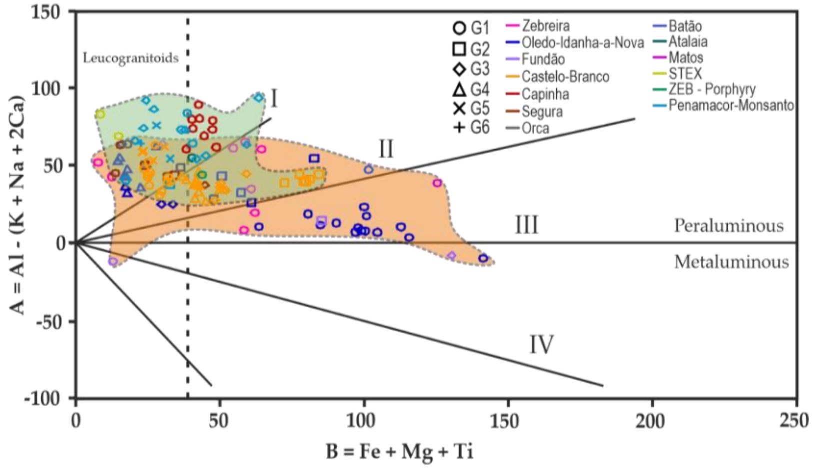


- **Variscan magmatism:**
    - Highly peraluminous S-type;
    - Ms>Bt/Bt>Ms monzogranite to granite;
    - Calc-alkalic to alkali-calcic and magnesian to ferroan granites





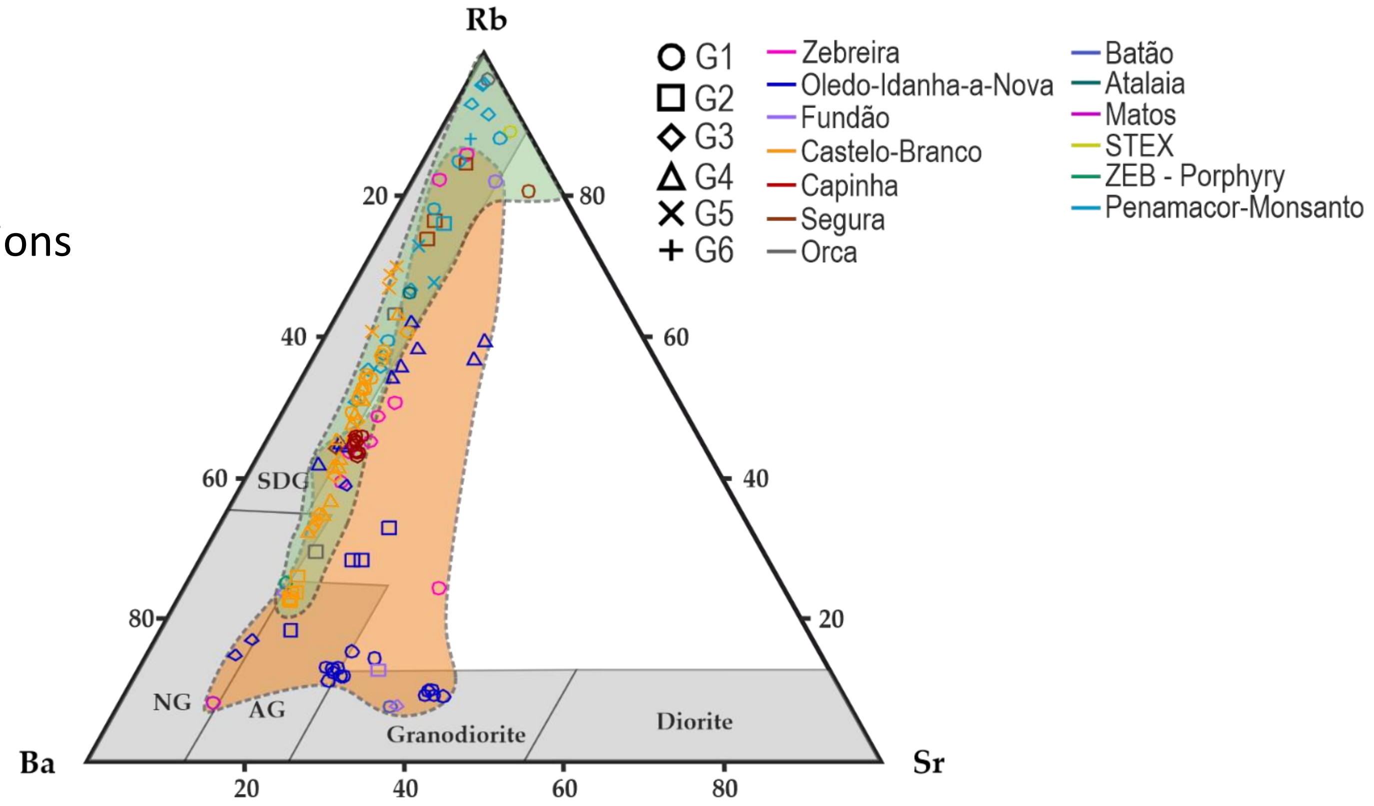


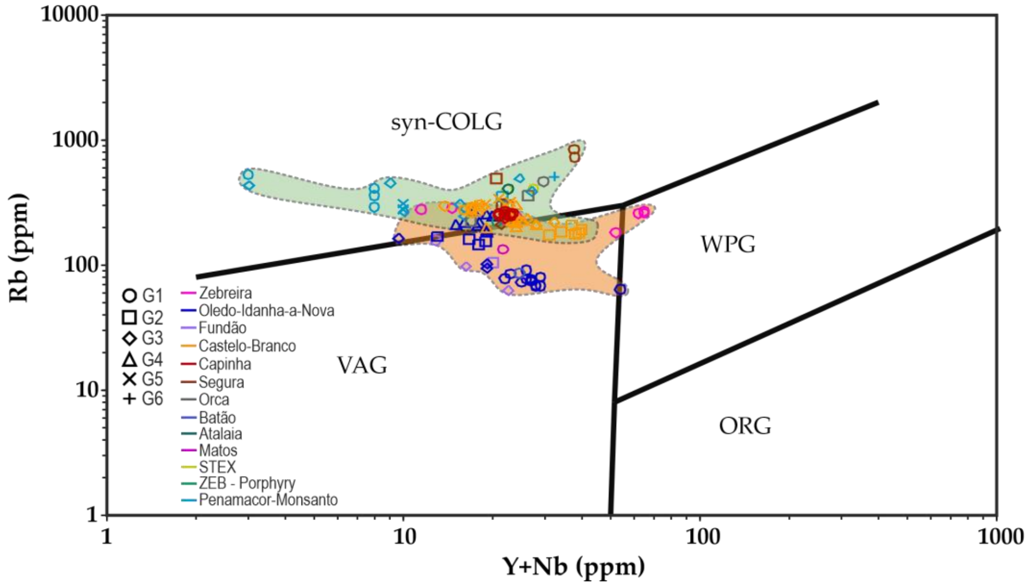


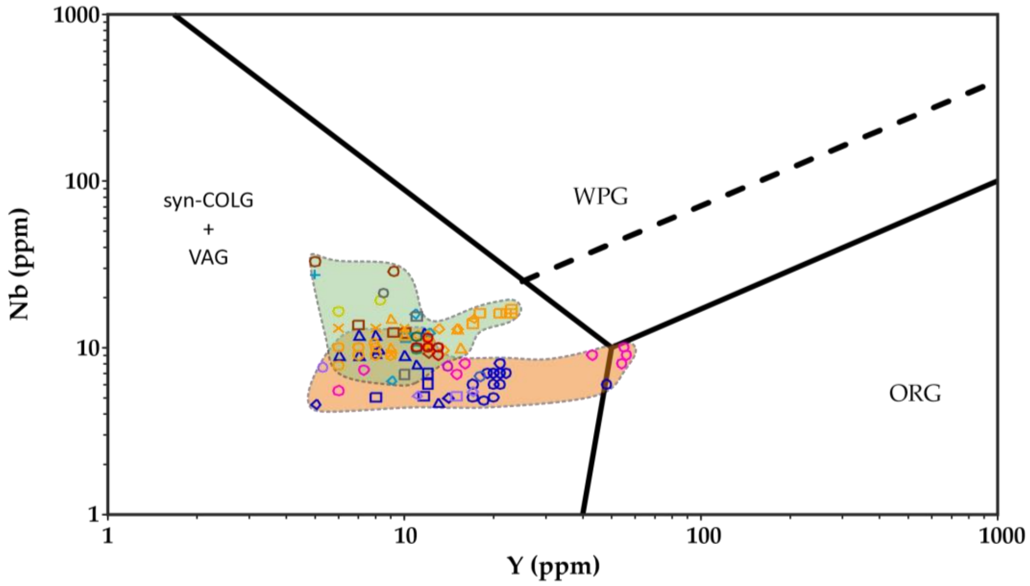
Compositional features

- **Cambrian-Ordovician magmatism:**
  - Tonalite/granodiorite to normal granite compositions (condensed differentiation trends);
  - Volcanic arc granitoids.

- **Variscan magmatism:**
  - Strongly differentiated rocks;
  - Syn-collisional granites.







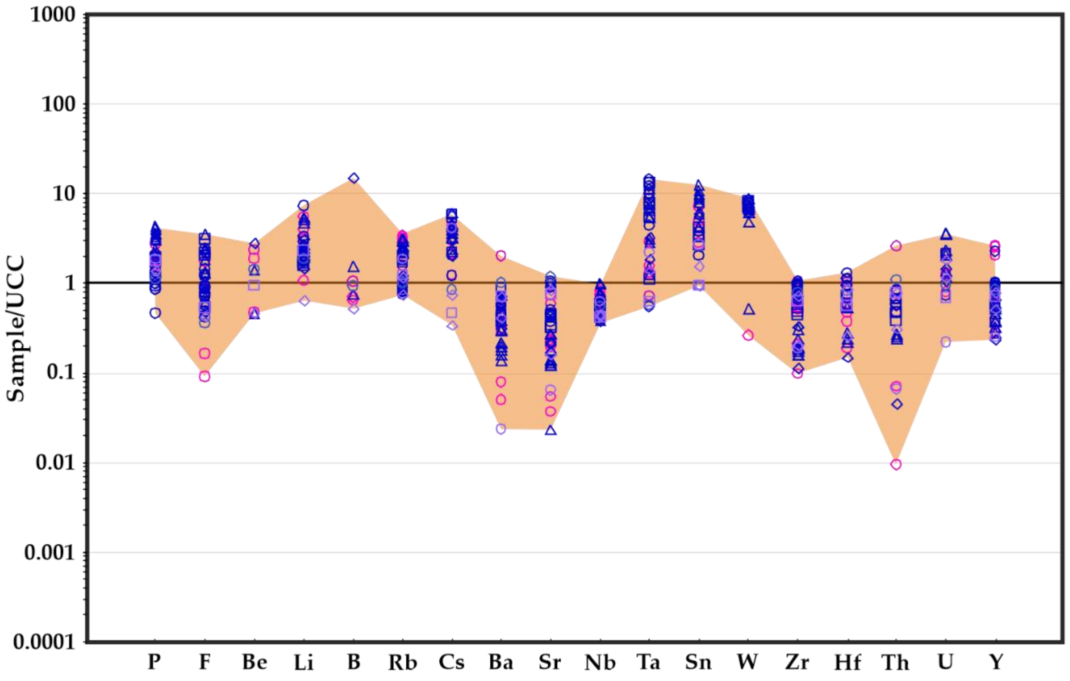
Compositional features

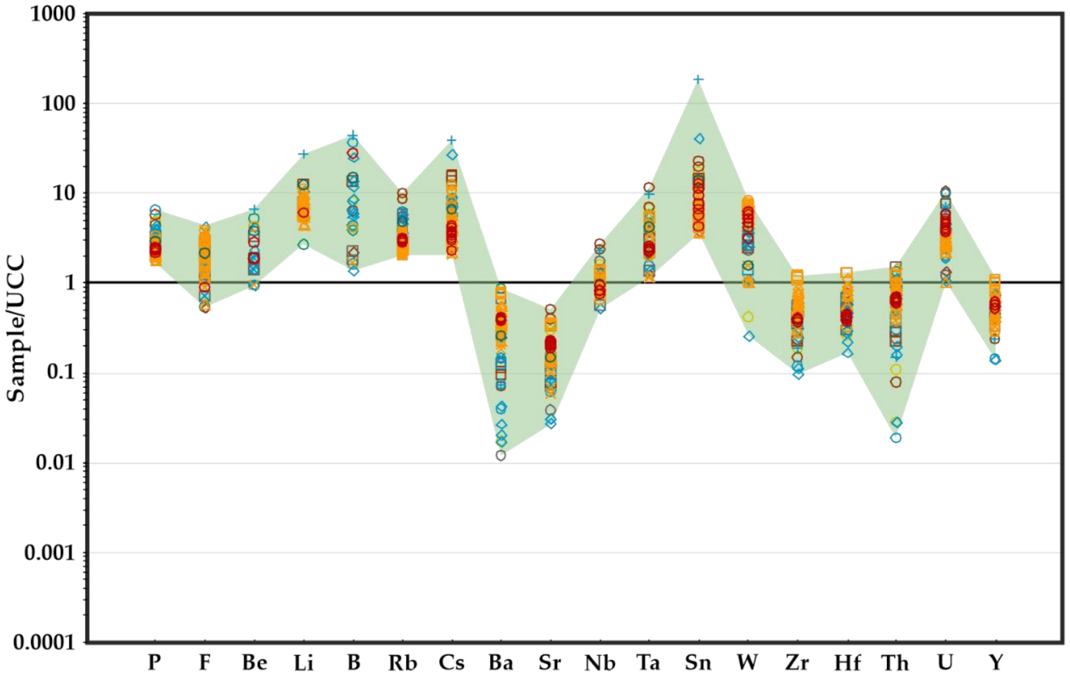
- **Cambrian-Ordovician magmatism:**

  - Enrichment (up to 20×UCC) in P, F, Be, Li, B, Rb, Cs, Ta, Sn, W and U;
  - Depletion in Ba, Sr, Zr, Hf, Th and Y.

- **Variscan magmatism:**

  - Prominent enrichments (up to 200×UCC, usually ranging from 20 to 50×UCC) and depletions in similar elements





Compositional features | Whole rock multi-system isotope analysis

Cambrian-Ordovician magmatism (11 samples)

- Main granitoid facies, excluding those from Idanha-a-Nova – Oledo (already reported in Antunes et al. 2010).
- Two-mica granite from the latter pluton and some highly differentiated facies, mostly forming dykes criss-crossing the granitoid facies (some of them also dated as Early Ordovician).

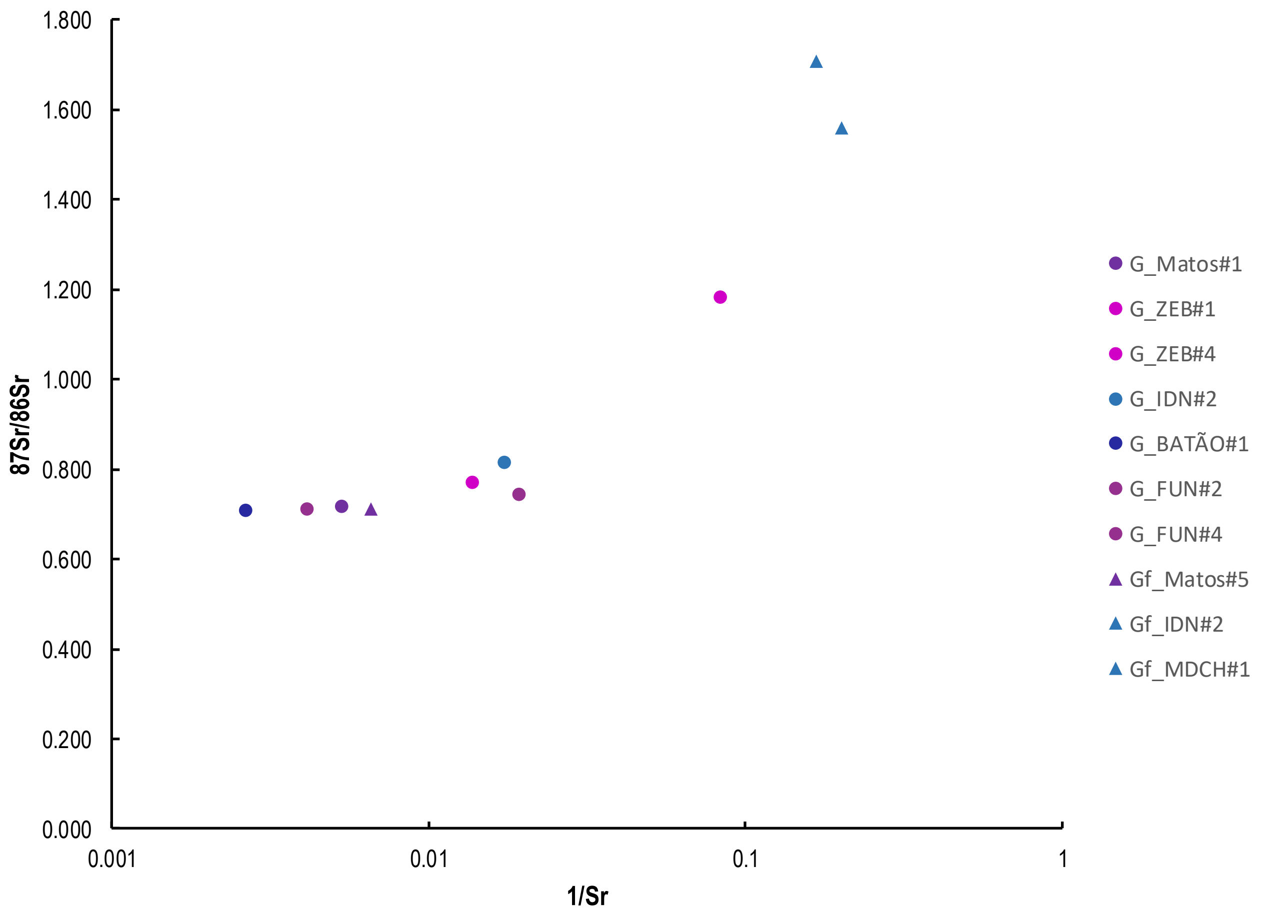
Variscan magmatism (22 samples)

- Main granite facies and dyke arrays from Salvaterra do Extremo, Segura, Penamacor-Monsanto (including the differentiated *ms*-rich facies of Medelim), Orca and Argemela, and excluding those from Castelo Branco (reported in Antunes et al. 2008).
- Several other facies, namely:
    - The *bt*-rich granite body of Capinha, to the north of Orca and Penamacor-Monsanto plutons;
    - The hidden two-mica granite of Panasqueira (SCB2#11) and an aplitic dyke (SMN1#4), both intersected by drilling, besides the greisen nearby the underground mined quartz lodes (P11-G);
    - A late granite body criss-crossing the Fundão granitoids (G-LP#1); and
    - The late porphyry rocks forming laccoliths and dykes at Marcelina and Furão (Zebreira area).

Compositional features | Cambrian-Ordovician magmatism

Sr systematics

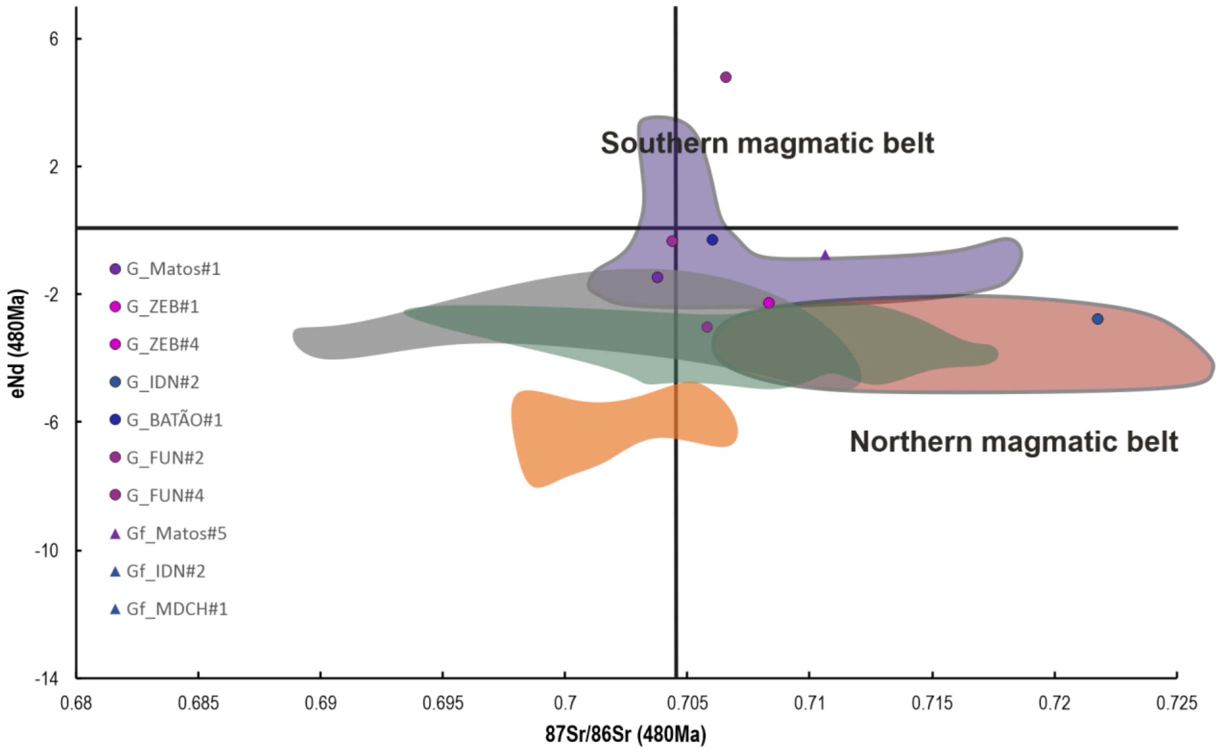
- **Variable Sr and Rb contents, causing large Rb/Sr fluctuations**:
  - 0.23 in the Batão tonalite;
  - 3.16 - 23.17 in granitoid facies from Zebreira;
  - 0.43 - 1.90 in granitoid facies from Fundão;
  - 4.71 in the two-mica granite, and up to 73.50 in highly differentiated dykes from Idanha-a-Nova – Oledo; and
  - 0.71 in granitoids from Matos.
- $^{87}Sr/^{86}Sr_{480\ Ma}$ values are:
  - 0.706 for Batão,
  - 0.704-0.709 for Fundão,
  - 0.704-0.711 for Matos,
  - 0.707-0.708 for Zebreira, and
  - 0.722 for the Idanha-a-Nova – Oledo leucogranite.
  - **Comparable with ranges reported for similar rocks across the CIZ southern domain and other Variscan orogenic segments** (e.g., Talavera et al., 2013).



Compositional features | Cambrian-Ordovician magmatism

Nd systematics

- **Limited variation of Sm and Nd contents**, and Sm/Nd ratios (0.18-0.28).
- **Positive $\varepsilon Nd_{480\ Ma}$** for one of the granitoid facies forming the Fundão pluton (4.783; G-FUN#4) and for two of the dykes from Idanha-a-Nova – Oledo (0.756 and 1.008).
- **$-0.331 \leq \varepsilon Nd_{480\ Ma} \leq -1.485$** for granitoid rocks from Matos, Batão and Fundão.
- **$-3.048 \leq \varepsilon Nd_{480\ Ma} \leq -2.788$** for granitoids from Zebreira and the two-mica granite from Idanha-a-Nova – Oledo.
- **TDM model ages define two main groups**:
  - The older, comprises the two-mica granite from Idanha-a-Nova – Oledo (ca.1.50 Ga) and the granitoids from Zebreira (ca. 1.40 to 1.50 Ga);
  - The younger, includes the Batão tonalite (1.24 Ga), the granitoids from Matos (1.27 to 1.33 Ga), the dykes from Idanha-a-Nova – Oledo (1.15 to 1.33 Ga) and the granitoids from Fundão (0.82 to 1.24 Ga).

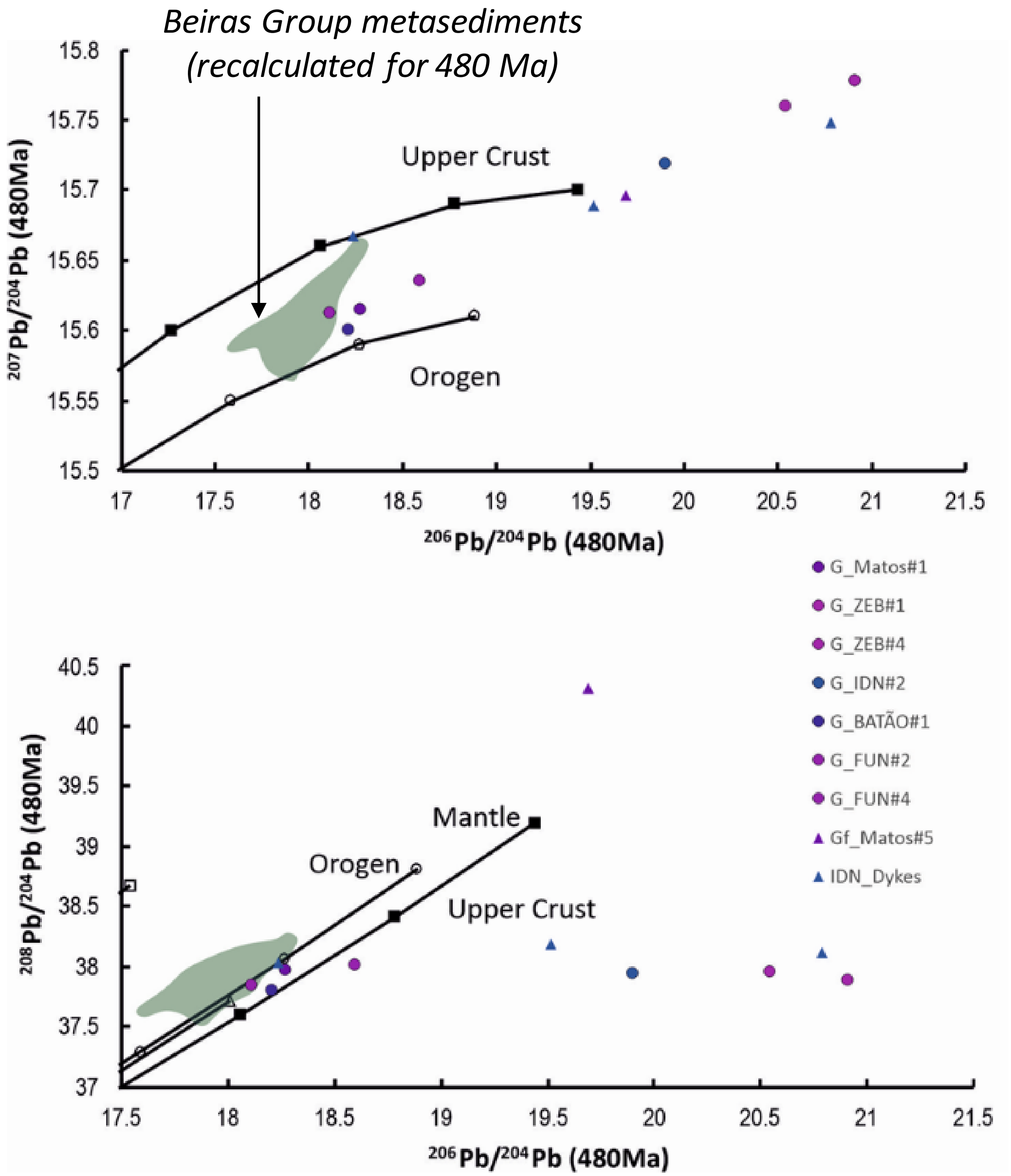


Compositional fields of meta-igneous rocks from the two C-O magmatic belts (purple and dark-pink areas) and the metasedimentary Neoproterozoic succession in each subzone (grey = Série Negra; orange = Douro Group; green = Beiras Group). Details on the isotopic data in Villaseca et al. (2014) and references therein.

Compositional features | Cambrian-Ordovician magmatism

Pb systematics

- **Variable U (2-10 ppm), Th (0.8-28 ppm), and Pb (7-30 ppm) contents**.
- **Usually, Th > U and 0.20 < U/Th < 0.38**; exceptions are the *bt*-rich granites from Zebreira and Fundão (G-ZEB#4 and G-FUN#4), the two-mica granite from Idanha-a-Nova – Oledo (G-IDN#2) and two dykes from the latter pluton (Gf-IDN#2 and Gf-MDC#1), which show 1.5 ≤ U/Th ≤23.3.
- **Pb-Pb isotopic ratios (480 Ma) spreading between the "*orogen*" and "*upper crustal*" reference curves**.
- **Slight overlapping with the Beiras Group metapelites ⇒ protoliths isotopically distinct from these metasediments involved in crustal melting processes**. Main deviations are granitoids from Zebreira and the two-mica granite from Idanha-a-Nova – Oledo, all displaying negative $\varepsilon Nd_{480\ Ma}$ values and older TDM model ages.



Cambrian-Ordovician magmatism

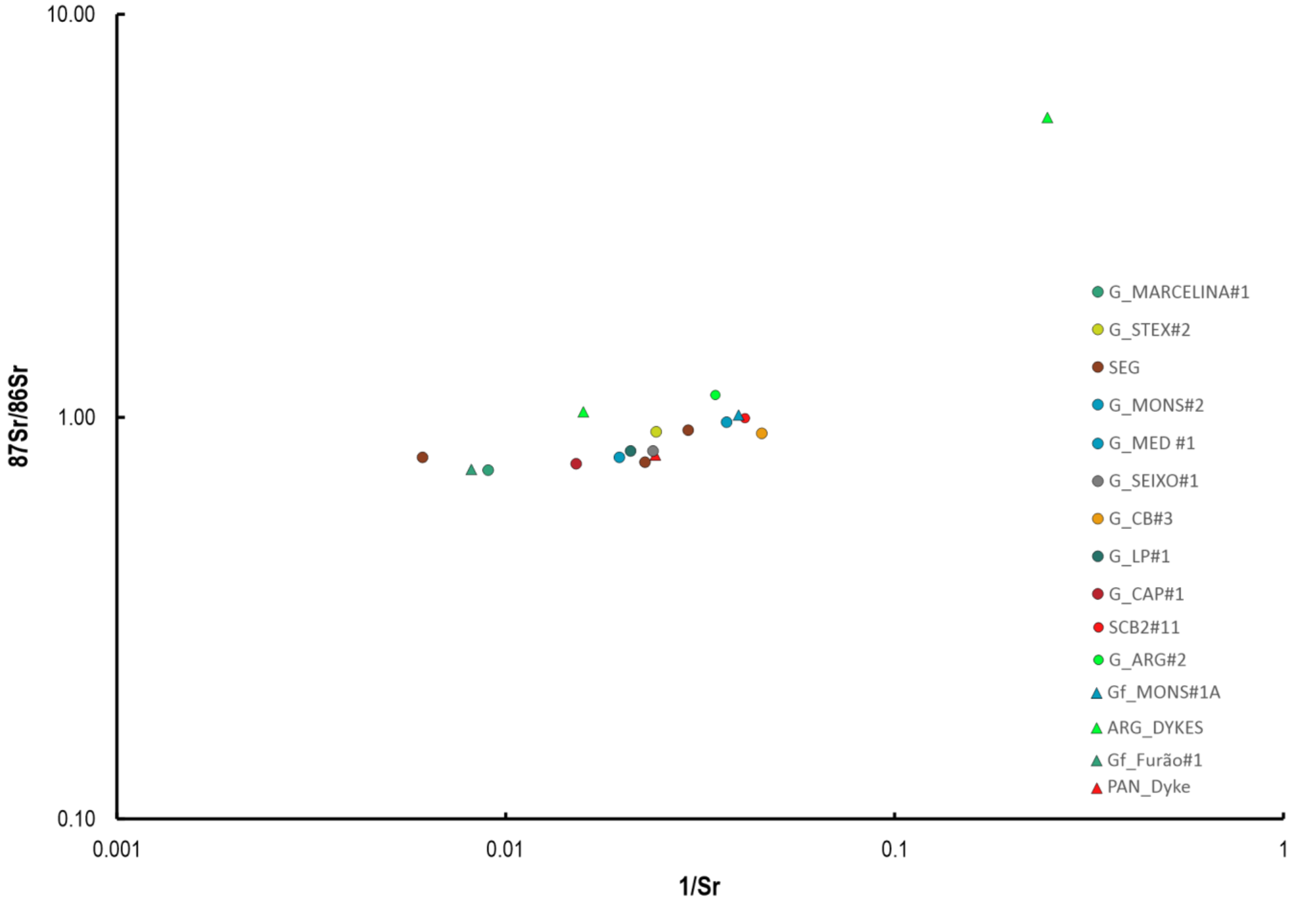
(Batão, Zebreira, Idanha-a-Nova-Oledo, Fundão, Matos)

- Independent magma batches reflecting different proportions of mixing between melts that preserve a "*orogen*" Pb-signature with melts generated in upper crustal levels (with variable degrees of partial melting).
- Consistent with the proposal of Castro et al. (2020) for the formation of granodiorite/tonalite plutons and minor intrusions during Cambrian-Ordovician times:
  - Emplacement of sanukitoid magmas at the lower crust, transferring the heat and releasing water during their crystallisation;
  - Subsequent partial melting of the lower crust, which includes the roots of the calc-alkaline Cadomian arc; and
  - Further magma rising through the crust, assimilating and/or triggering partial melting of metasediments (deeper portions of the siliciclastic succession forming the Beiras Group).

Compositional features | Variscan magmatism

Sr systematics

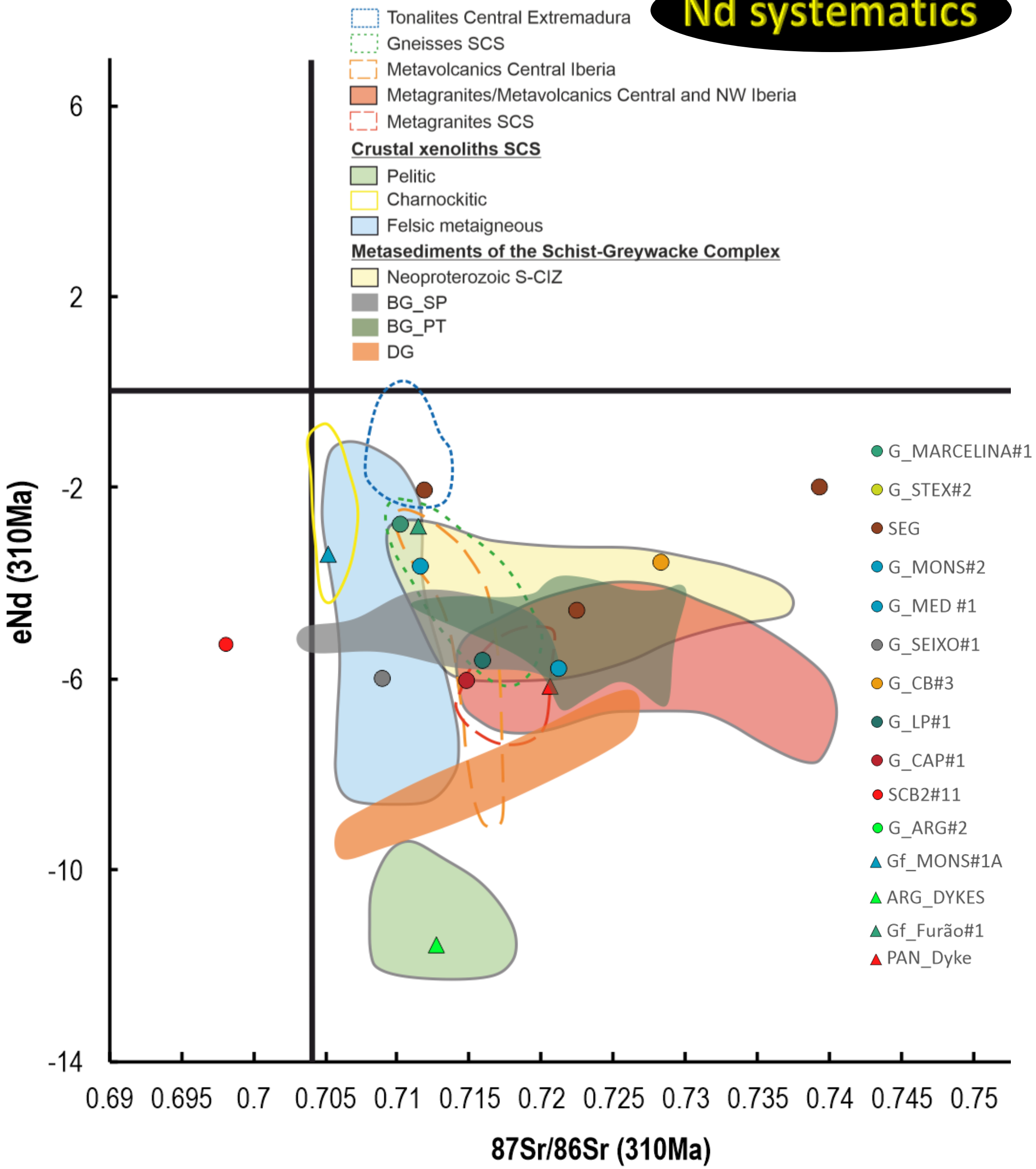
- **Wide range** of Rb (223-845 ppm) and Sr (27-164 ppm) contents; remarkable **Rb enrichment in the Argemela** suite (1110-1480 ppm) + lower Sr values (4-29 ppm)
- **Usually, 2 ≤ Rb/Sr ≤ 10**, but rise to
  - 14-20 in highly differentiated facies of Segura, Medelim and Castelo Branco.
  - 23-30 in pegmatites (e.g. Monsanto) and granitic facies recording compositional changes concurrent of mineralising processes (e.g. Panasqueira)
  - spread up to 232 in cases of exceptional Rb enrichments (Argemela).
- **$^{87}Sr/^{86}Sr_{310\ Ma}$: 0.705-0.716** in "common" granites; **0.721-0.729** in granites showing higher differentiation degrees and/or post-emplacement compositional changes; **0.710-0.712** in late porphyry rocks.
  - First subset compares well with "late to post-D_3, *bt*-dominant Iberian Variscan suites" (≈ 312-300 Ma, 0.7064 ≤ $^{87}Sr/^{86}Sr$ ≤ 0.7085).
  - The other two subsets deviate significantly from the "signature" ascribed to the post-D_3 (≈ 299-290 Ma) granite suite (0.7033 ≤ $(^{87}Sr/^{86}Sr)_i$ ≤ 0.7079) .



Compositional features | Variscan magmatism

- **Variable Sm (0.7-3.8 ppm) and Nd (1.3-18.7 ppm) contents**. Argemela samples + Panasqueira aplitic dyke show lower Sm (0.05-0.43 ppm) and Nd (0.13-1.05 ppm), also diverging from the ranges (3.9 ≤ Sm ≤ 4.5 ppm; 24 ≤ Nd ≤ 27 ppm) in late porphyry rocks.
- **Sm/Nd ratio confined to the 0.20-0.54 range; 0.16-0.17 in late porphyry rocks**.
- $\varepsilon Nd_{310\ Ma}$ vary between:
  - ca. -6.5 and -5.7 in granites from Capinha, Salvaterra do Extremo, Medelim, Orca and Fundão, and aplite dykes from Argemela and Panasqueira;
  - ca. -5 and -3 in the inner granite facies of Segura, granite and pegmatite of Monsanto, Castelo Branco (differentiated granite), Panasqueira (two-mica granite) and Argemela (differentiated/modified granite);
  - ca. -2.9 and -2.7 in late porphyry rocks;
- $\varepsilon Nd_{310\ Ma}$ is around:
  - -2 for the *ms*-rich granite border facies of Segura; and
  - -11.6 for one of the aplite dykes sampled in Argemela

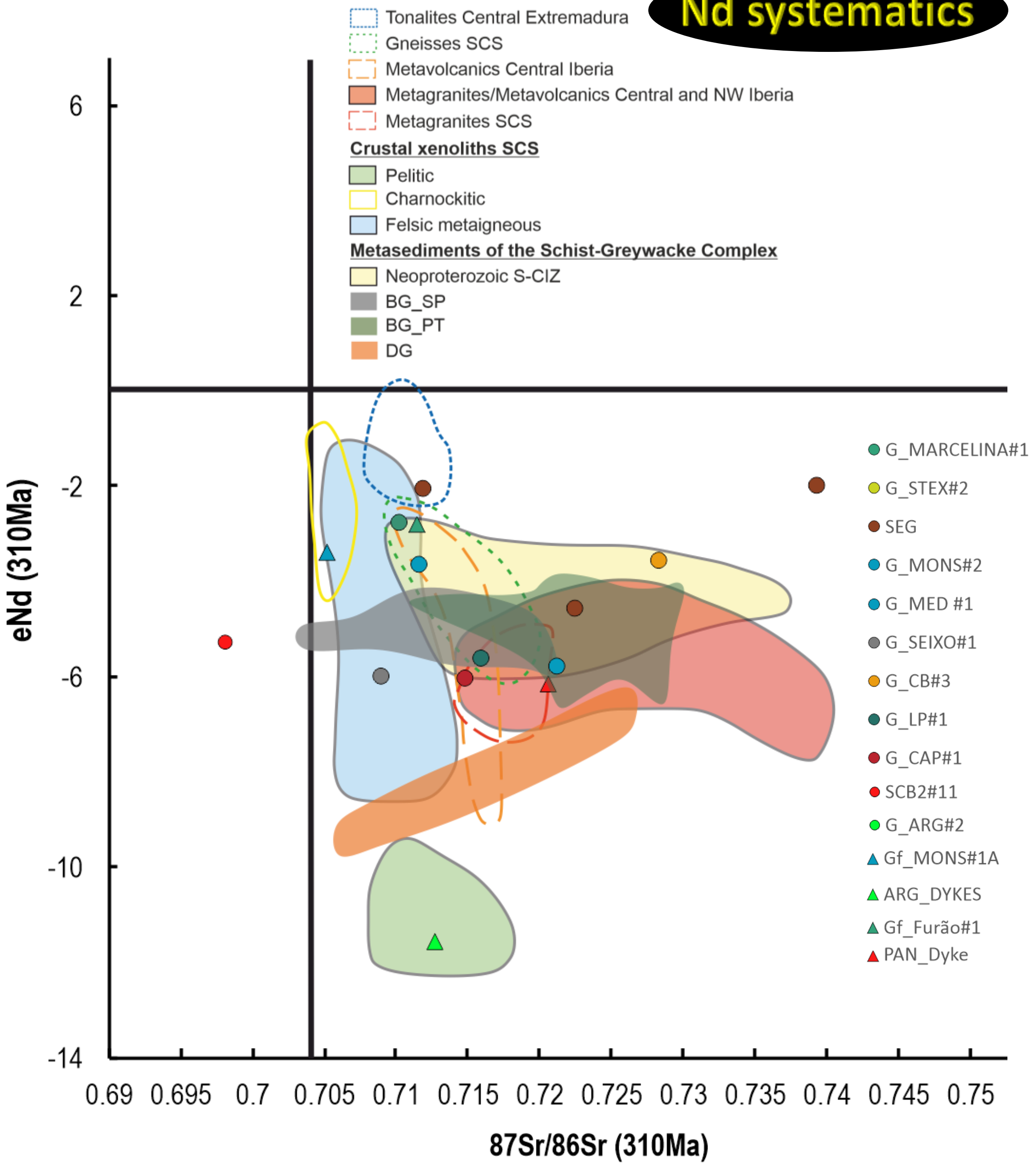
Nd systematics



Compositional features | Variscan magmatism

- **-6.5 ≤ εNd$_{310\ Ma}$ ≤ -5.7 ≡ ranges of "late to post-D$_3$, *bt*-dominant suites"** (-6.2 ≤ εNd$_i$ ≤ -4) in CIZ (e.g., Ribeiro et al., 2019). Prevalent crustal origin of the melts also consistent with $^{87}Sr/^{86}Sr_{310\ Ma}$ values.
- **Moderate negative εNd$_{310\ Ma}$ values ⇒ other protoliths than metapelites in partial melting processes** (meta-greywackes and/or meta-igneous sources).
- **εNd$_{310\ Ma}$ shifting (-5 to -3) ⇒ higher heterogeneity of the crustal source region + possible contributions of deeper sources** (inc. lower crust partial melting).
- **Late porphyry rocks (εNd$_{310\ Ma}$ ≈ -2.8) = melting of lower crustal sources**, although contaminated with pelitic-derived components during their ascent in the crust ($^{87}Sr/^{86}Sr_{310\ Ma}$ ≈ 0.711).
- **Aplite dyke in Argemela (lowest εNd$_{310\ Ma}$; -11.6) = partial melting of middle to lower crustal sources with dominant pelitic composition** ($^{87}Sr/^{86}Sr_{310\ Ma}$ = 0.713).

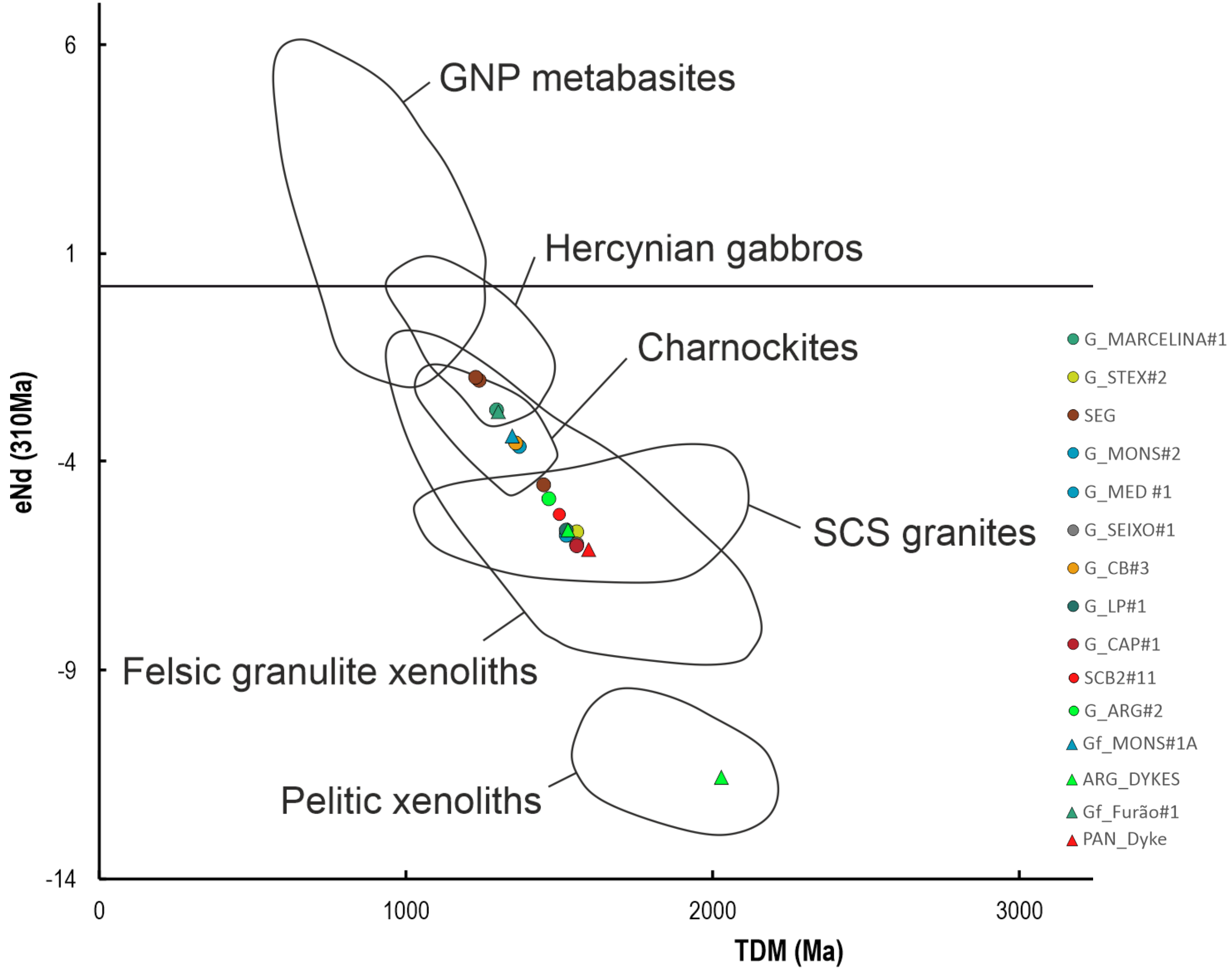
Nd systematics



Compositional features | Variscan magmatism

Nd systematics

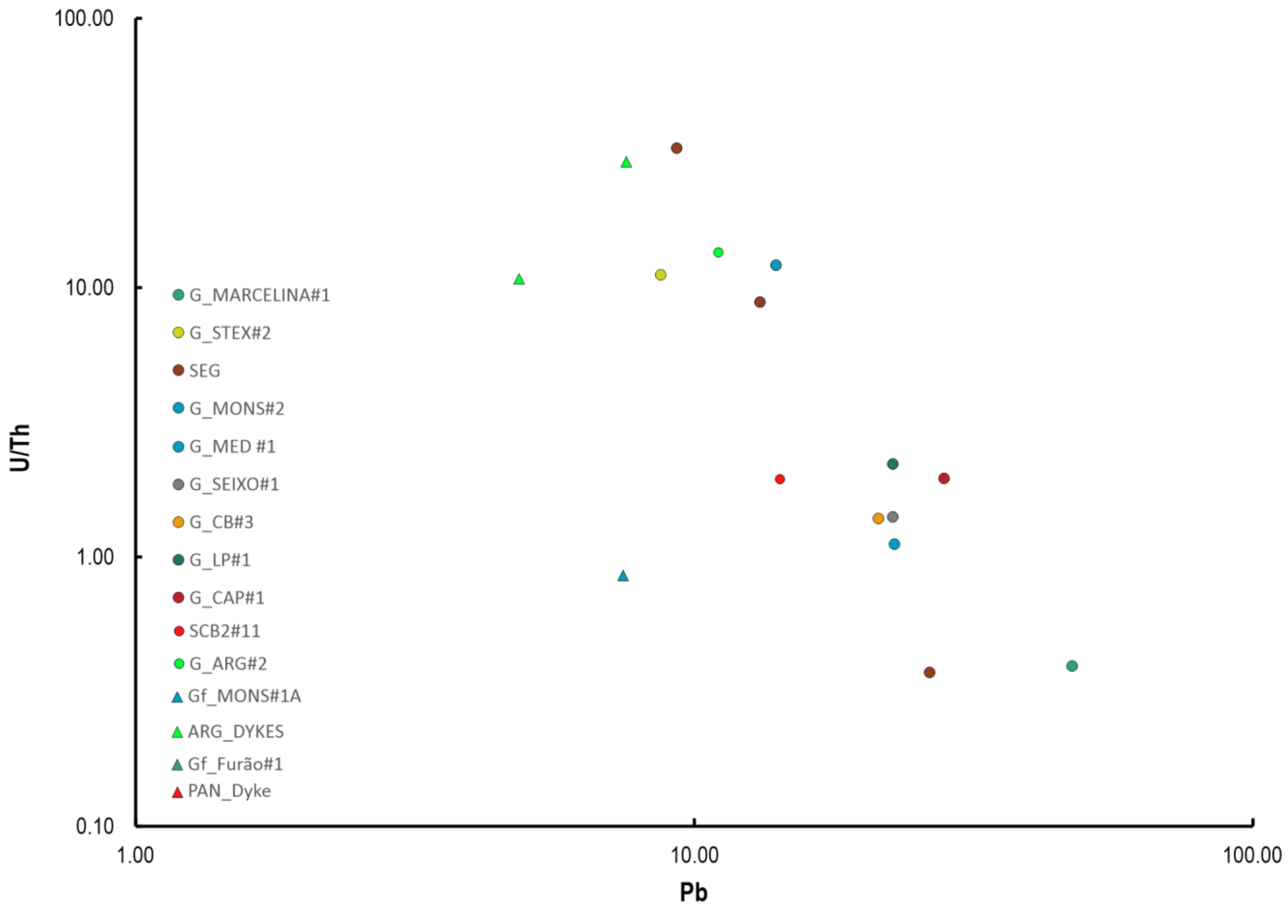
- **Inferences compatible with the estimated TDM model ages**:
  - **ca. 2 Ga** for the Argemela aplite dyke with the lowest $\varepsilon Nd_{310\ Ma}$ value;
  - **ca. 1.6 to 1.5 Ga** for the Capinha, Salvaterra do Extremo, Medelim, Orca, Fundão and Panasqueira granites, as well as for the aplite dykes from Argemela and Panasqueira;
  - **ca. 1.4 to 1.3 Ga** for samples from Segura (granite inner facies), Monsanto (granite and pegmatite), Castelo Branco (differentiated granite), and Argemela (differentiated/modified granite);
  - **ca. 1.3 Ga** for the late porphyry rocks; and
  - **ca.1.2 Ga** for the *ms*-rich granite border facies of Segura.



Compositional features | Variscan magmatism

Pb systematics

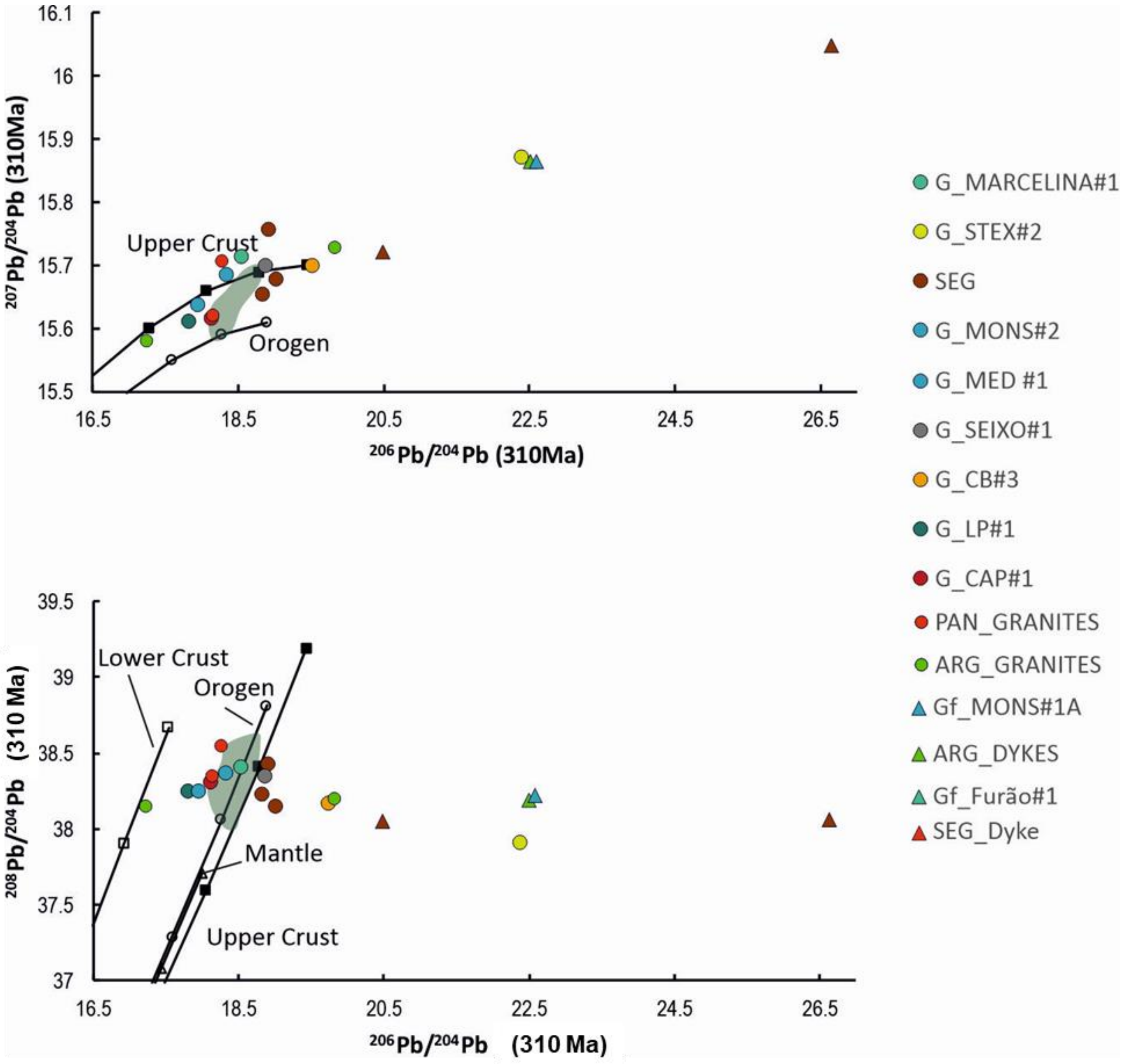
- **10 ≤ Pb ≤ 25 ppm**, but
  - ≈ 28 ppm for Capinha granite, ≈ 48 ppm for Marcelina porphyry, and 123 ppm for Panasqueira greisen. Pb < 10 ppm for Salvaterra do Extremo granite, one granite facies of Segura, Monsanto pegmatite and all the dykes sampled at Segura and Argemela.
- **≈ 11 ≤ U ≤ 27 ppm**, although
  - ≈ 3-8 ppm for some granitic facies of Segura, Castelo Branco and Argemela, as well as the Monsanto pegmatite and the Marcelina porphyry.
- **≈ 1 ≤ Th ≤ 11 ppm**, reaching 14 ppm in Marcelina porphyry.
- **Based on the U/Th ratio, 4 subgroups could be distinguished**, but mostly importantly **higher U/Th ratios (> 10) characterise granite and dyke facies showing signs of mineralisation and/or effects of mineral/textural changes triggered by mineralising processes.**



Compositional features | Variscan magmatism

Pb systematics

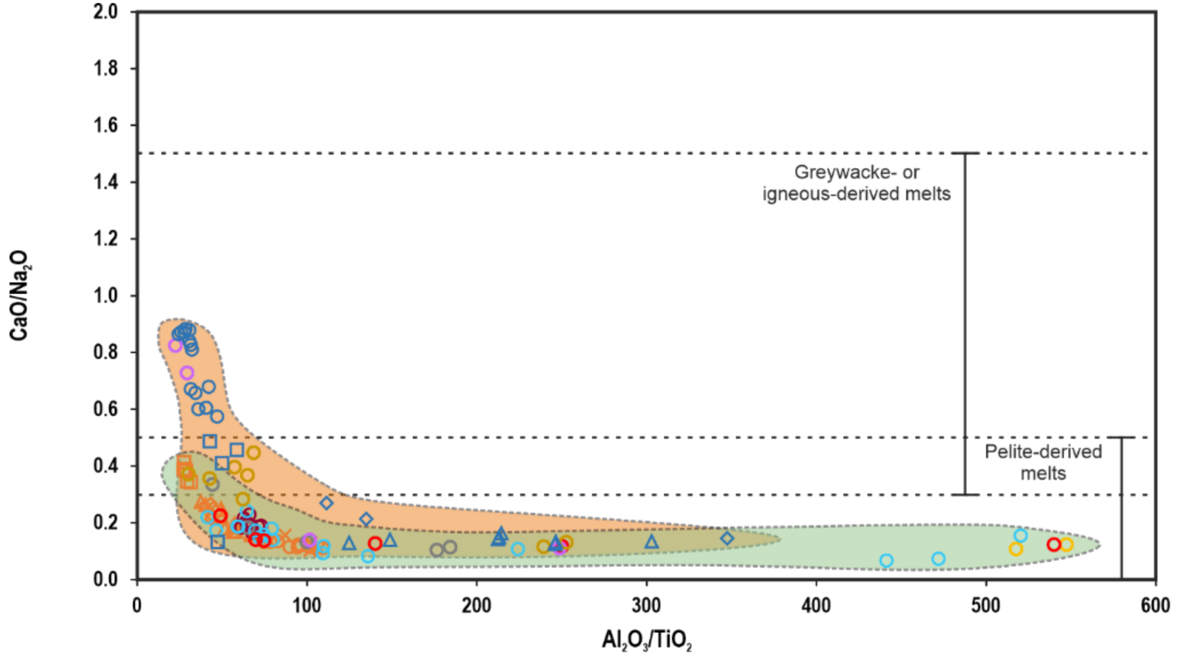
- **Pb-Pb isotopic ratios** spread between the "*orogen*" and "*upper crustal*" reference curves of the plumbotectonic model, but also plot above the "*upper crustal*" growth curve, displaying evident $(^{207}Pb/^{204}Pb)_{310\ Ma}$ and $(^{206}Pb/^{204}Pb)_{310\ Ma}$ increase.
- **The overlap with the Pb-Pb isotopic signature of the Beiras Group metapelites is limited**, indicating the involvement of other Pb sources, such as immature metasediments and/or meta-igneous protoliths.
- **The "Pb signature" for the Variscan granite suites supports a dominant upper crustal Pb derivation without significant juvenile contamination.**

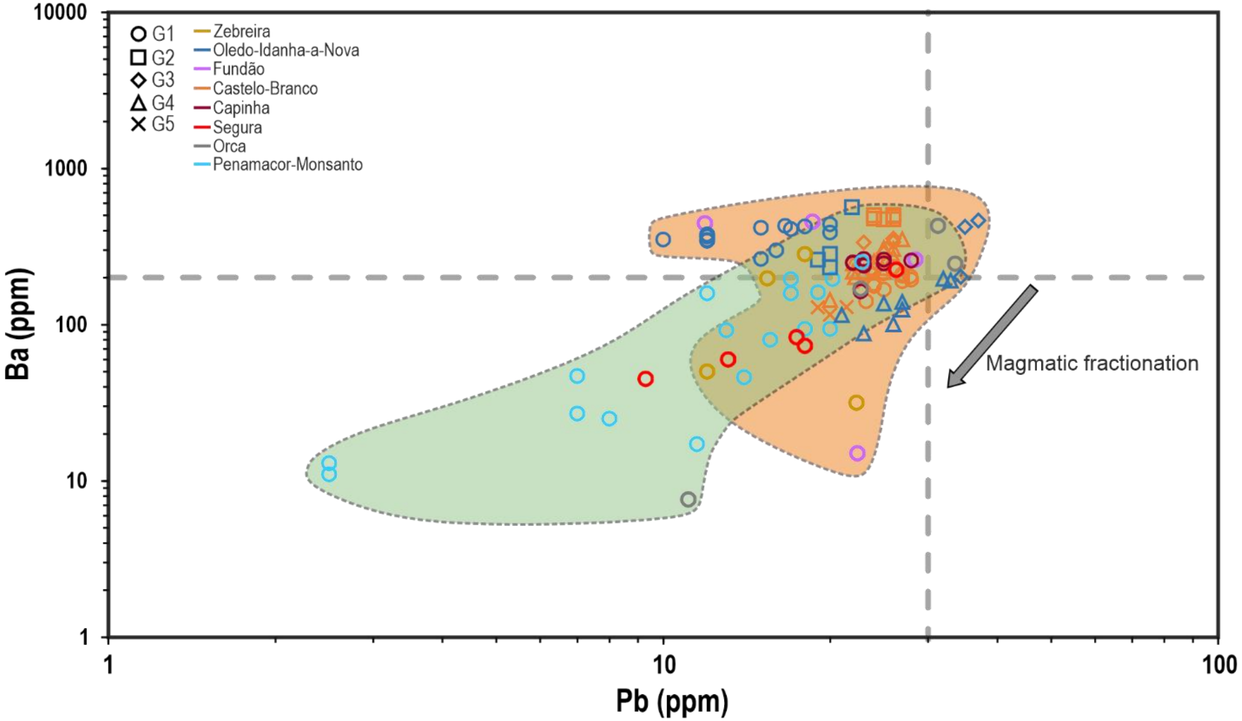


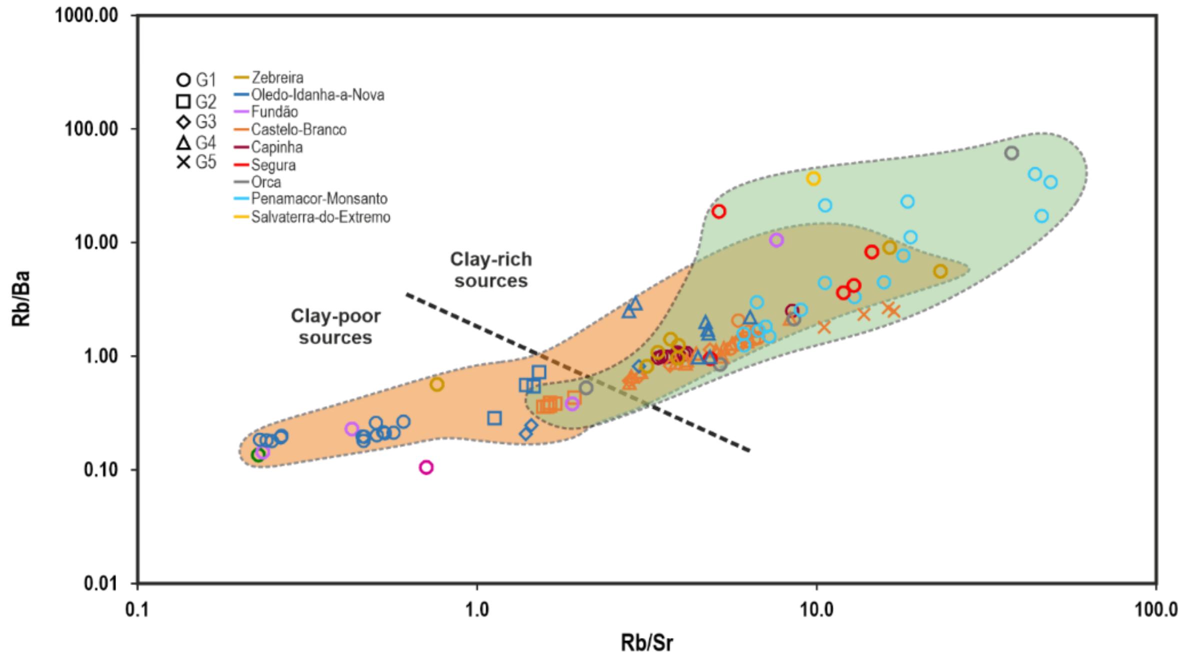
Variscan magmatism

(Panasqueira, Argemela, Castelo Branco, Orca, Capinha, Monsanto, Salvaterrra do Extremo, Segura)

- **Multi-stage partial melting of different crustal levels.**
- **Some of these crustal levels also acted as protoliths of the previous Cambrian-Ordovician magmatic event, as suggested by εNd values, Nd TDM model ages and Pb-Pb isotope ratios.**







Finger and Schiller (2012):

- primary low-T granites;
- secondary low-T granites, fractionated from high-T parental magma (Pb < 30 ppm, Ba < 200 ppm).

Constraints to the estimation of zircon saturation temperatures (T^{zir}_{sat}; Watson and Harrison, 1983)

T^{zir}_{sat} (°C)

Temperature conditions for the extraction of a granitic melt from its source assuming no significant fractional crystallisation has occurred

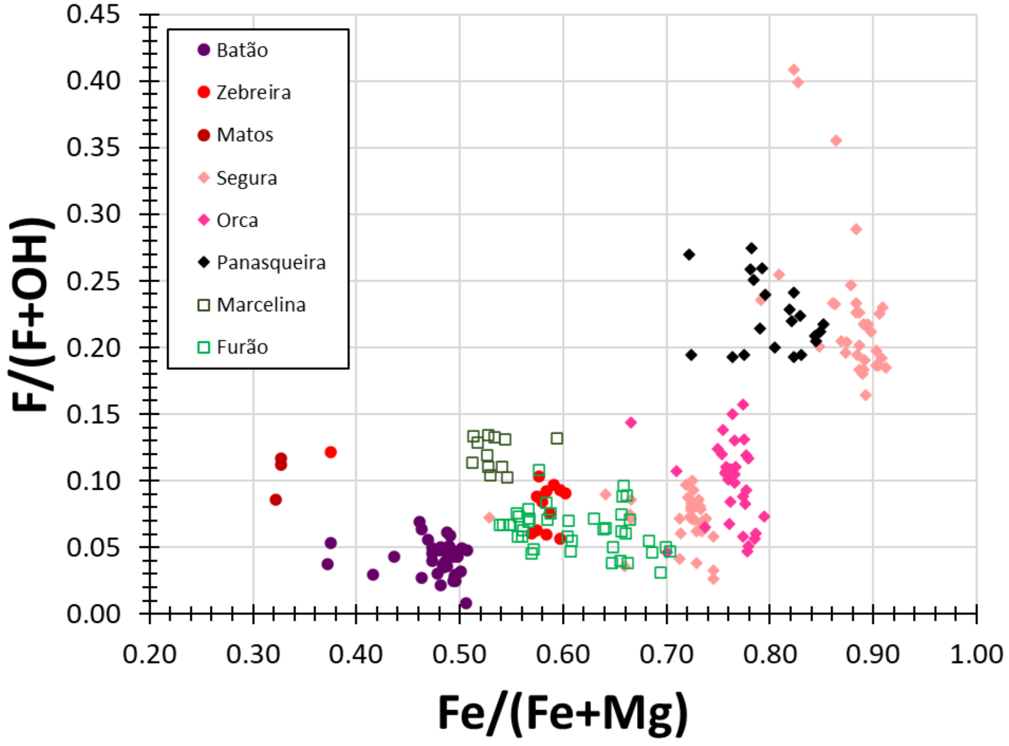
	Cambrian-Ordovician granites								
Facies	**Zebreira**		**OIN-G1**		**OIN-G2**	**OIN-G3**		**Fundão**	
Sample	*G_ZEB#1*	*G_ZEB#2*	*GPF*	*OLX*	*G_IDN#1*	*REPA1*	*REPA2*	*G_FUN#2*	*G_FUN#3*
T (ºC)	761	765	754	764	755	718	720	742	737

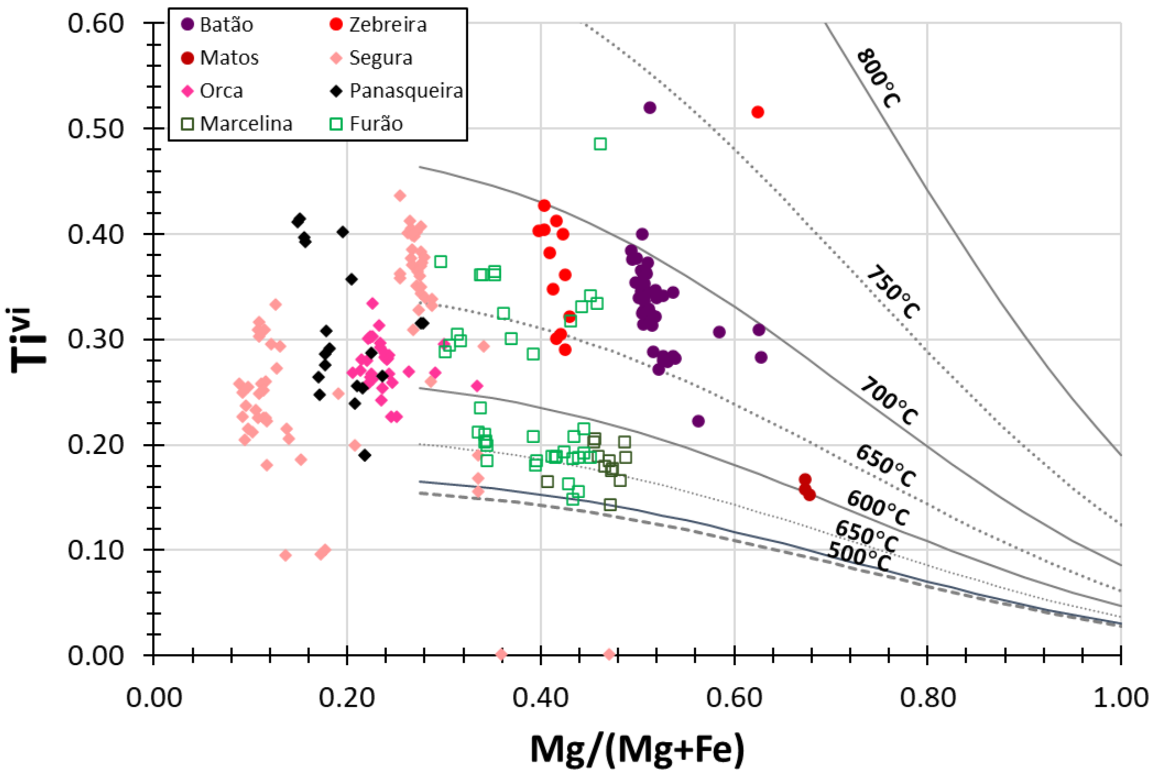
	Variscan granites										
Facies	**CB-G2**						**SEG**	**P-M**		**Orca**	
Sample	*GIN*	*GIN2*	*GIN4*	*G14*	*INFX1*	*INFX2*	*G_SEG#4*	*G_MONS#2*	*P-39*	*G_STC#1*	*G_MDCH#1*
T (ºC)	824	820	821	818	821	813	767	763	792	759	712

Facies	**Capinha**								
Sample	*G_CAP#1*	*1*	*4*	*11*	*15*	*18*	*19*	*Q1*	*Q2*
T (ºC)	750	753	755	749	757	744	749	752	751

Biotite | *ongoing work*

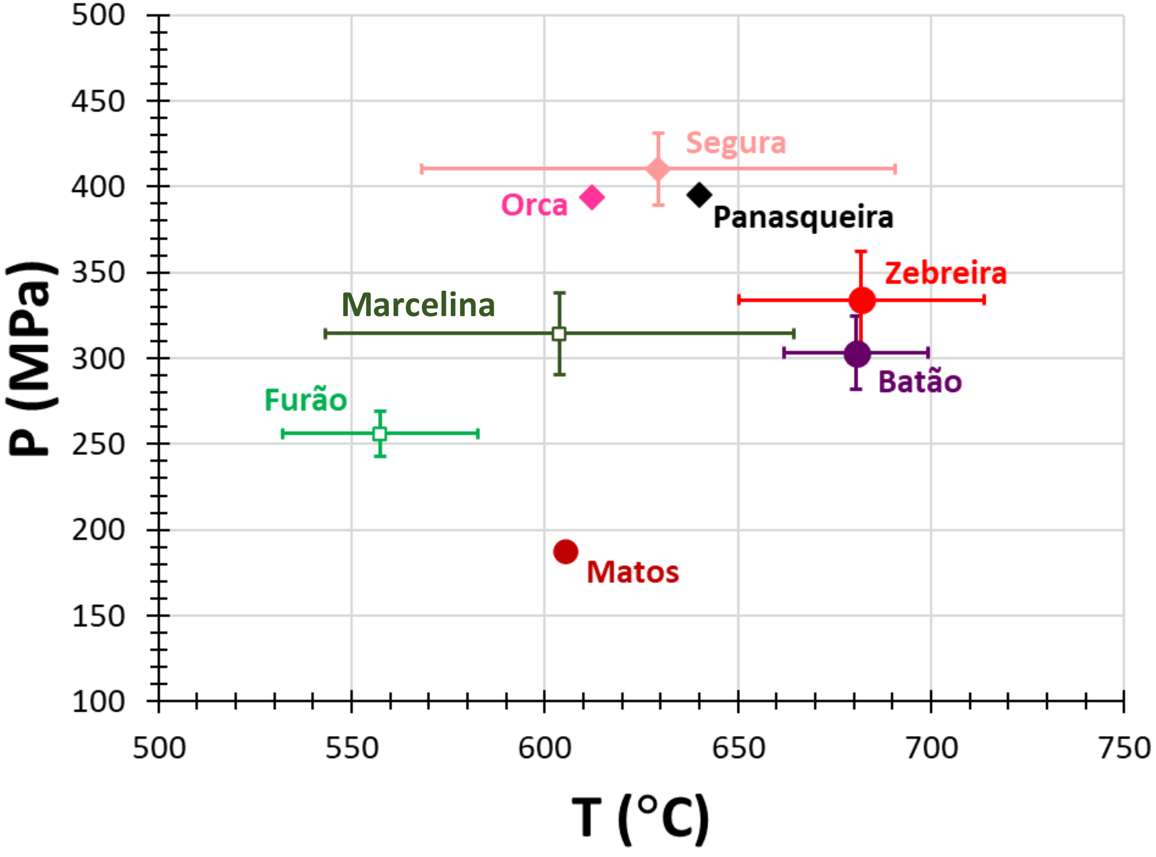
- Protracted crystallisation path
- Usual interstitial growth (in relation to alkali feldspar, quartz, and plagioclase), suggesting similar timing of biotite saturation
- Biotite composition should record conditions at comparable extents of magma evolution for different rock suites.



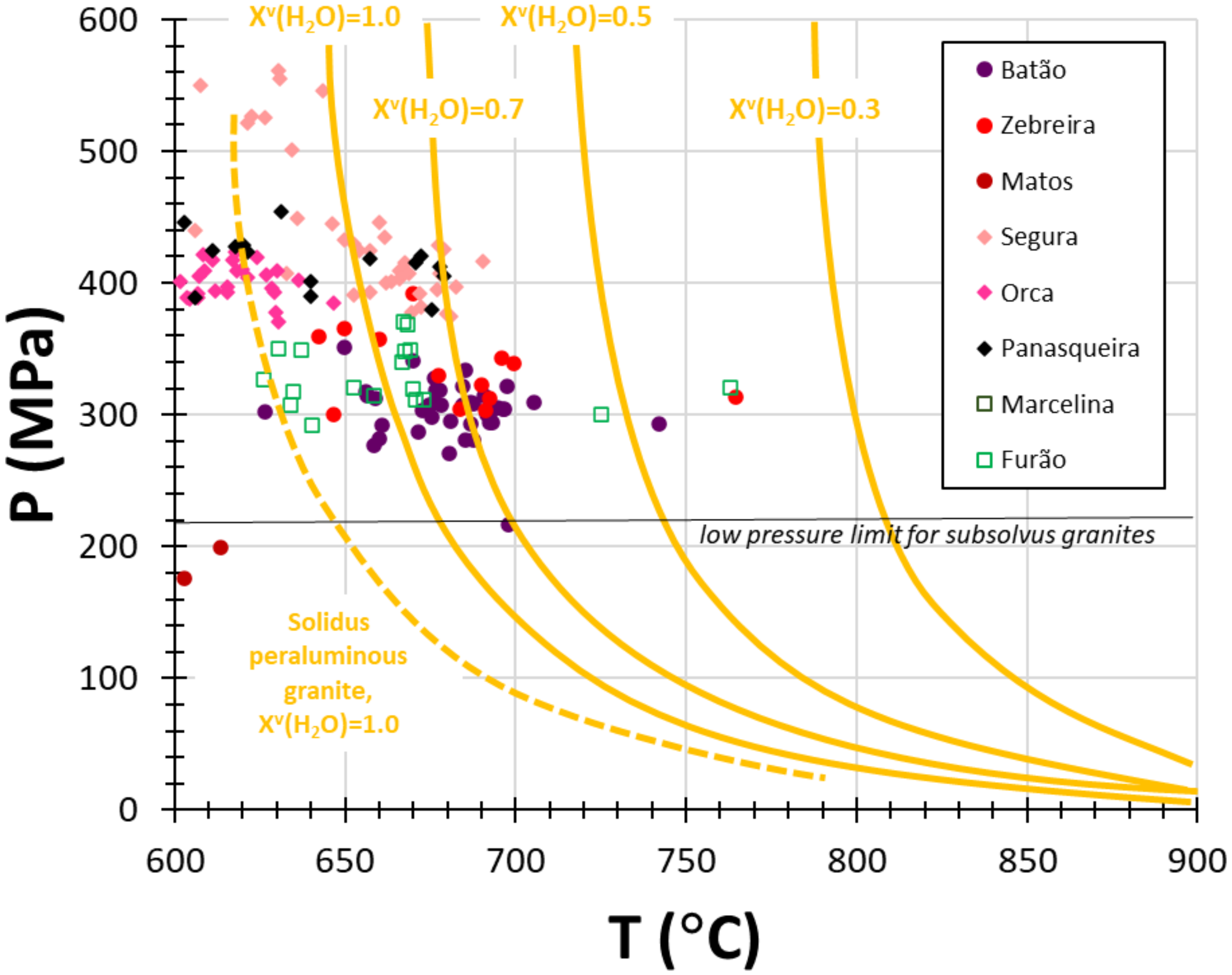


- Biotite T-crystallisation based on Ti contents and Mg/(Mg+Fe) (Henry et al., 2005)
- Application limited to 0.04 ≤ Ti ≤ 0.60 apfu and 0.275 ≤ Mg/(Mg+Fe) ≤ 0.60

Biotite | *ongoing work*



P estimates using the Al content and the relationship of Henry et al. (2005)



Minimum water contents above 6-7 wt% for the magmas, conceivably higher in Variscan suites in comparison to those generated during the Cambrian-Ordovician transition

Geochronology | *starting point*

Several studies; see Mateus et al. (2020)

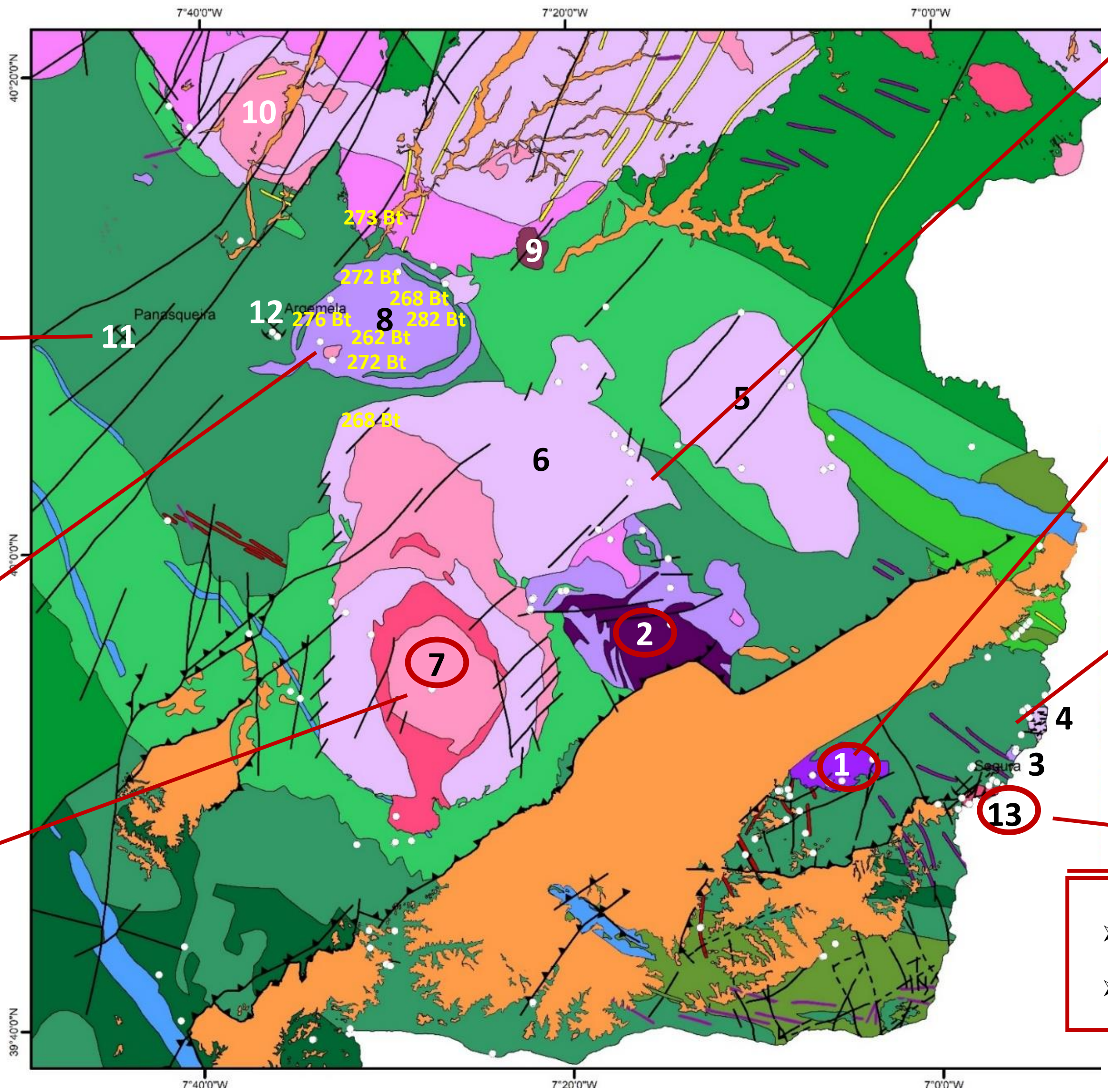
Panasqueira
- WR Rb-Sr, two-mica γ: 289±4 Ma
- U-Pb uraninite in greisen: 298±2 Ma
- U-Pb rutile (border of qz-lodes): 305±3.3 Ma
- U-Pb cassiterite (qz-lodes): 303±3.3 Ma and 301±4.2 Ma
- Ar-Ar muscovite: 296.3±0.8 Ma (thick selvages), 291.6±0.8 Ma (relative late mica)

Portugal Ferreira et al. (1977)

Fundão (Covilhã, Alpedrinha)
- K-Ar biotite: 262±2 Ma e 282±2 Ma (different facies forming the Fundão pluton)
- K-Ar biotite: ≈270 Ma porphyroid γs of Covilhã and Alpedrinha

Antunes et al. (2008)

CASTELO BRANCO
- **"Ms>Bt γ core"**: ID-TIMS U-Pb zircon: 309.0±1.1 Ma; ID-TIMS U-Pb monazite: 309.5±0.9 Ma
- **"Bt>Ms granodiorite ring"**: ID-TIMS U-Pb zircon: 310.1±0.8 Ma; ID-TIMS U-Pb monazite: 310.5±1.5 Ma
- **Porphyritic "Bt>Ms granodiorite"** grading to **Bt≡Ms γ**
- **"Ms>Bt external γ ring"**: ID-TIMS U-Pb zircon: 309.7±0.4 Ma; ID-TIMS U-Pb monazite: 309.0±3.2 Ma



Antunes et al. (2009)

Oledo – Idanha-a-Nova
- **"Granodiorite G1"**: ID-TIMS U-Pb zircon: 480.5±1.0 Ma; ID-TIMS U-Pb monazite: 478.3±1.1 Ma
- **"Granodiorite G2"**:
- **"Granodiorite G3"**: ID-TIMS U-Pb zircon: 479.0±4.0 Ma
- **"G4 γ "**: ID-TIMS U-Pb zircon: 479.0±3 Ma

Pereira et al. (1986)

Zebreira
- **"Granodiorite"**: K-Ar biotite: 372±7 Ma; K-Ar muscovite: 472±7 Ma
- **"Monzo-γ dykes"**: K-Ar muscovite: 440±8 Ma

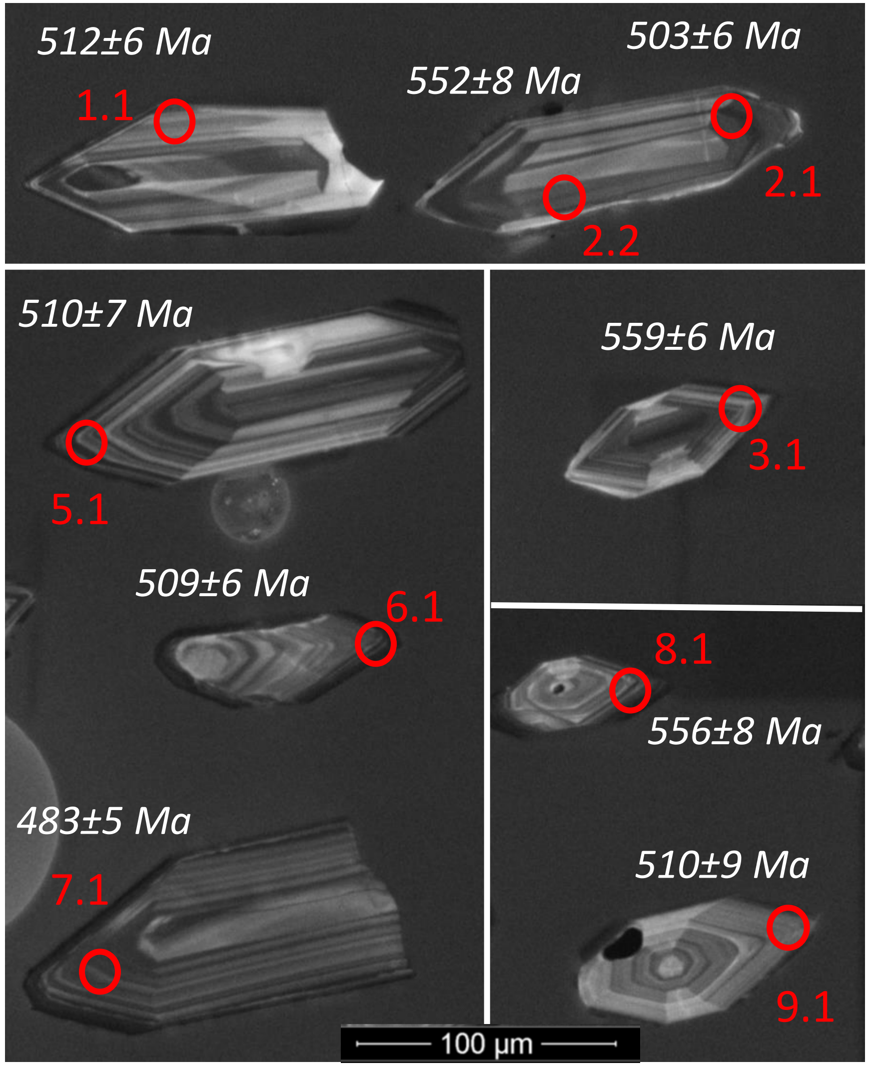
Ribeiro et al. (2010)

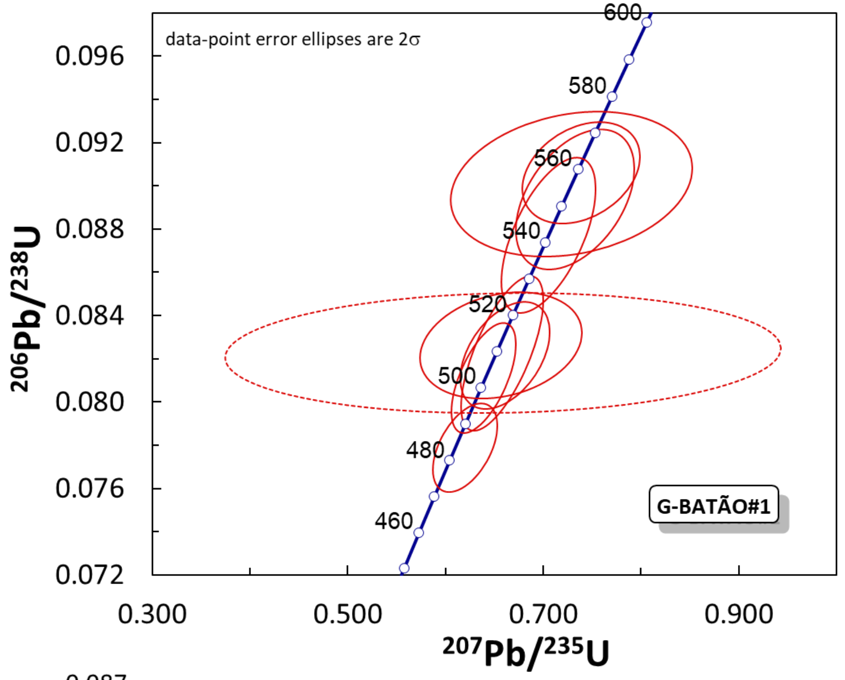
Salvaterra do Extremo area
- **Foliated mafic dykes, ascribed to the Cambrian-Ordovician magmatic event**

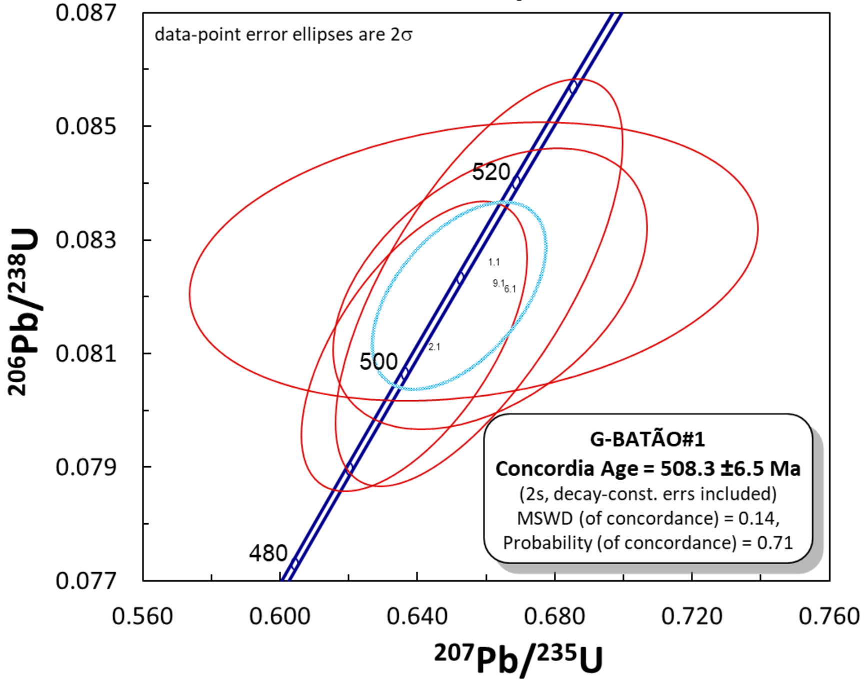
Antunes et al. (2013)

SEGURA
- **"Two-mica γ"**: ID-TIMS U-Pb zircon: 311.0±0.5 Ma; ID-TIMS U-Pb monazite: 312.9±2.3 Ma
- "**Ms-γ**": ID-TIMS U-Pb zircon: 312.9±2.0 Ma

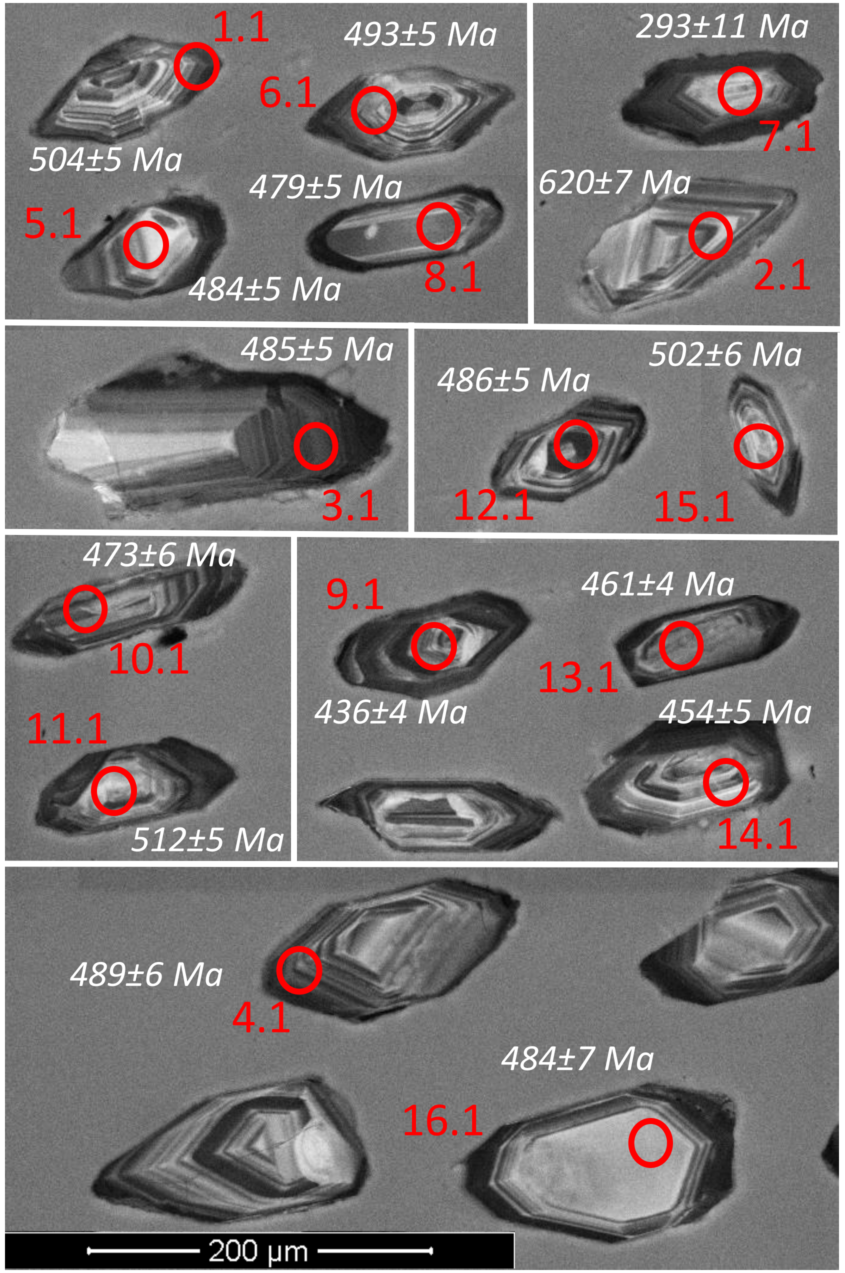
Batão tonalite | Cambrian-Ordovician magmatism

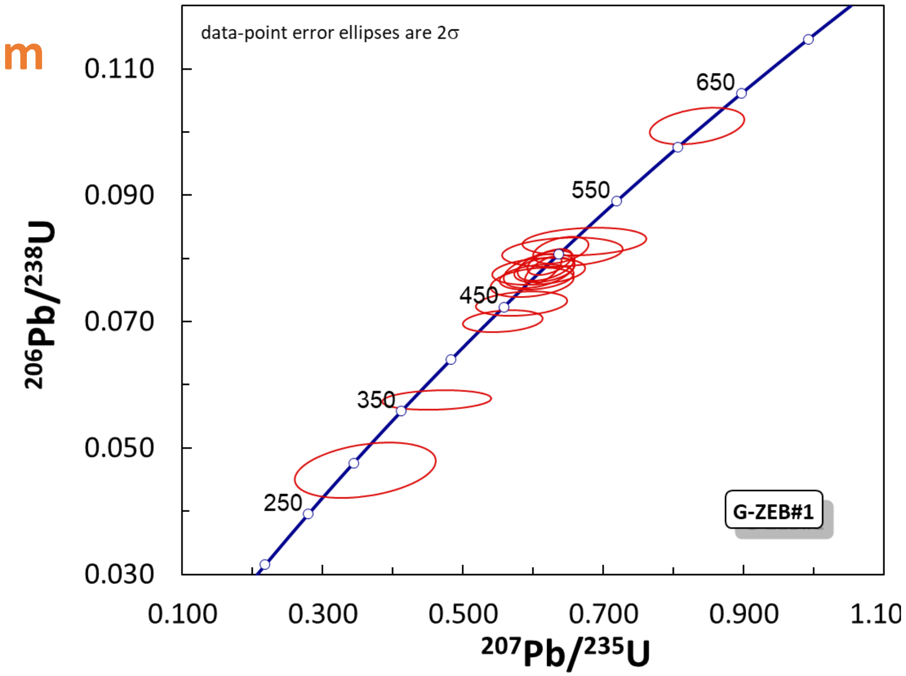


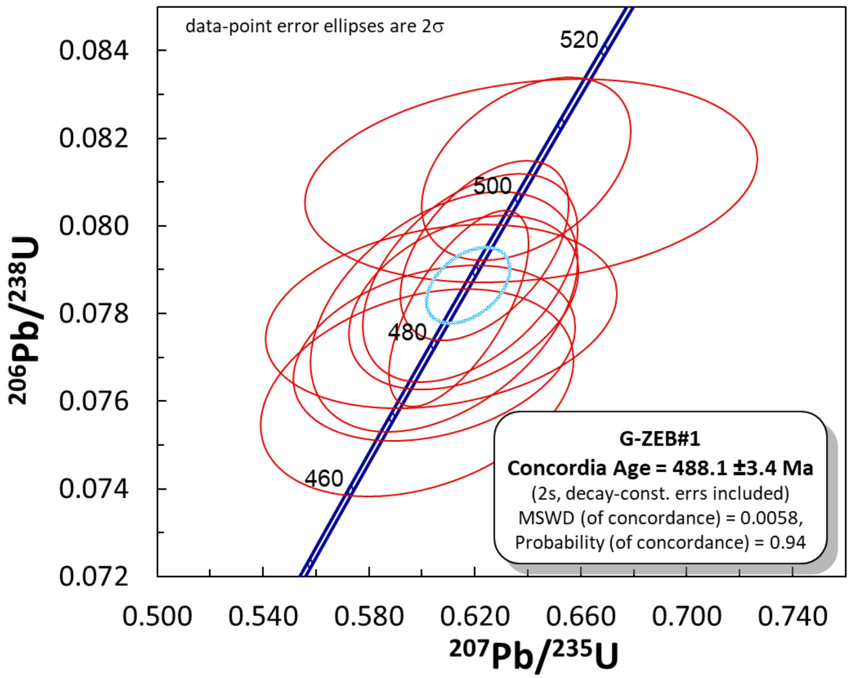




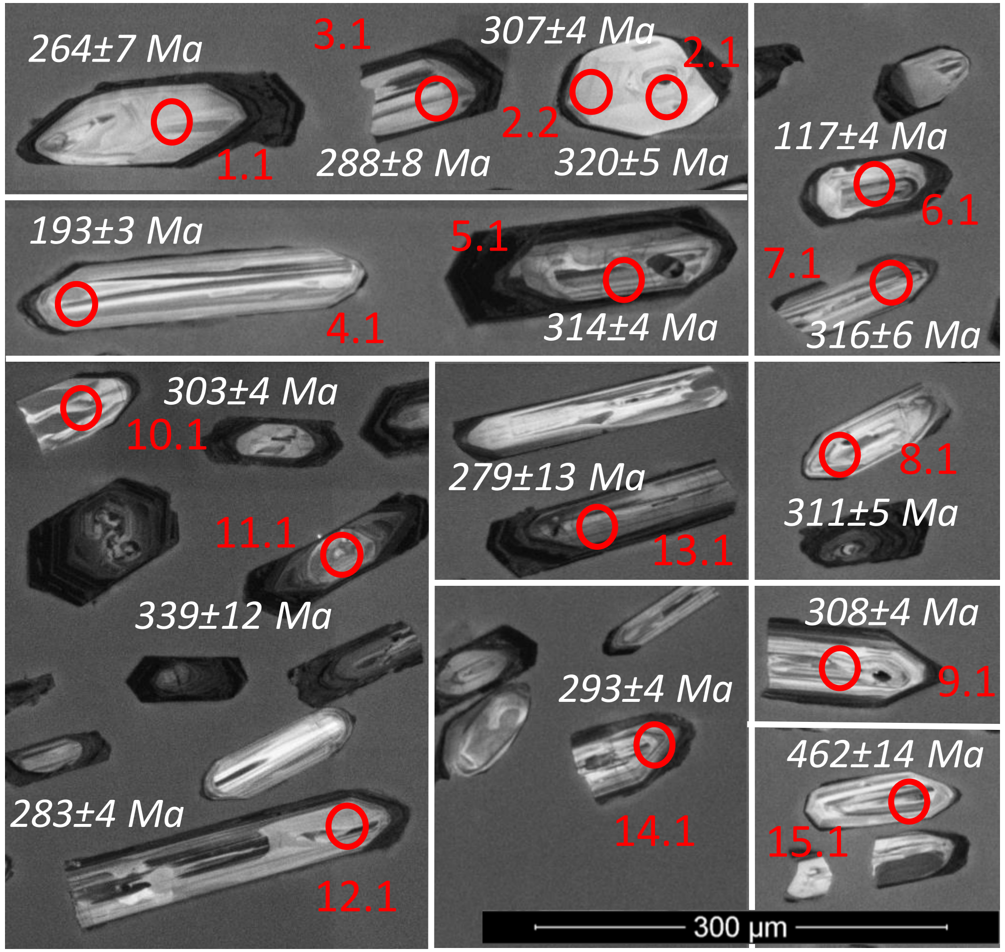
Zebreira granodiorite | Cambrian-Ordovician magmatism

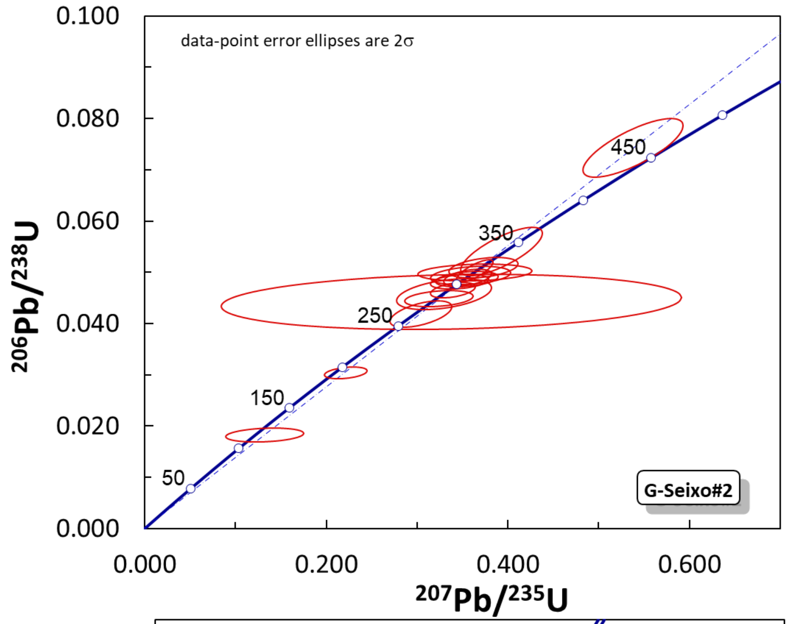


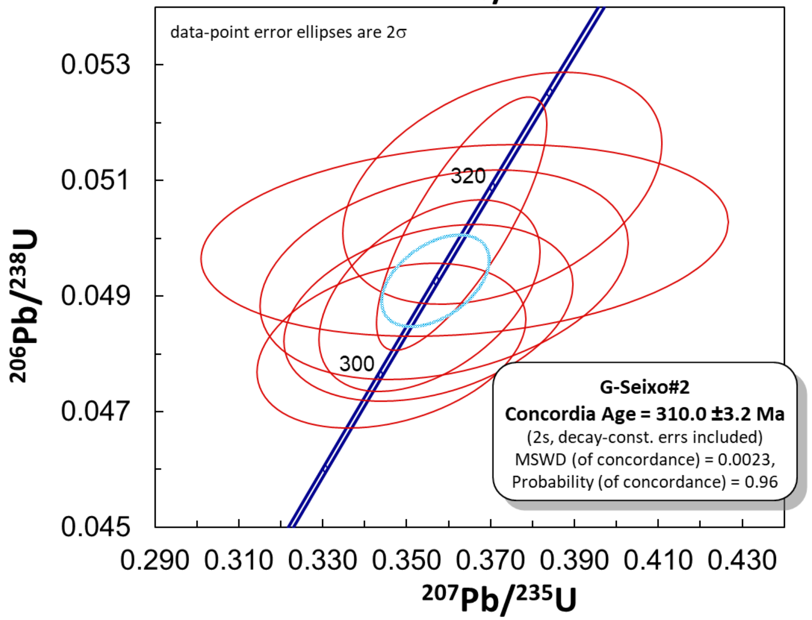




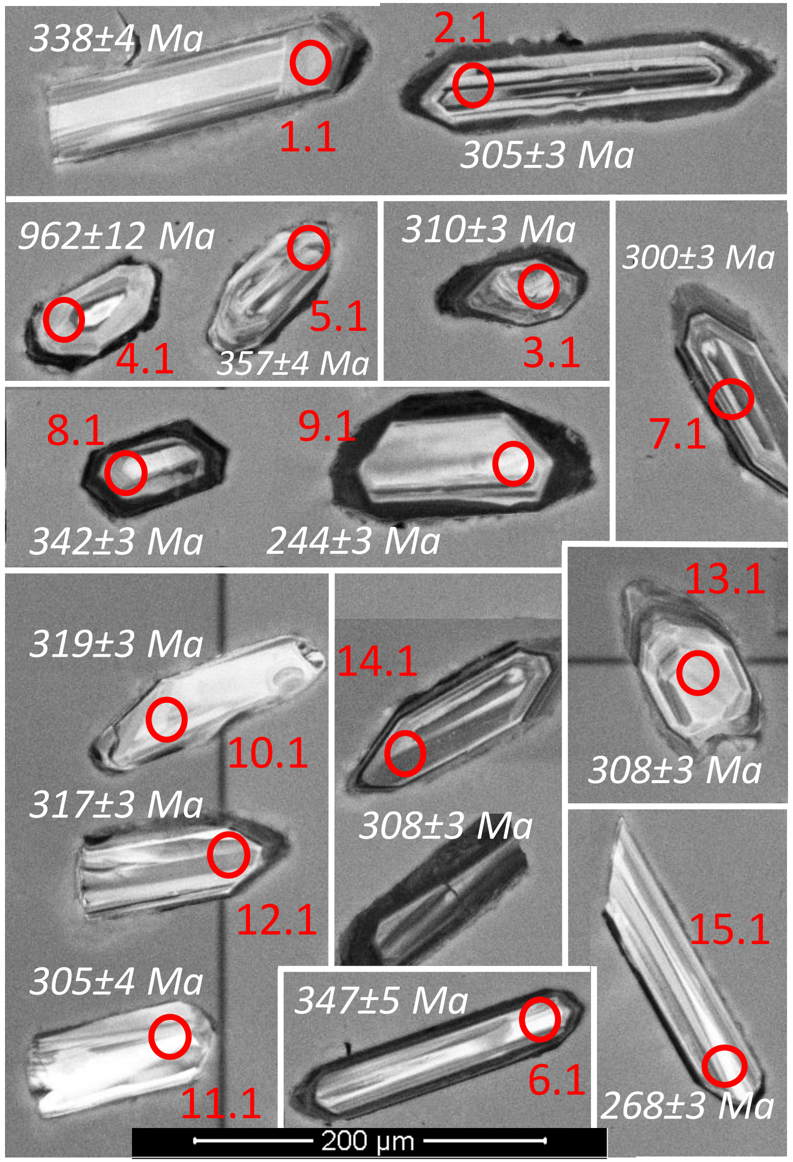
Orca granite | Variscan magmatism

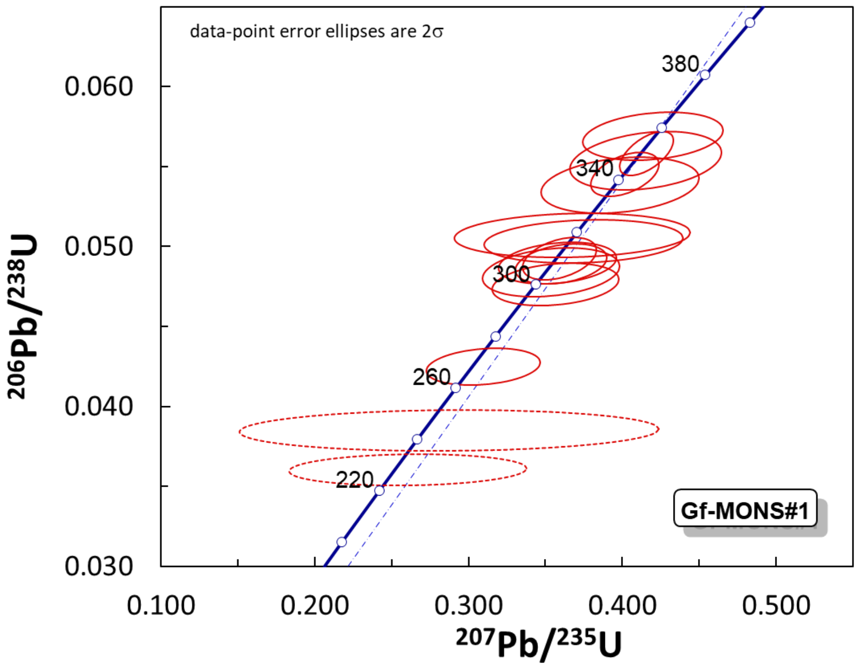


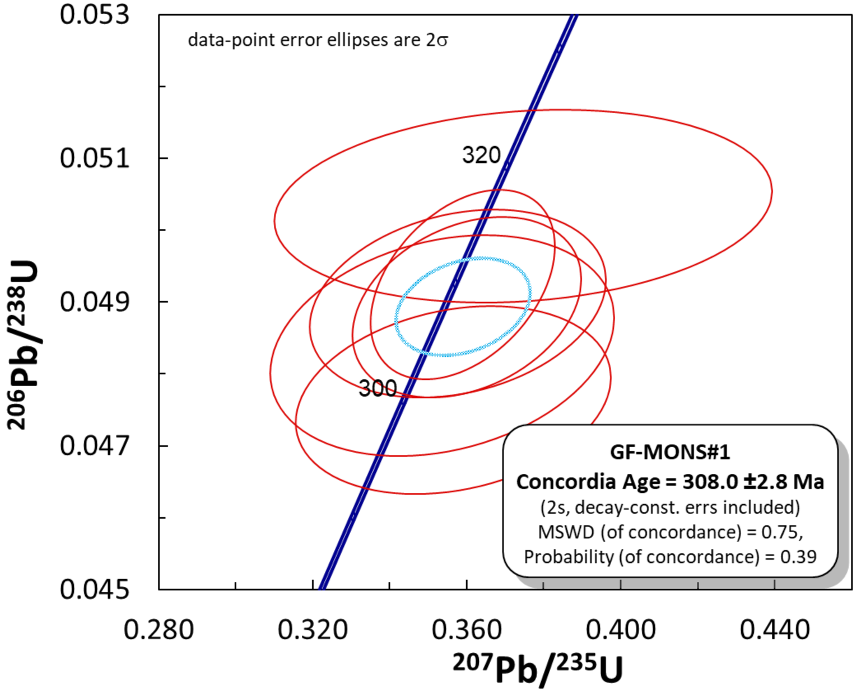




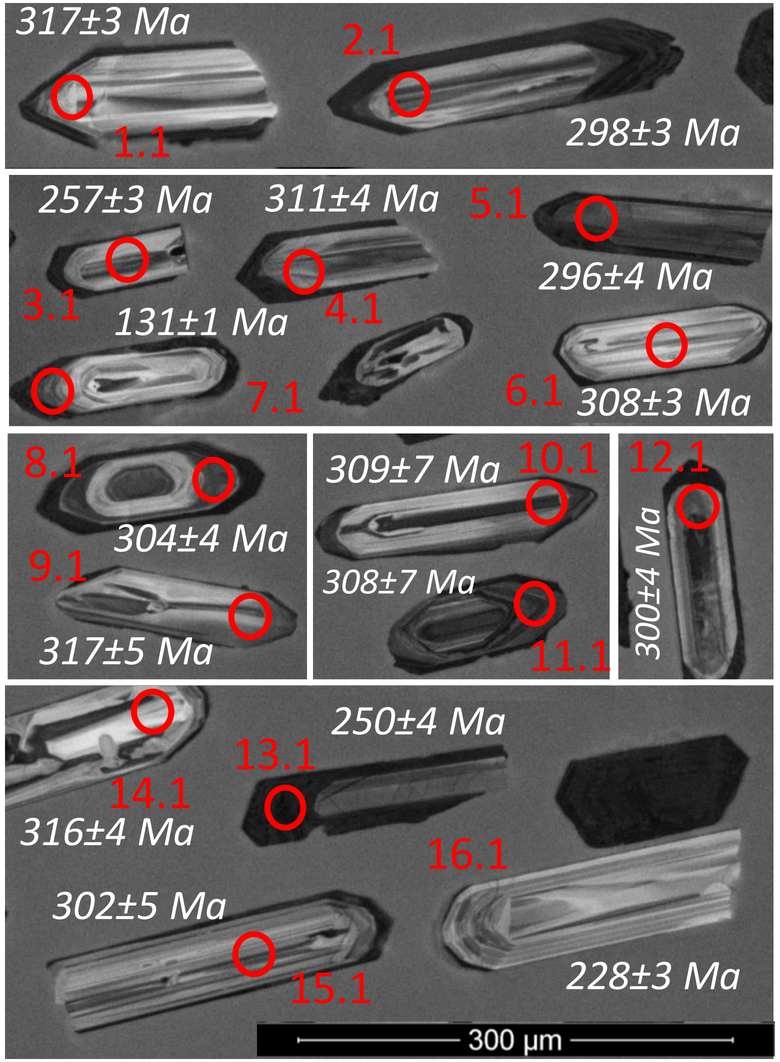
Monsanto pegmatite | Variscan magmatism

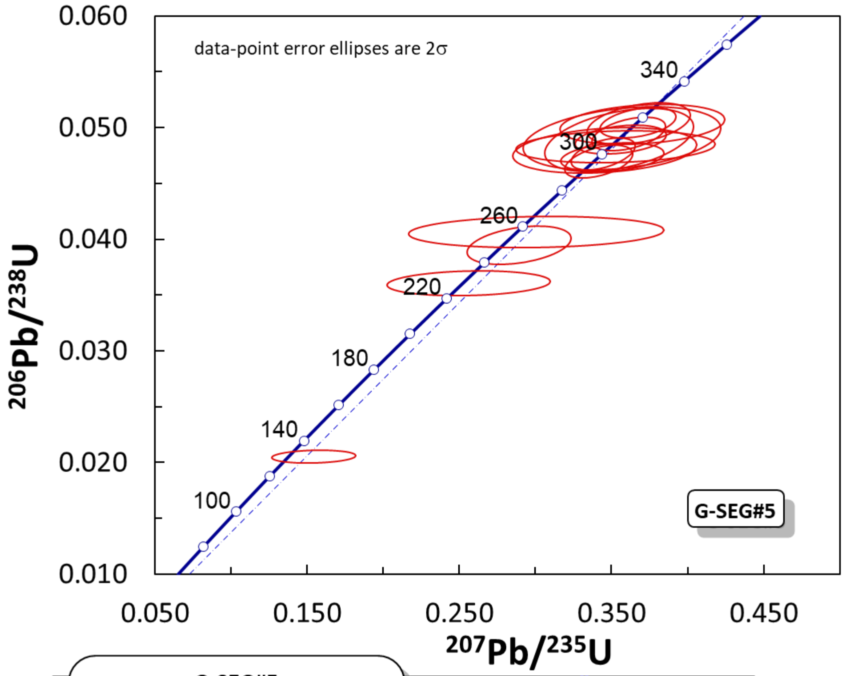


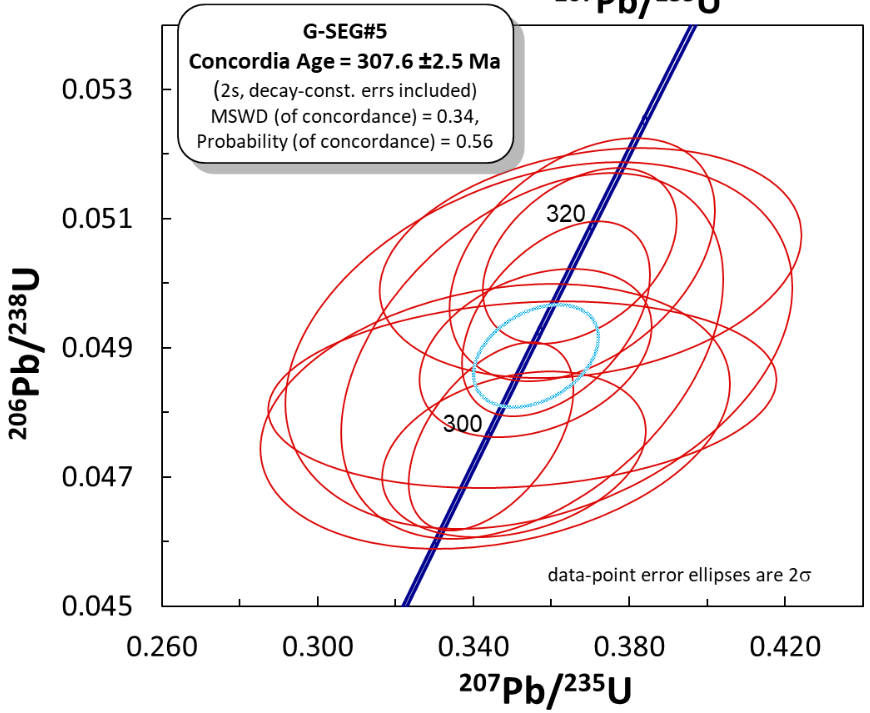




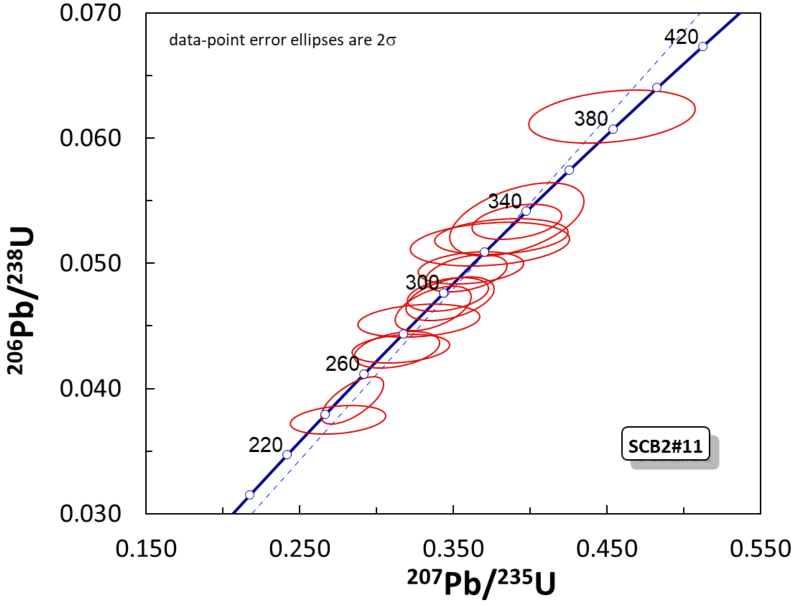
Segura *ms*-granite | Variscan magmatism

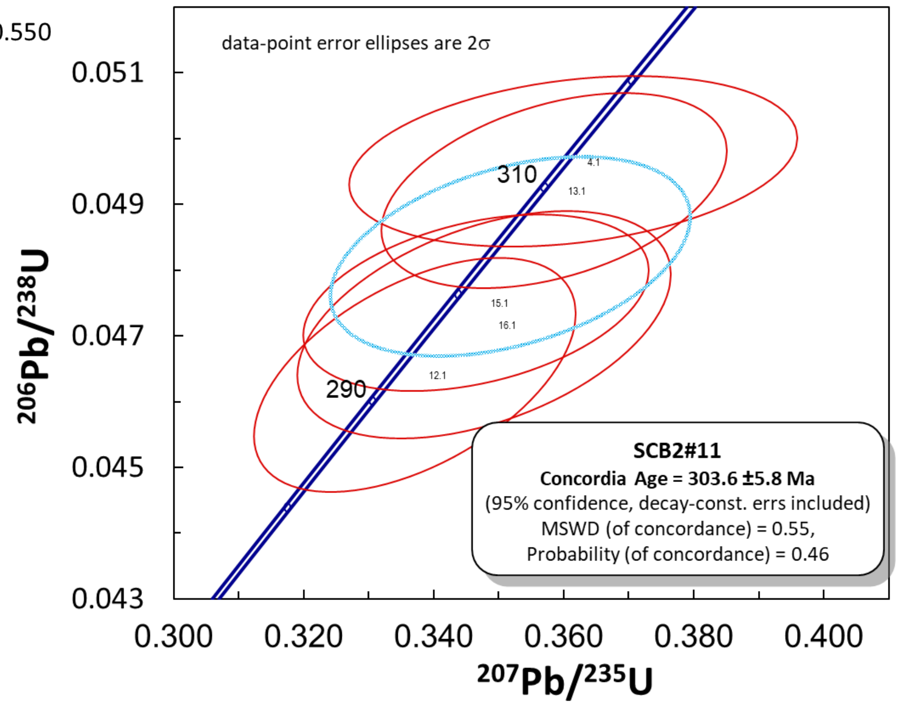


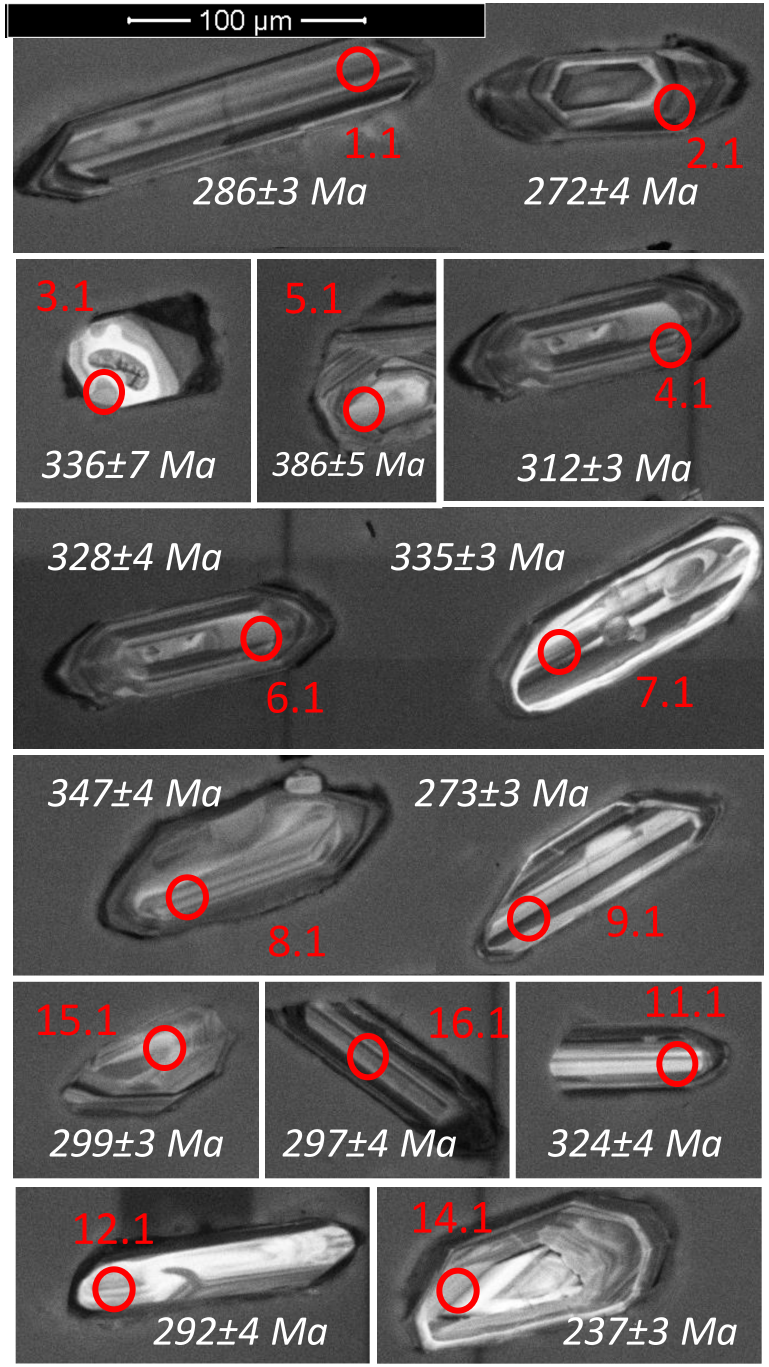


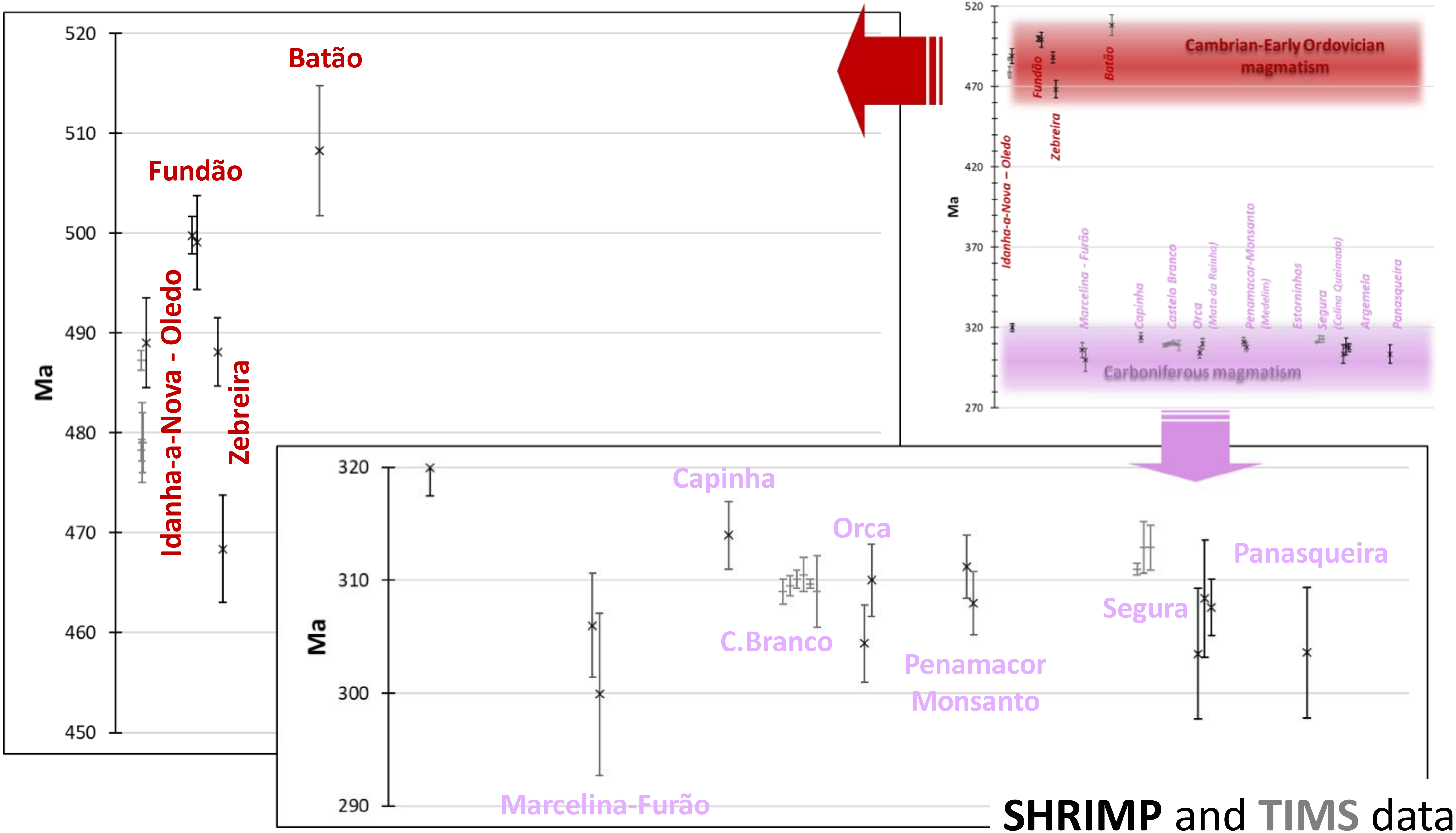


Panasqueira two-mica granite | Variscan magmatism









SHRIMP and **TIMS** data

Geochronology | *SHRIMP U-Pb zircon*

Notwithstanding the good match of results, several problems have come up with different samples selected for geochronological studies, due to:

- Extreme difficulty, or even impossibility, to obtain zircon concentrates in various highly differentiated or compositionally modified granite facies from, e.g., Panasqueira, Argemela, and Medelim;
- Abundant inherited zircon populations in many granite facies, hindering a robust dating and often yielding ages with poor representativity/statistics of data;
- Insufficient zircon overgrowth encircling inherited cores or late rims with adequate thickness but containing too much uranium;
- Pb and even U loss, generating abundant discordant data, most of the times in zircon populations that include grains with evident effects of metamict processes; and
- The use of TEMORA standard in SHRIMP measurements (natural zircon with low to “normal” U content), possibly not so suitable for dating high-U zircons as those usually present in many of the sampled plutonic and dyke granite facies.

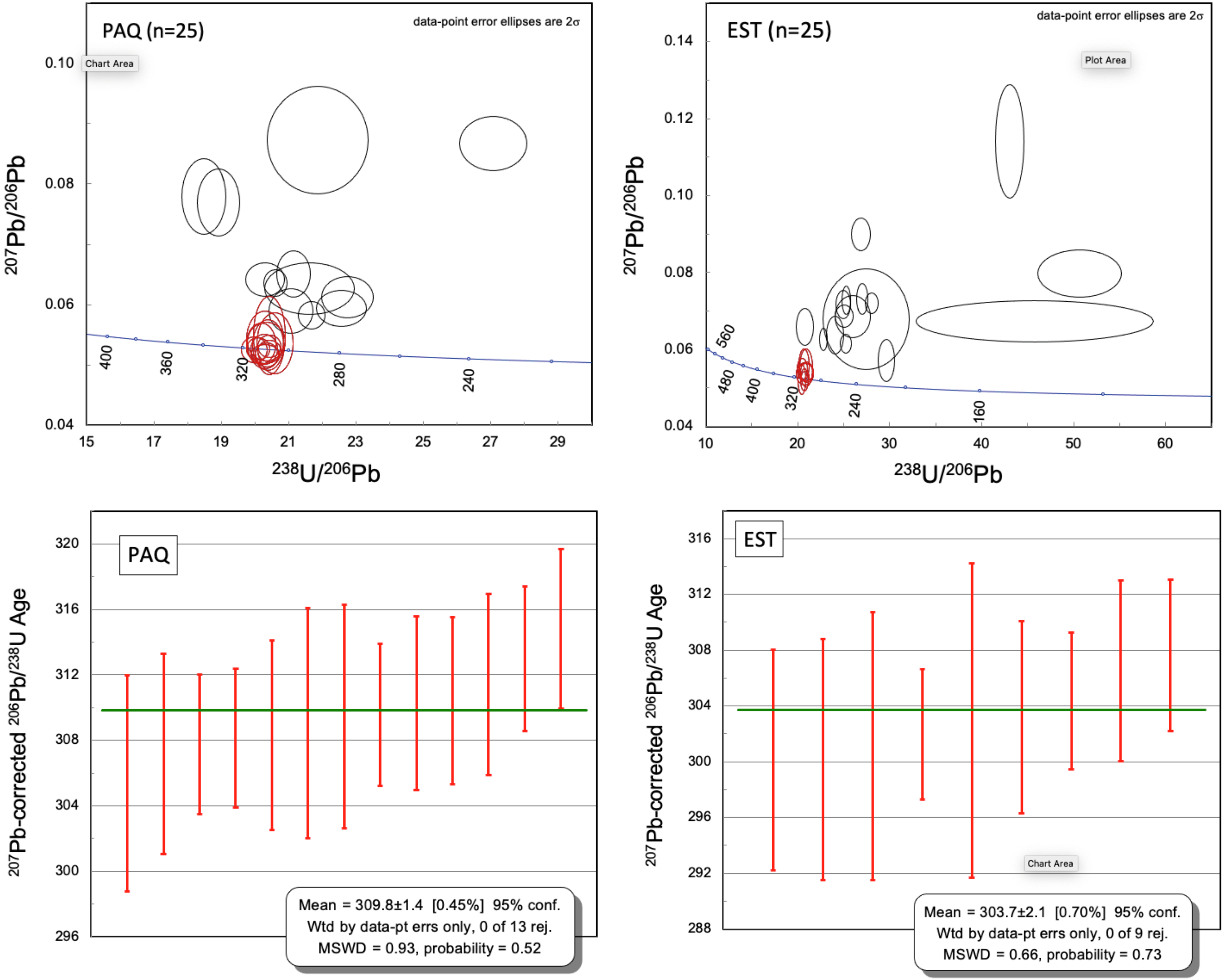
Geochronology | *complementary approaches*

To overcome these difficulties and better constrain the temporal development of "fertile" granite melts and related mineralisation in the Góis-Panasqueira-Argemela-Segura strip, it was decided:

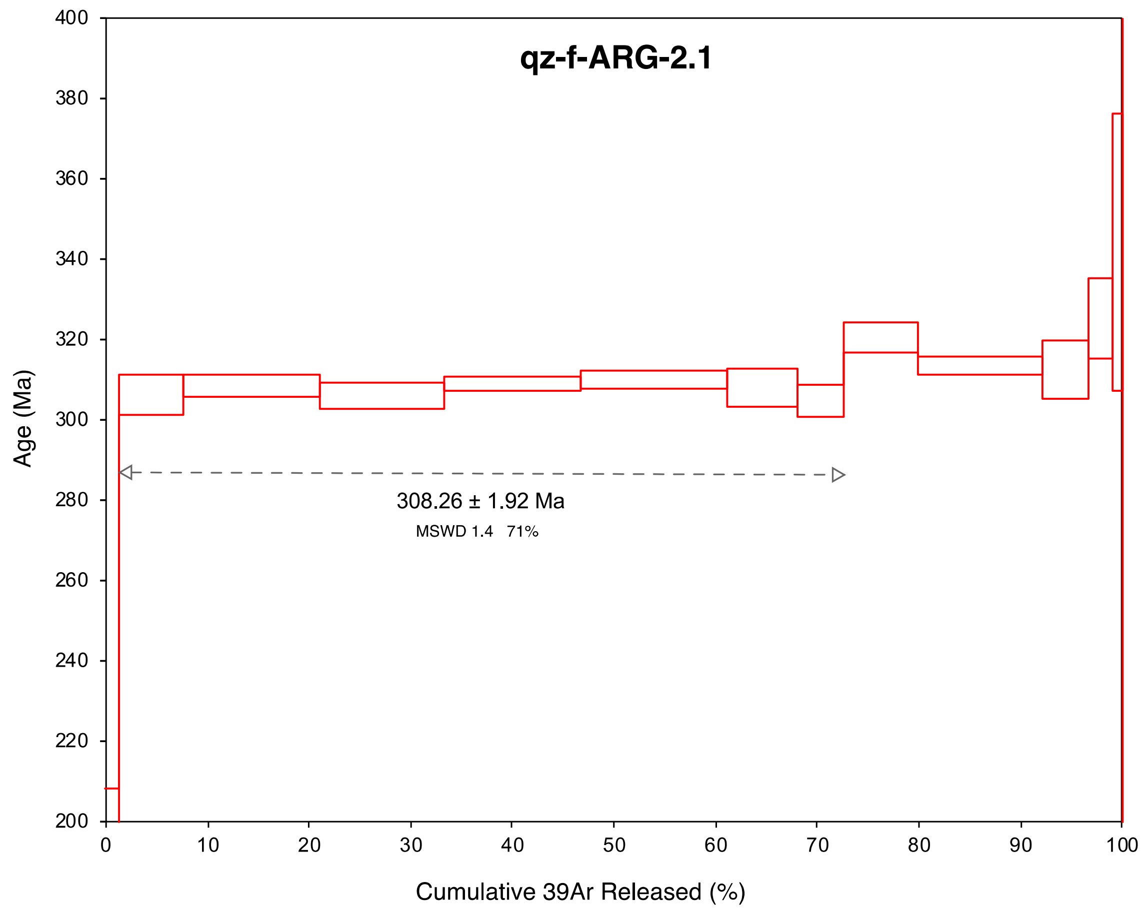
- to use LA-ICP-MS U-Pb zircon data to estimate the age of the cordierite facies of the Cabeza de Araya batholith (PAQ – Piedras Albas Quarry, the core domain of the Segura pluton) and the Estorniños (EST) two-mica granite; and

- to complement the available U-Pb zircon data with K-Ar and Ar-Ar ages of muscovite extracted from a 28 samples collected in different sites.

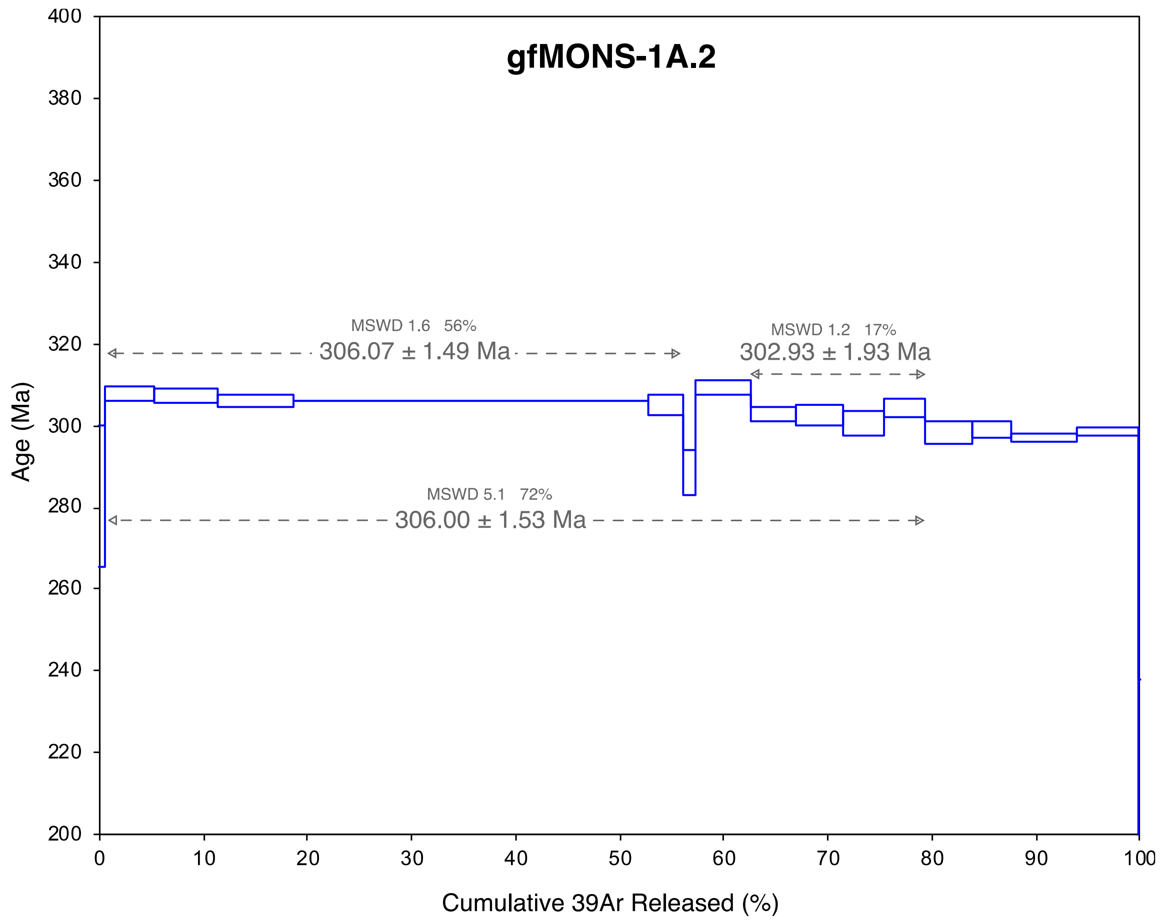
- The K-Ar ages are roughly equivalent to the whole age (WMA) using the Ar-Ar technique when plateau ages cannot be obtained on the whole spectra. The main advantage of dating muscovite grains with these two techniques results in the **estimation of the granite/aplite/pegmatite minimal age**, when the use of other approaches (such as U-Pb in zircon) is impossible or generates unlikely results from the geological point of view.



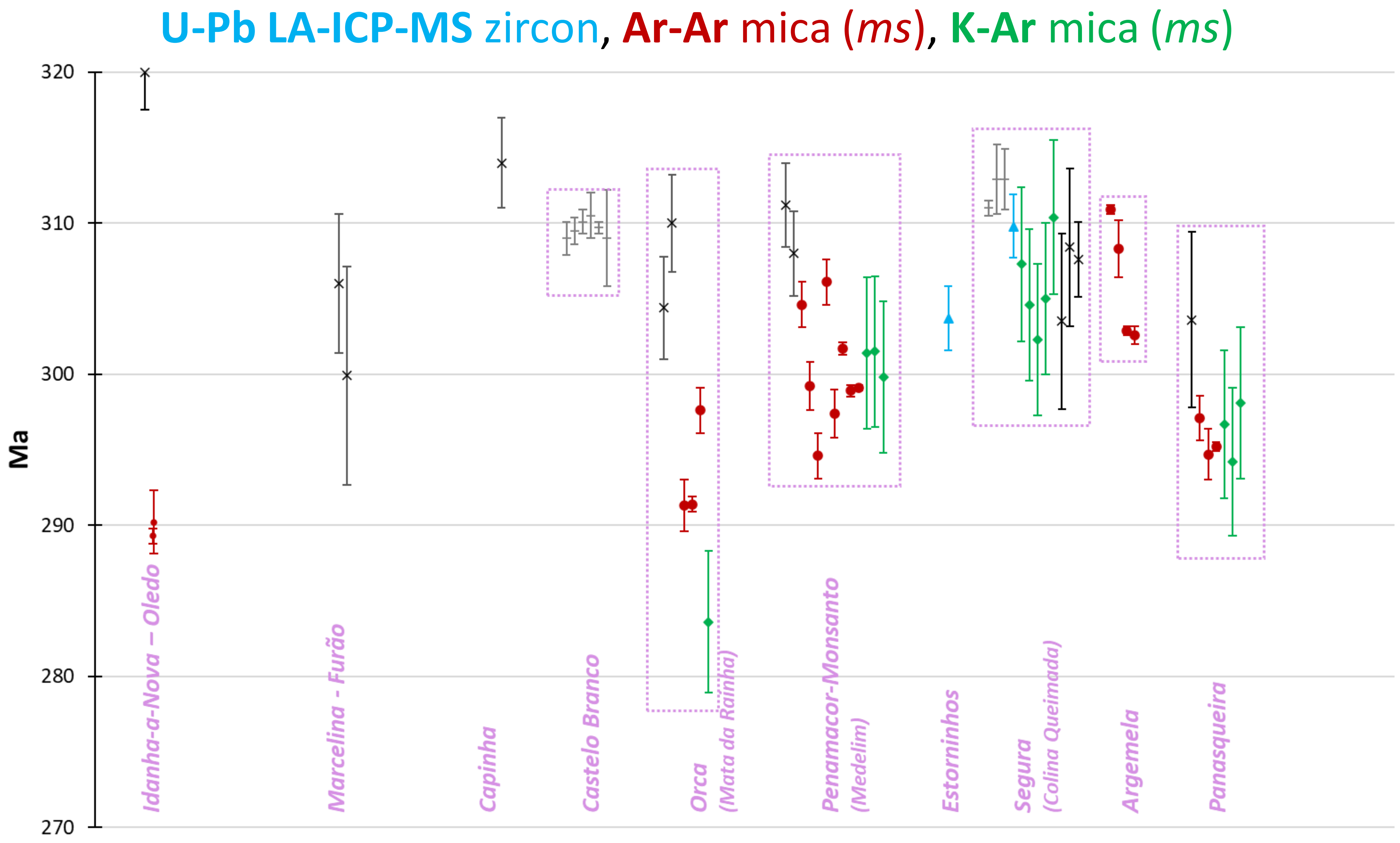
PAQ (n=25)
data-point error ellipses are 2σ
Chart Area
0.10
0.08
0.06
0.04
400
360
320
280
240
15
17
19
21
23
25
27
29
$^{207}Pb/^{206}Pb$
$^{238}U/^{206}Pb$
EST (n=25)
data-point error ellipses are 2σ
Plot Area
0.14
0.12
0.10
0.08
0.06
0.04
560
480
400
320
240
160
10
20
30
40
50
60
$^{207}Pb/^{206}Pb$
$^{238}U/^{206}Pb$
PAQ
320
316
312
308
304
300
296
^{207}Pb-corrected $^{206}Pb/^{238}U$ Age
Mean = 309.8±1.4 [0.45%] 95% conf.
Wtd by data-pt errs only, 0 of 13 rej.
MSWD = 0.93, probability = 0.52
EST
316
312
308
304
300
296
292
288
^{207}Pb-corrected $^{206}Pb/^{238}U$ Age
Chart Area
Mean = 303.7±2.1 [0.70%] 95% conf.
Wtd by data-pt errs only, 0 of 9 rej.
MSWD = 0.66, probability = 0.73



Ar/Ar muscovite plateau age (308.3 ±1.9 Ma) for muscovite extracted from one amblygonite-bearing quartz vein at Cabeço de Argemela (Qz-f-ARG#2)

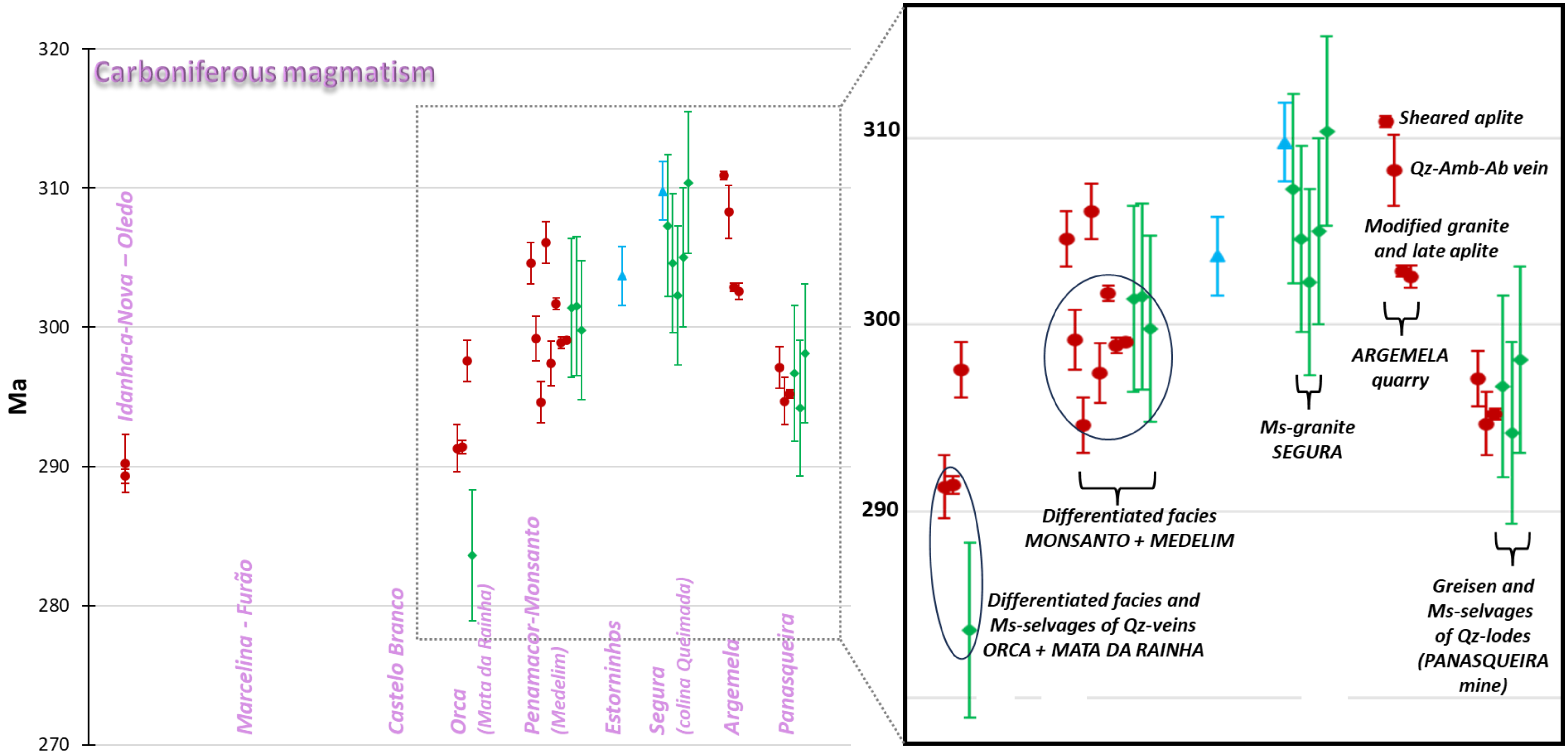


Ar/Ar muscovite (plateau) ages for the pegmatite body (G-MONS#1A, 306.1 ± 1.5 Ma;



U-Pb LA-ICP-MS zircon, Ar-Ar mica (ms), K-Ar mica (ms)
Ma
320
310
300
290
280
270
Idanha-a-Nova – Oledo
Marcelina - Furão
Capinha
Castelo Branco
Orca
(Mata da Rainha)
Penamacor-Monsanto
(Medelim)
Estorninhos
Segura
(Colina Queimada)
Argemela
Panasqueira

U-Pb LA-ICP-MS zircon, Ar-Ar mica (*ms*), K-Ar mica (*ms*)



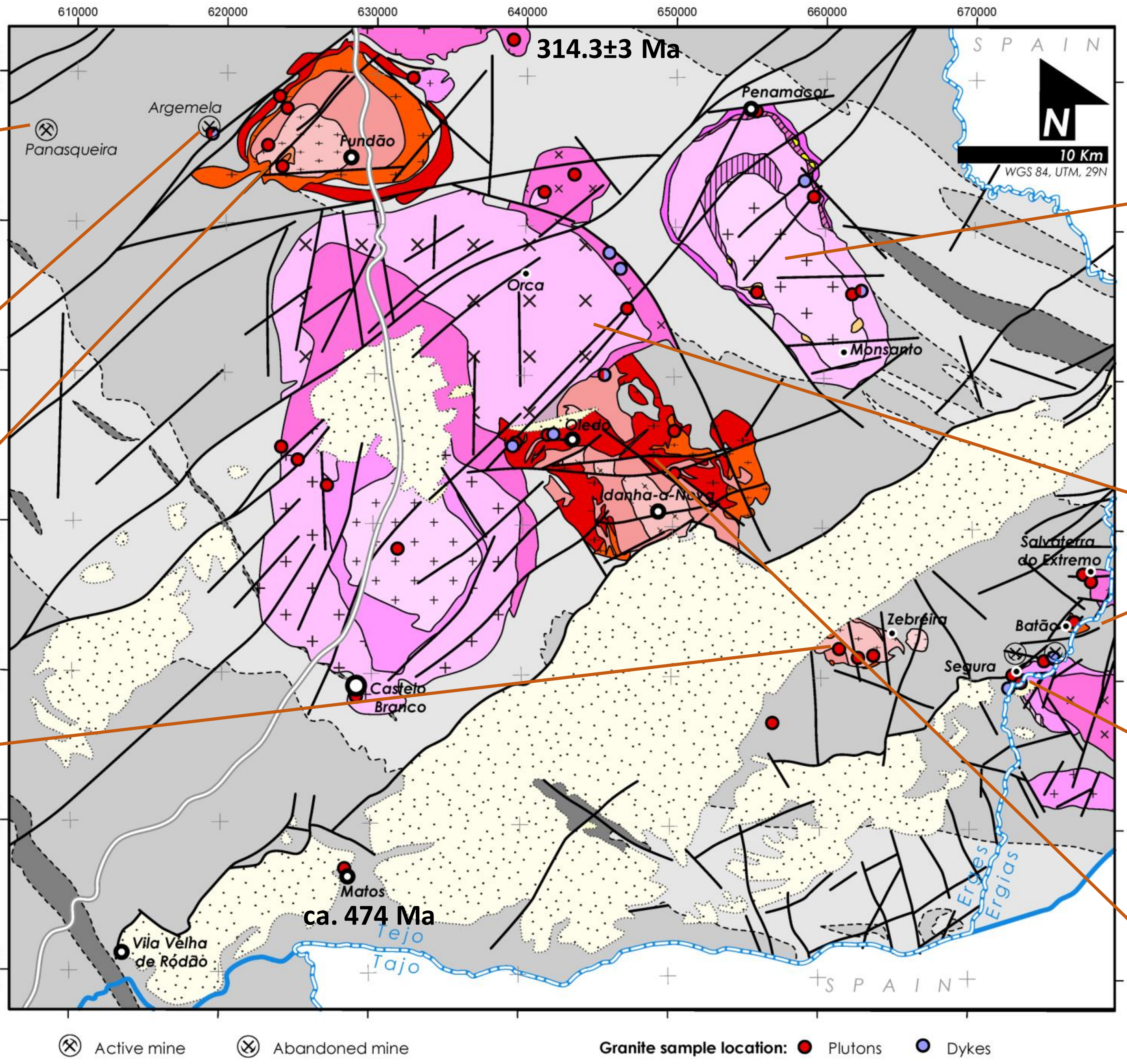
PANASQUEIRA
γ "two-mica":
304±5.8 Ma; 297±1.5 Ma
γ "ms": 294.7±1.7 Ma
Greisen: *295.5 – 294.8*Ma

ARGEMELA
γ : 302.6±0.6 Ma
γ f: 302.9±0.3 Ma
γ f*: *312 – 310* Ma

FUNDÃO
γ*: 499±2 Ma
γ**: 498±5 Ma

ZEBREIRA
γ: 488±3.4 Ma
γ*(dif):
468±5Ma; 460.9±2.9 Ma

FURÃO/MARCELINA
Prf: 306±4.6 Ma
Prf: 299.9±7.2 Ma



U-Pb in zircon (SHRIMP)
Ar-Ar in muscovite

PENAMACOR-MONSANTO
γ*: 311.2±2.8 Ma
γ**: 308±3 Ma; 304.6±1.9 Ma
γ***: 294.6±1.5 Ma
Peg: 306±1.5 Ma
Qz-T: 297.4±1.2 Ma
Medelim
γ (b): 298.9±1.2 Ma
γ (bf): 299.08±0.3 Ma
γ f: *302 – 301* Ma

ORCA
γ : 310±3 Ma
γ (b): 304±3 Ma; 291±1.5 Ma
γ f: *305 – 295* Ma
MRainha: 297.6±1.5 Ma

BATÃO (ton): 508±7 Ma

SEGURA
γ : 307.6±2.5 Ma
γ ms: 305±2 Ma
Peg: 303±5 Ma

IDANHA-A-NOVA-OLEDO
γ : 489±4.5 Ma
γ f: 293.1±1.5 Ma
γ*(t): 290±2.5 Ma

Intense and recurrent magmatic activity identified in some sites *vs.* crustal domains influenced by large-scale (lithospheric?) structures able to control the rising and emplacement of several magma suites.

- Zebreira area: protracted magmatic activity during Ordovician (from ca. 490 Ma – granodiorites – to 463 Ma – *ms*-rich granite), further rejuvenated in late Variscan times (porphyry laccoliths and dykes emplaced at 306 ± 4.6 – 299.9 ± 7.2 Ma).
- Idanha-a-Velha – Oledo: Ordovician (sheared) granodiorites crossed by Variscan (differentiated) granites as dykes or irregular bodies (293.1 ± 1.5 Ma).

Successive granite melts were generated and emplaced during a short time-span in the Carboniferous period, some of them followed by the:

- **Production of incremental volumes of highly differentiated (and metal-fertile) batches** to which several younger aplite-pegmatite swarms are related, and/or
- **Separation and further extraction of supercritical fluids**, which favoured the late development of some other types of mineralised bodies.

Discrimination of various mineralising events throughout the 310-290 Ma time window might be possible, separating W-dominant systems from those characterised by the prevalence of Sn and/or Li.

The validation of this interpretation, impacting on the design of future mineral exploration surveys across the strip under study and other similar Variscan orogenic segments, requires additional support.

Segura-Cabeza de Araya pluton (Erges canyon,Segura)