Advantages of using the mineral-systems approach in planning exploration surveys

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ERA-MIN 2
RESEARCH & INNOVATION PROGRAMME ON RAW MATERIALS TO FOSTER CIRCULAR ECONOMY

ERA-MIN Joint Call 2019 (EU Horizon 2020 ERA-NET Co-fund Project ERA-MIN2, Grant agreement Nº 730238)

FCT Fundação para a Ciência e a Tecnologia
ANR Agence Nationale de la Recherche

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Mineral Systems Approach

General view of the Panasqueira mine

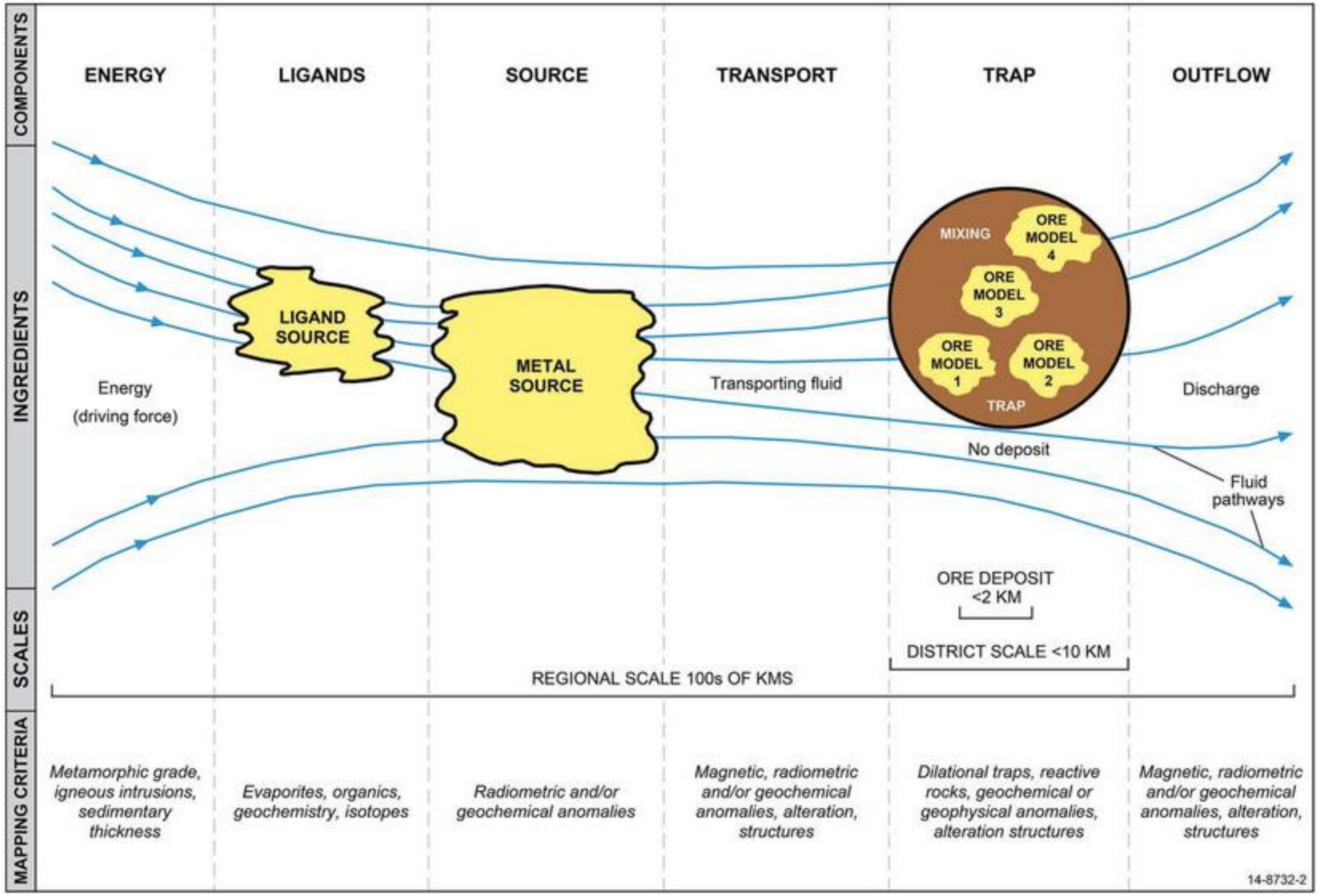
Mineral Systems Approach

General view of the Panasqueira mine

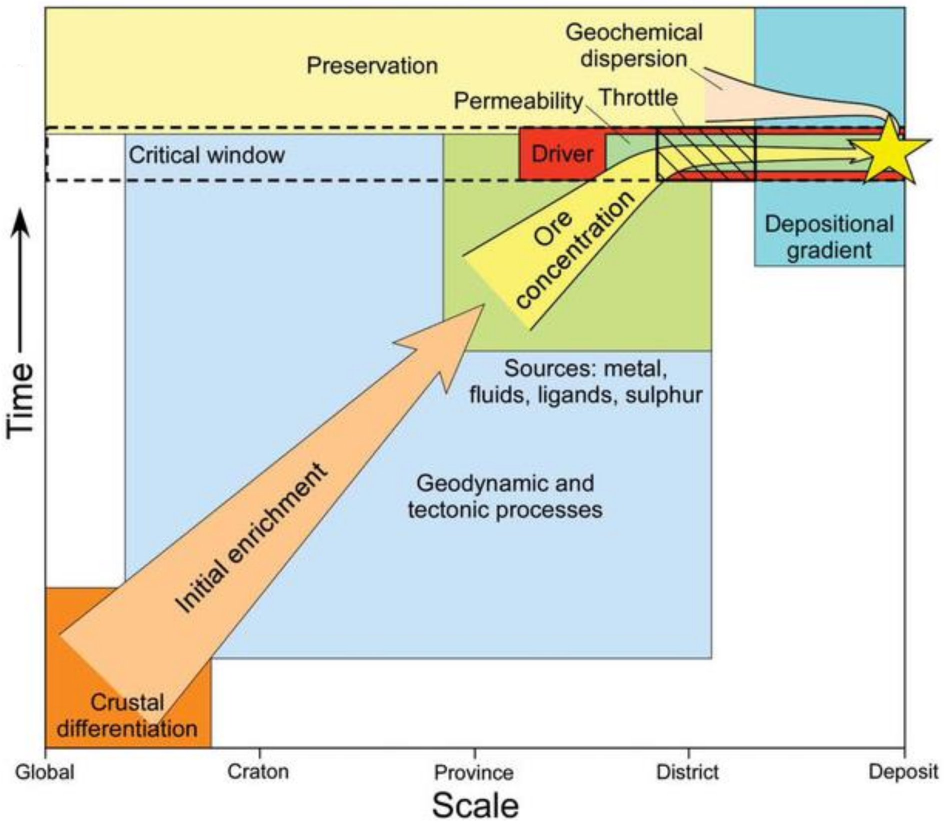
- Considers the foundation of ore-forming systems in the framework of lithospheric-scale processes from a time-privileged viewpoint of metal, ligand and fluid sources, followed by transport and deposition in traps.

- Improves the predictability of geological models when used in exploration surveys.

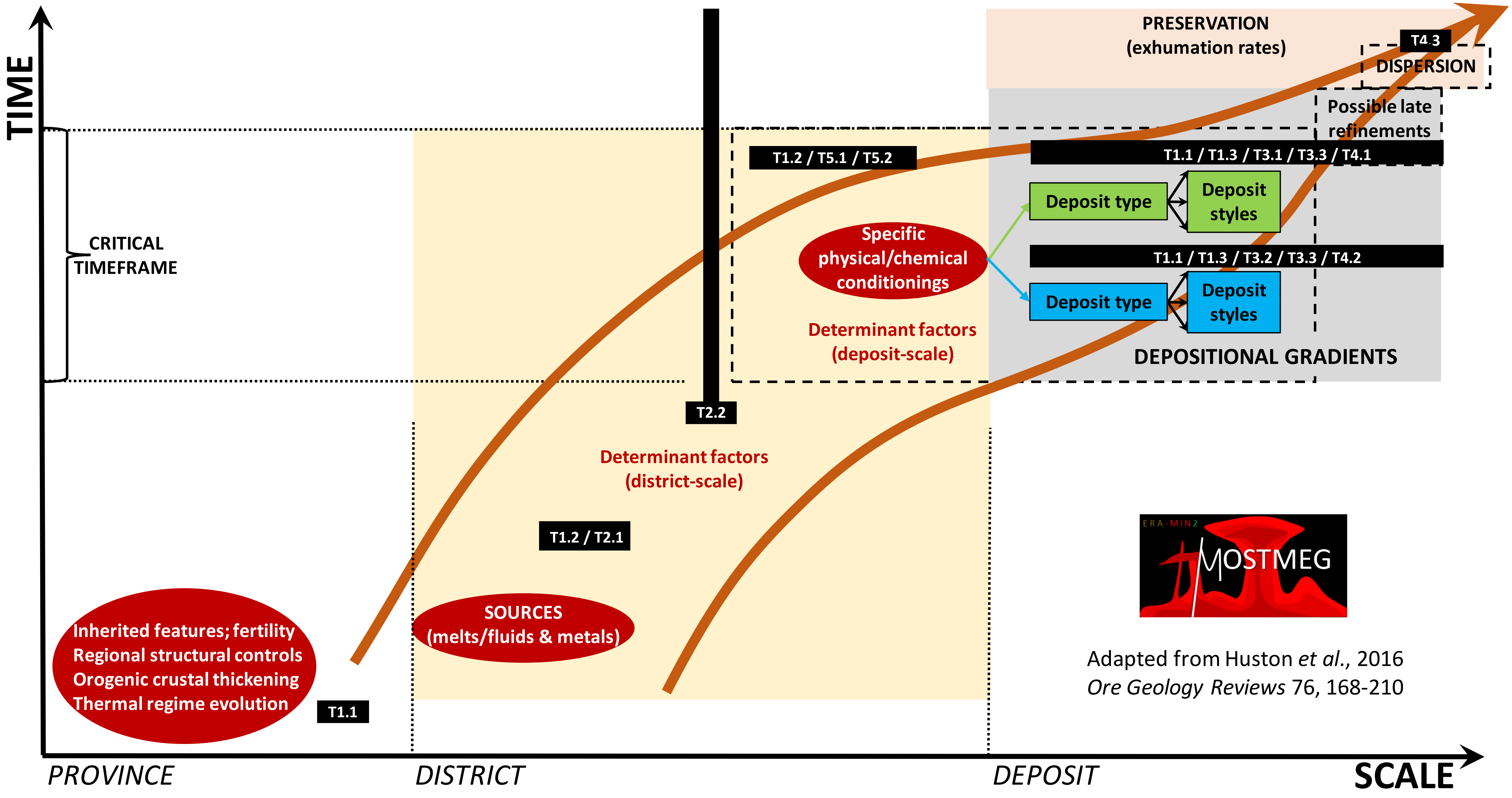
After Knox-Robinson and Wyborn (1997) and (Huston et al., 2016)



Range of spatial scales involved and mapping criteria



Conceptual model in a time–space context



TIME

CRITICAL TIMEFRAME

PRESERVATION
(exhumation rates)

T4.3

DISPERSION

Possible late refinements

T1.2 / T5.1 / T5.2

T1.1 / T1.3 / T3.1 / T3.3 / T4.1

Deposit type

Deposit styles

Specific physical/chemical conditionings

T1.1 / T1.3 / T3.2 / T3.3 / T4.2

Deposit type

Deposit styles

Determinant factors
(deposit-scale)

DEPOSITIONAL GRADIENTS

T2.2

Determinant factors
(district-scale)

T1.2 / T2.1

Inherited features; fertility
Regional structural controls
Orogenic crustal thickening
Thermal regime evolution

T1.1

SOURCES
(melts/fluids & metals)

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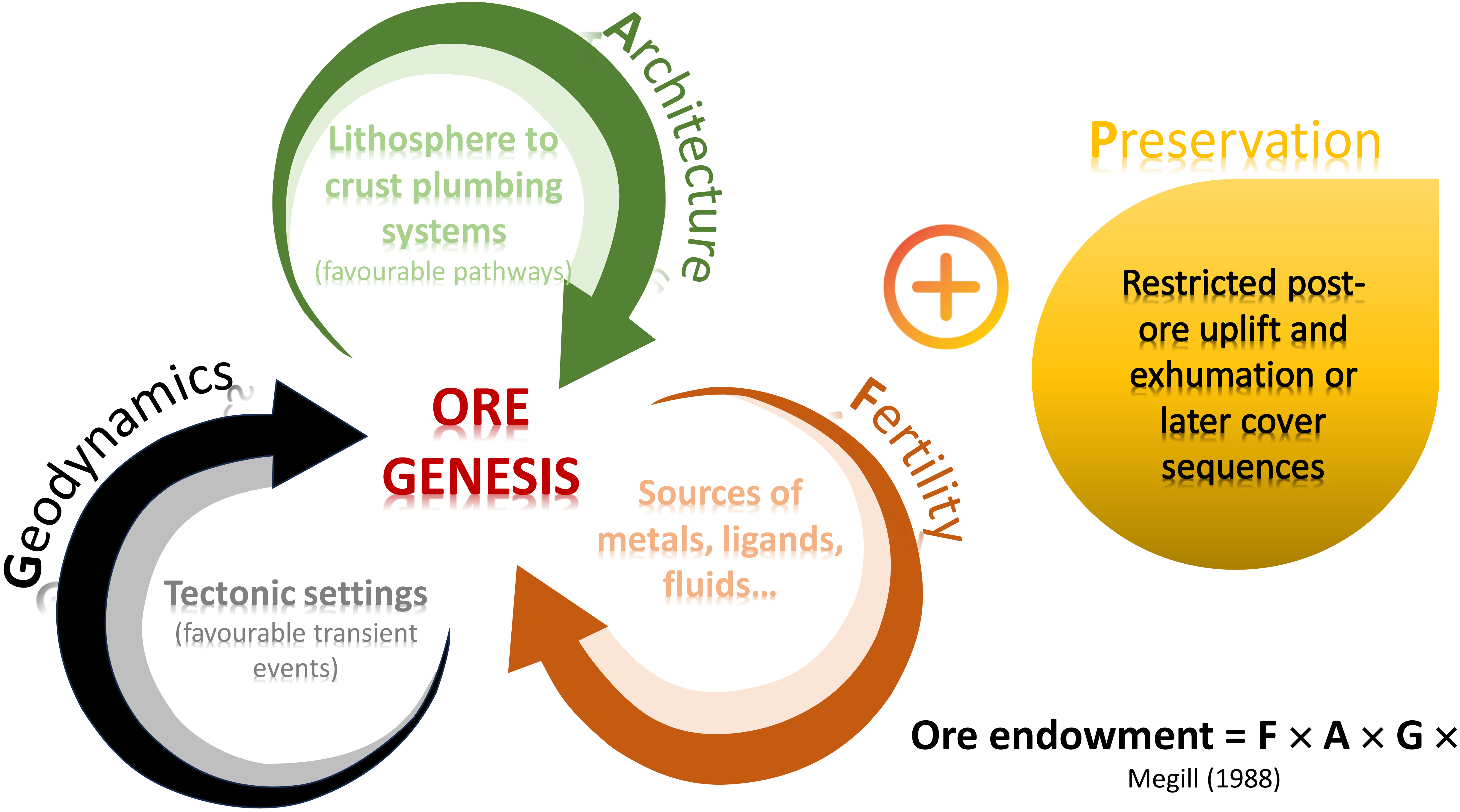
Adapted from Huston *et al.*, 2016
Ore Geology Reviews 76, 168-210

PROVINCE

DISTRICT

DEPOSIT

SCALE



ORE GENESIS

Architecture

Lithosphere to crust plumbing systems
(favourable pathways)

Geodynamics

Tectonic settings
(favourable transient events)

Fertility

Sources of metals, ligands, fluids…

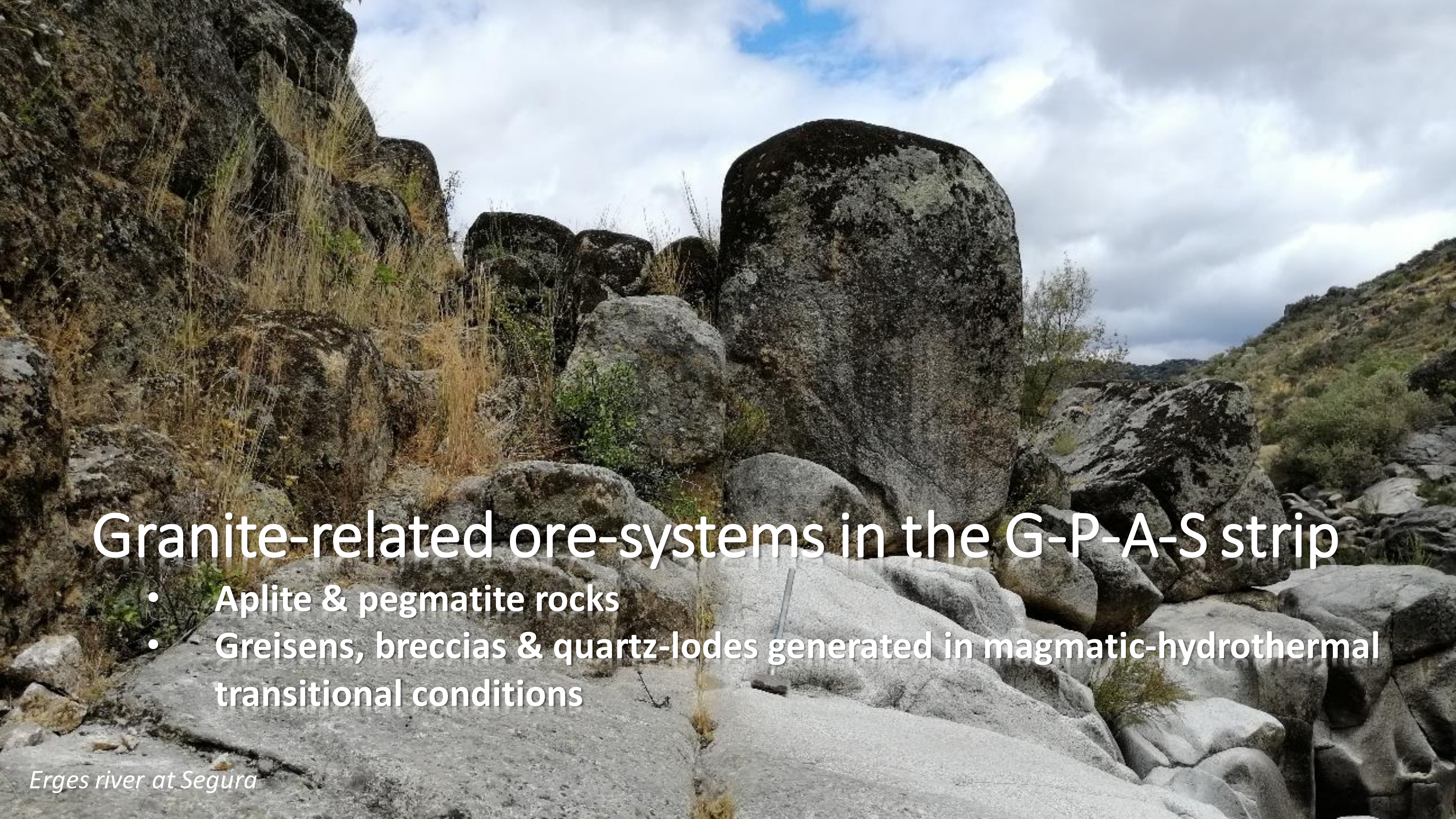
+

Preservation

Restricted post-ore uplift and exhumation or later cover sequences

Ore endowment = F × A × G × P

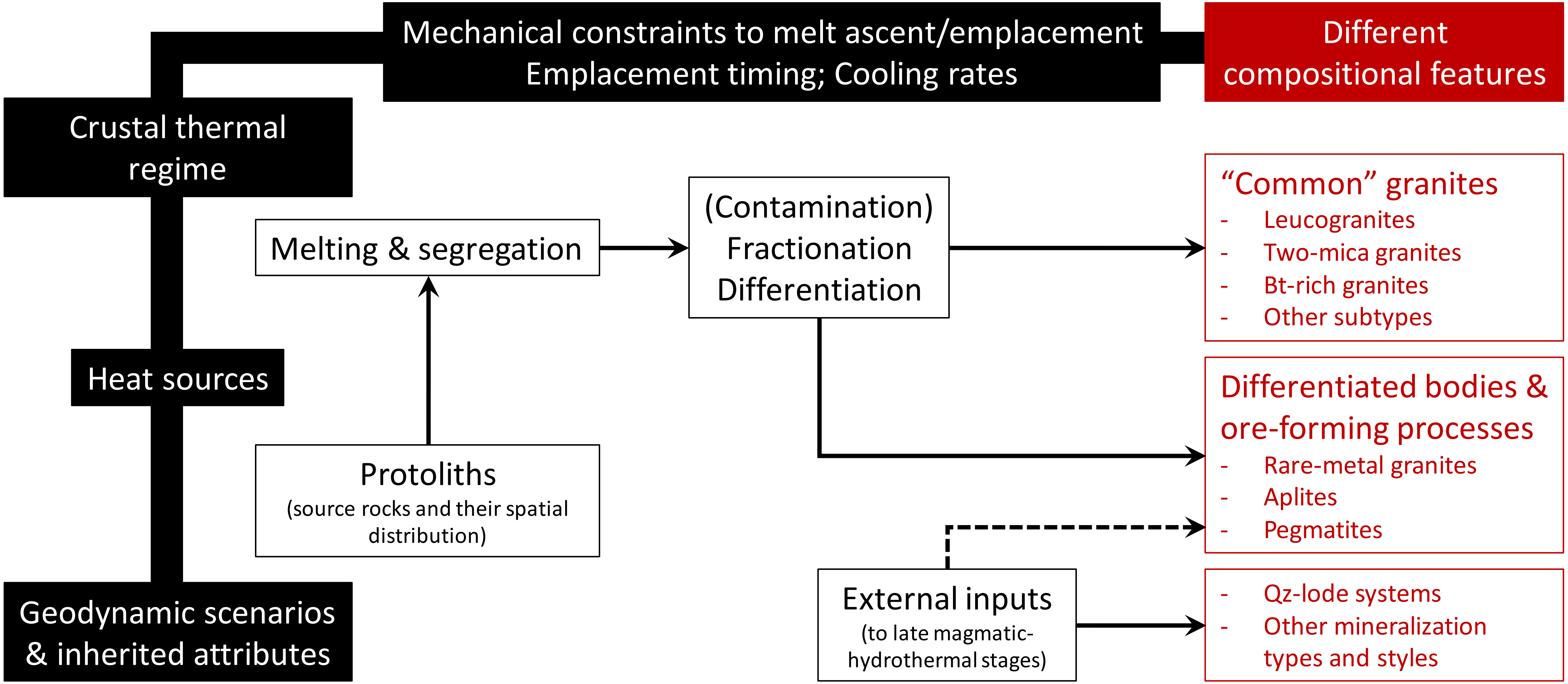
Megill (1988)



Granite-related ore-systems in the G-P-A-S strip

- **Aplite & pegmatite rocks**
- **Greisens, breccias & quartz-lodes generated in magmatic-hydrothermal transitional conditions**

Erges river at Segura



Mechanical constraints to melt ascent/emplacement
Emplacement timing; Cooling rates

Different compositional features

Crustal thermal regime

Heat sources

Geodynamic scenarios & inherited attributes

Melting & segregation

Protoliths
(source rocks and their spatial distribution)

(Contamination)
Fractionation
Differentiation

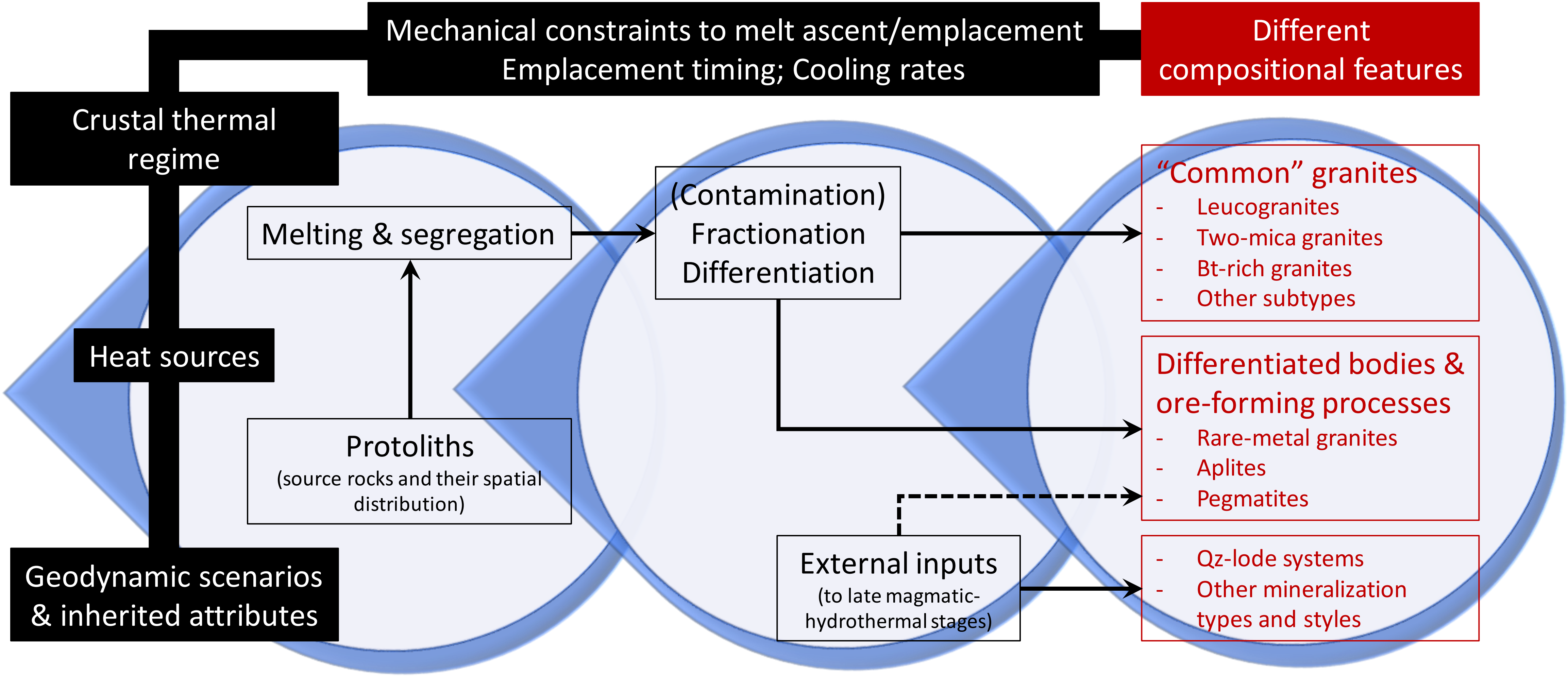
External inputs
(to late magmatic-hydrothermal stages)

“Common” granites
- Leucogranites
- Two-mica granites
- Bt-rich granites
- Other subtypes

Differentiated bodies & ore-forming processes
- Rare-metal granites
- Aplites
- Pegmatites

- Qz-lode systems
- Other mineralization types and styles

Major links addressed *(in red what could be observed and characterised)*



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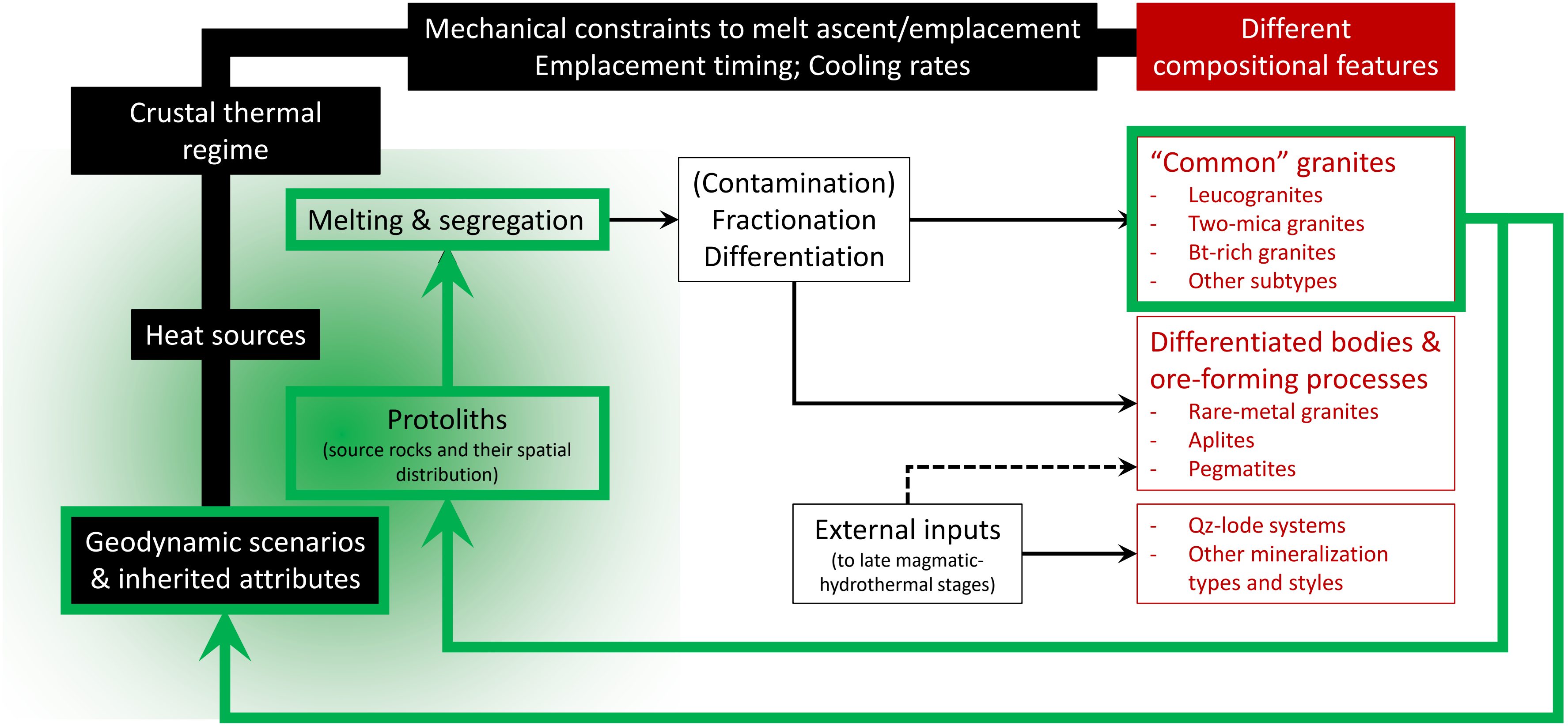
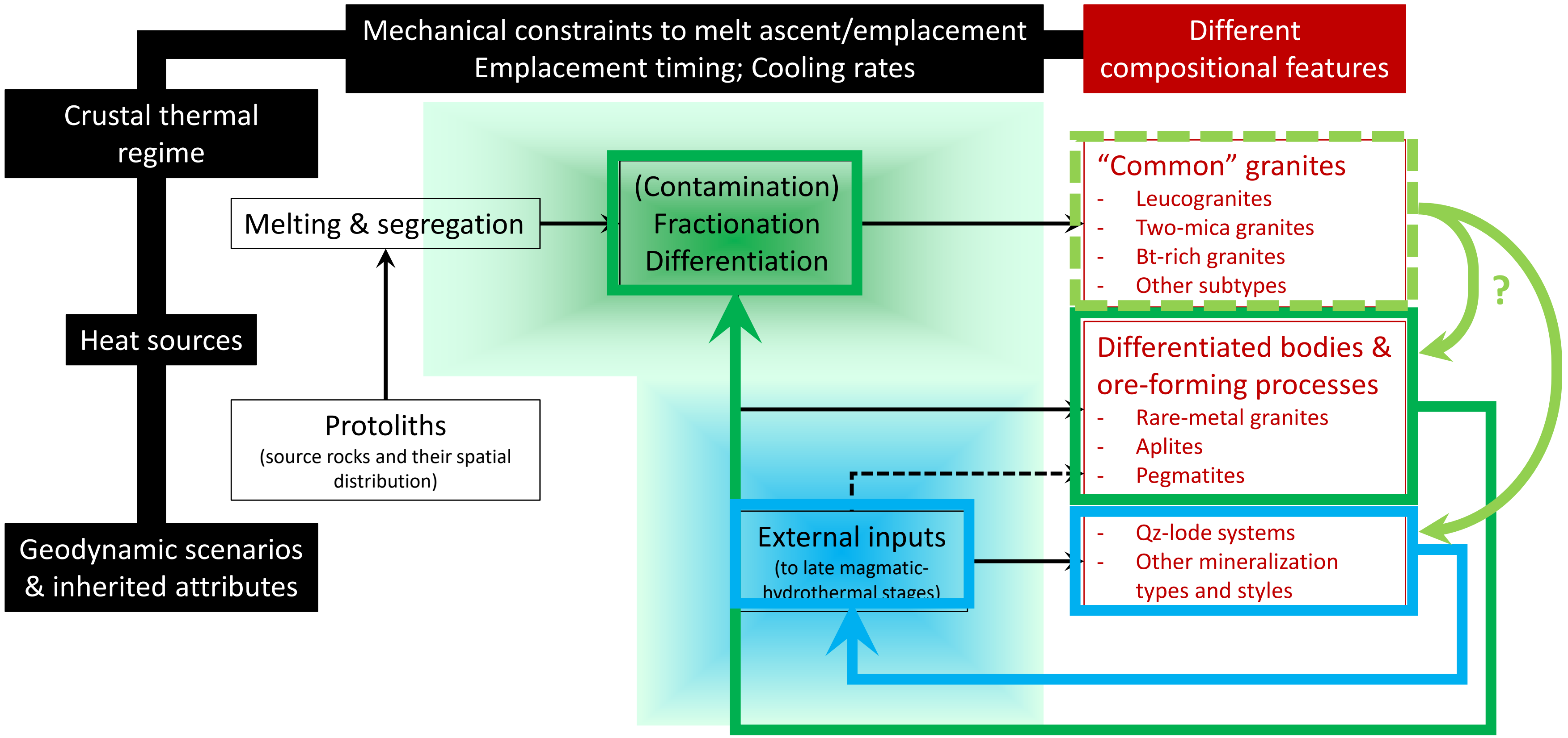
- Qz-lode systems
- Other mineralization types and styles

How to do it? *(following an inverse approach/modelling)*

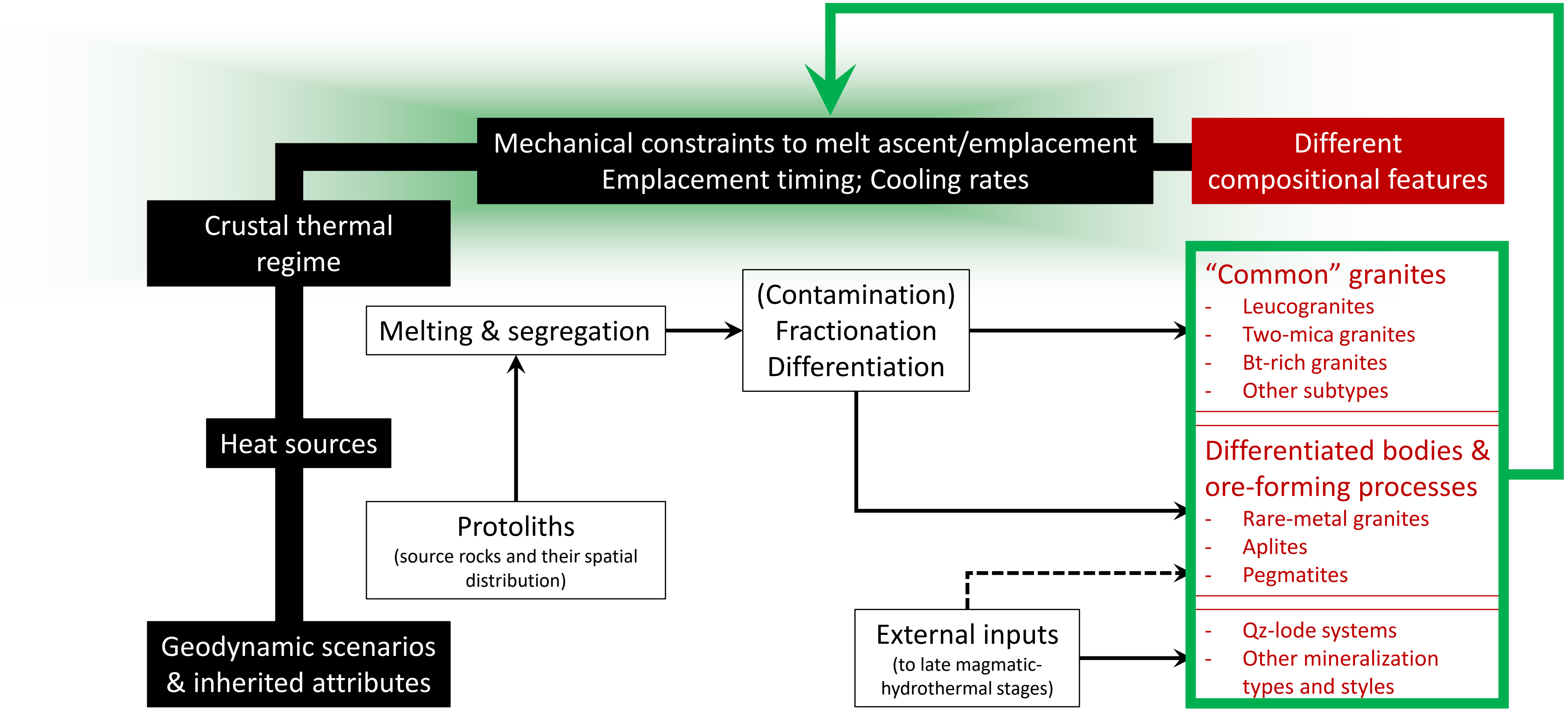
Step 1: Main compositional attributes of the sampled granitoid suites; possible protoliths, estimation of melting temperatures and discussion of heat sources considering the prevalent geodynamic constraints.

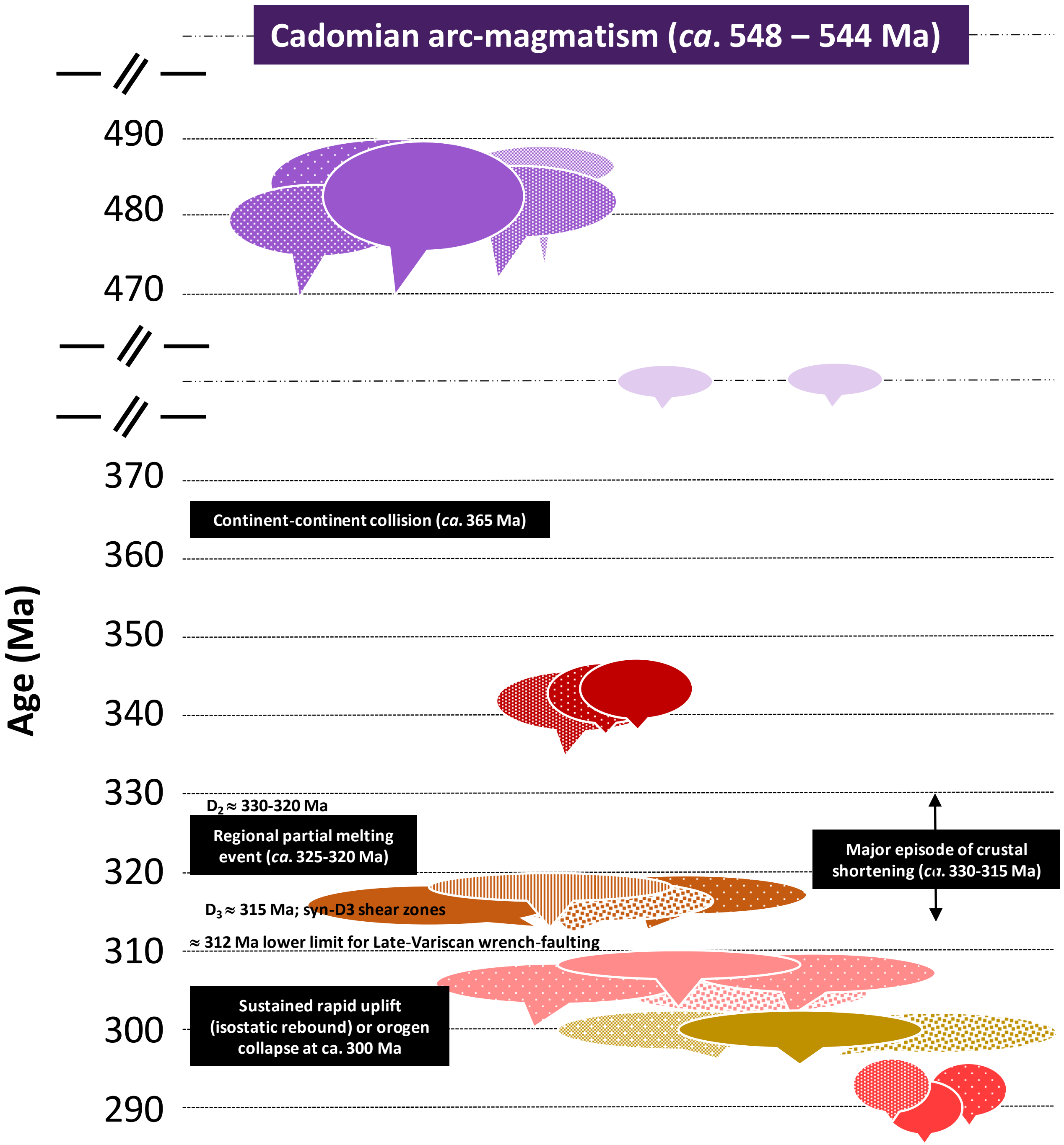


Step 2: Main compositional trends to (highly) differentiated γ suites; geochemical affinities, the role of prevailing fluxing agents (F, B, P) and relevance of external fluid inputs.



Step 3: Emplacement timing, cooling rates & “mineralization ages”





Cadomian arc-magmatism (*ca*. 548 – 544 Ma)

Continent-continent collision (*ca*. 365 Ma)

D_2 ≈ 330-320 Ma

Regional partial melting event (*ca*. 325-320 Ma)

Major episode of crustal shortening (*ca*. 330-315 Ma)

D_3 ≈ 315 Ma; syn-D3 shear zones

≈ 312 Ma lower limit for Late-Variscan wrench-faulting

Sustained rapid uplift (isostatic rebound) or orogen collapse at ca. 300 Ma

Voluminous Late Cambrian-Ordovician magmatic event (*ca*. 490-470 Ma) related to extreme thinning of continental margins during a rifting event or a back-arc extension. Abundant whole-rock multi-element and isotopic data, besides geochronological information in Iberia and other Variscan segments.

Poorly represented volcanic event at *ca*. 400-390 Ma interpreted to represent the extension associated to the far-field effect of the Rheic ridge subduction under its northern margin.

NOTE: The following scheme is tentative because data for Variscan granitoid rocks in NW Iberia are quite fragmented. A systematic (harmonized) review is needed!

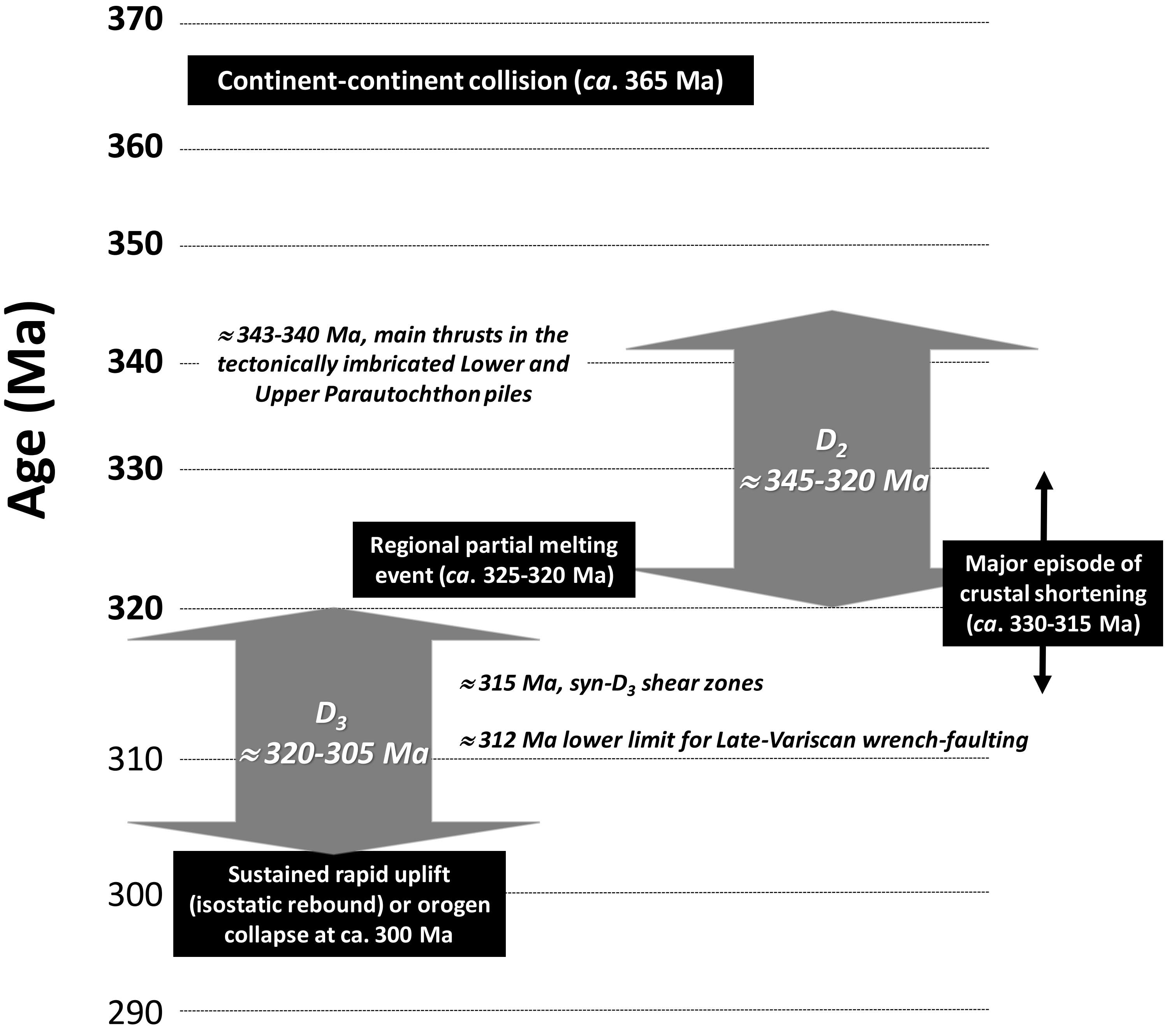
HT and LT, deep-seated peraluminous granodiorite and monzogranite suites (ca. 350-335 Ma), conceivably documenting crustal melting increments after initial lithospheric thickening (mostly under the allochthonous/parautochthonous pile).

Calc-alkaline aluminopotassic granodiorites & monzogranites (ca. 320-315 Ma). BDT ≈ 13-14 km

Subalkaline aluminopotassic monzogranites & Bt-dominant (HT) γs (ca. 310-305 Ma).

Moderate to strong peraluminous two-mica and Ms-dominant (LT) γs (ca. 300 Ma). BDT ≈10 km

Subalkaline ferropotassic (HT) γs (ca. 296-290 Ma). BDT ≈ 4-5 km



Continent-continent collision (*ca*. 365 Ma)

≈343-340 Ma, main thrusts in the tectonically imbricated Lower and Upper Parautochthon piles

D_2 ≈345-320 Ma

Regional partial melting event (*ca*. 325-320 Ma)

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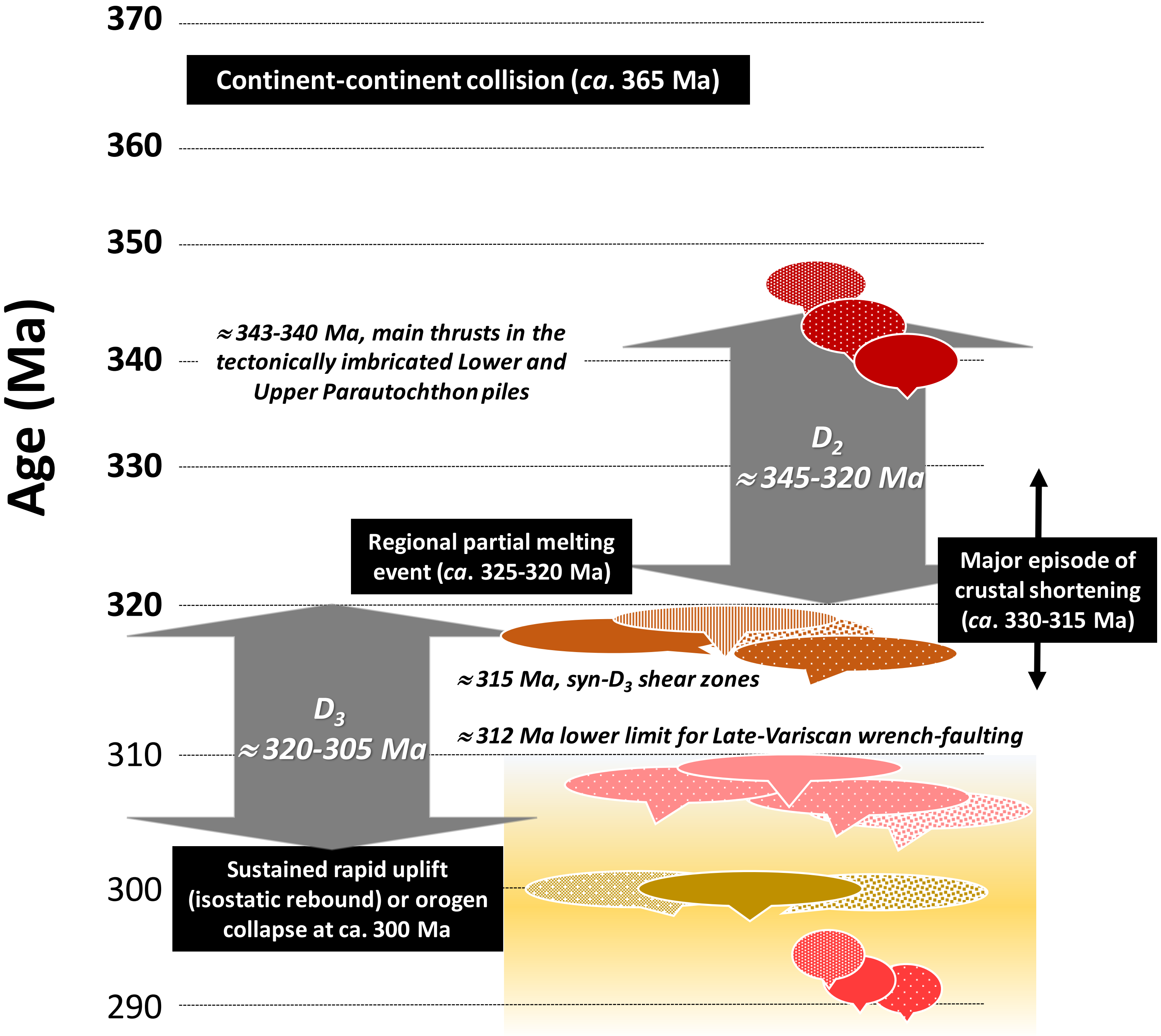

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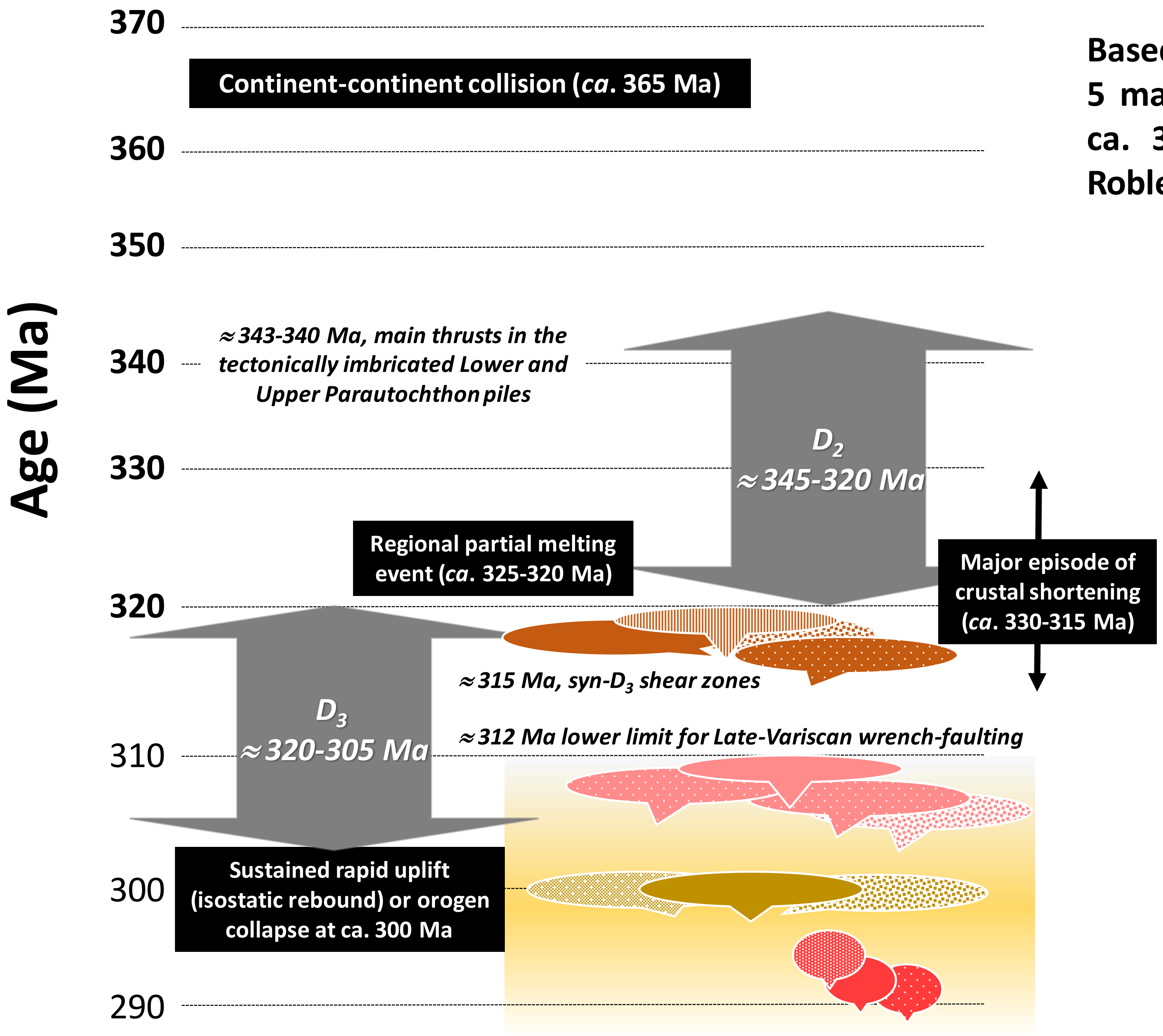
Moderate to strong peraluminous, two-mica and *Ms*-dominant (LT) granites (ca. 300 Ma). BDT ≈10 km

Subalkaline ferro-potassic (HT) granites (ca. 295-290 Ma). BDT ≈ 4-5 km

Based on petrographic and geochemical features, 5 main granite suites were emplaced during the ca. 320-295 Ma period (Villaseca, 2011; Roda-Robles et al., 2018)



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≈315 Ma, syn-D_3 shear zones

D_3
≈320-305 Ma

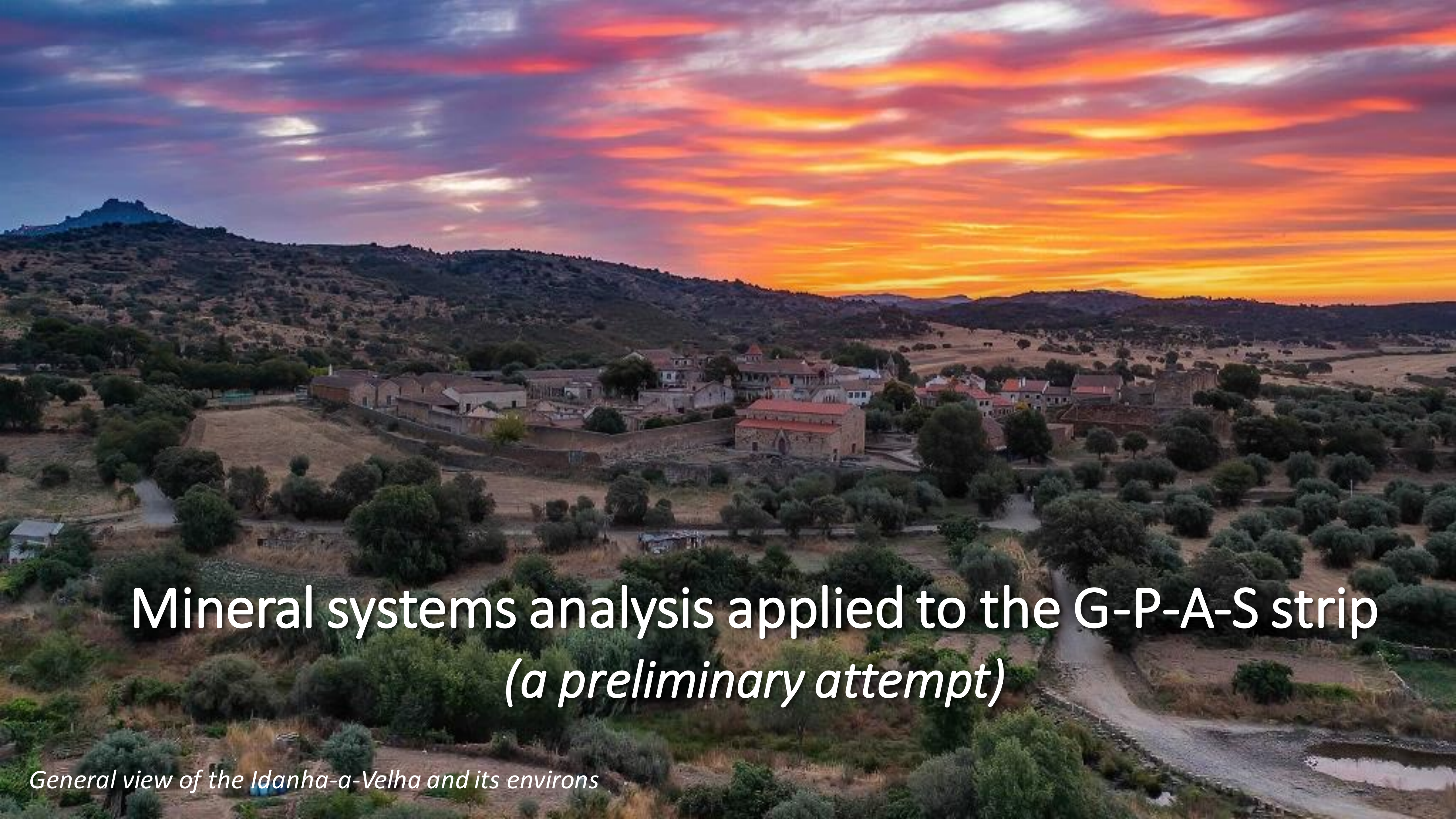
≈312 Ma lower limit for Late-Variscan wrench-faulting

Sustained rapid uplift (isostatic rebound) or orogen collapse at ca. 300 Ma

Highly peraluminous, Ca-poor, P-rich (biotite ± muscovite ± cordierite ± andalusite) monzogranites; prevailing metasedimentary source; emplaced at ca. 310-300 Ma.

P-poor, moderately peraluminous granites, mostly crystallized at 308–299 Ma, coupled with **moderately to low peraluminous granites, with features at the limit between S- and I-type granites**

I-type granites including metaluminous to low peraluminous amphibole-bearing biotite-granodiorites.



Mineral systems analysis applied to the G-P-A-S strip

(a preliminary attempt)

General view of the Idanha-a-Velha and its environs

Granite-related ore-forming systems in the G-P-A-S strip

	SOURCES	ACTIVE PATHWAYS	TRAPS	MODIFICATIONS
CRITICAL FACTORS	**Fertile magmas formation** (energy, protoliths nature, fluxing components) **Extreme fractionation** of pluton-sized batches of granite magma	**Magma transport** (directing flow through the crust and late separation of evolved residual melts or critical fluids)	**Cooling and rapid crystallisation** (chemical transport & differentiation; metal enrichment in residual portions)	**Exhumation vs preservation**

Granite-related ore-forming systems in the G-P-A-S strip

	SOURCES	ACTIVE PATHWAYS	TRAPS	MODIFICATIONS
	CRITICAL FACTORS	CRITICAL FACTORS	CRITICAL FACTORS	CRITICAL FACTORS
CONSTITUENT PROCESSES	**Crustal-melting** (variable degrees of partial melting that could involve the same protolith; mixing of melts generated in different crustal levels and P-T conditions) **Collisional features** **Late events able to produce decompression melts**	**Crustal-scale shearing/faulting** (cycles of renewed rock permeability increasing)	**Fractional crystallization, filter pressing or rapid diffusion of critical phases** **High contents of fluxing agents (P, F, B)** **Highly differentiated (and metal-fertile) batches** **Supercritical fluids split-up.** **Mixing with external fluid components**	**Supergene assemblages** **Secondary (alluvial) accumulations**

Granite-related ore-forming systems in the G-P-A-S strip

TARGETING

SOURCES

CRITICAL FACTORS

CONSTITUENT PROCESSES

Highly differentiated peraluminous γs, **ferroan leucogranites** enriched in a wide range of incompatible elements

Compositional overprints displayed by contact metamorphism aureoles

ACTIVE PATHWAYS

CRITICAL FACTORS

CONSTITUENT PROCESSES

Network of shear zones (connection domains of conjugate systems; evidence of multiple reactivation)

Networks of folding-related structural discontinuities

TRAPS

CRITICAL FACTORS

CONSTITUENT PROCESSES

Distal and proximal swarms of aplite-pegmatite bodies

Compositionally and texturally zoned pegmatites.

Quartz-lode systems (density, internal connection, evidence of multiple infilling stages)

MODIFICATIONS

CRITICAL FACTORS

CONSTITUENT PROCESSES

Topographic highs and ridges

Weathering vulnerability of critical mineral phases

Physical dispersion of heavy minerals

Granite-related ore-forming systems in the G-P-A-S strip

SOURCES

CRITICAL FACTORS

CONSTITUENT PROCESSES

TARGETING

ACTIVE PATHWAYS

CRITICAL FACTORS

CONSTITUENT PROCESSES

TARGETING

TRAPS

CRITICAL FACTORS

CONSTITUENT PROCESSES

TARGETING

MODIFICATIONS

CRITICAL FACTORS

CONSTITUENT PROCESSES

TARGETING

MAPPEABLE PROXIES

For granites:

- Mineral attributes
- Textural features
- Geochemical attributes
- Age

Fertility footprints:

- Mineral abundance and composition
- Geochemical ratios and indexes

Structural patterns:

- Density
- Connection
- Mineral infillings
- Age

Alteration pathways in country rocks:

- Mineral guides
- Geochemical guides
- Age

Mineral/Geochemical attributes

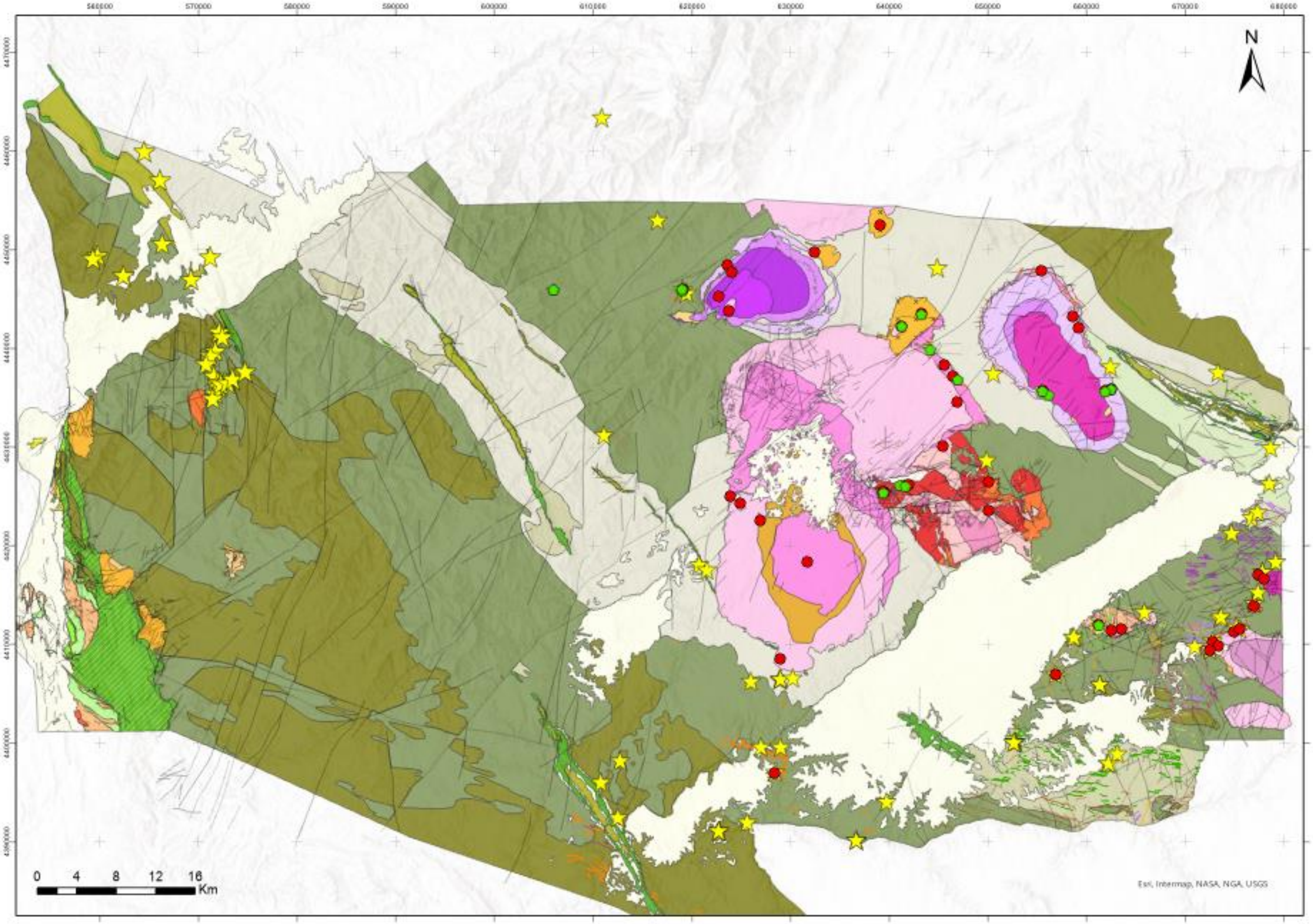
Alteration haloes:

- Mineral guides
- Geochemical guides

Heavy minerals in alluvial sediments:

- Classification
- Composition

Soil or stream sediment geochemistry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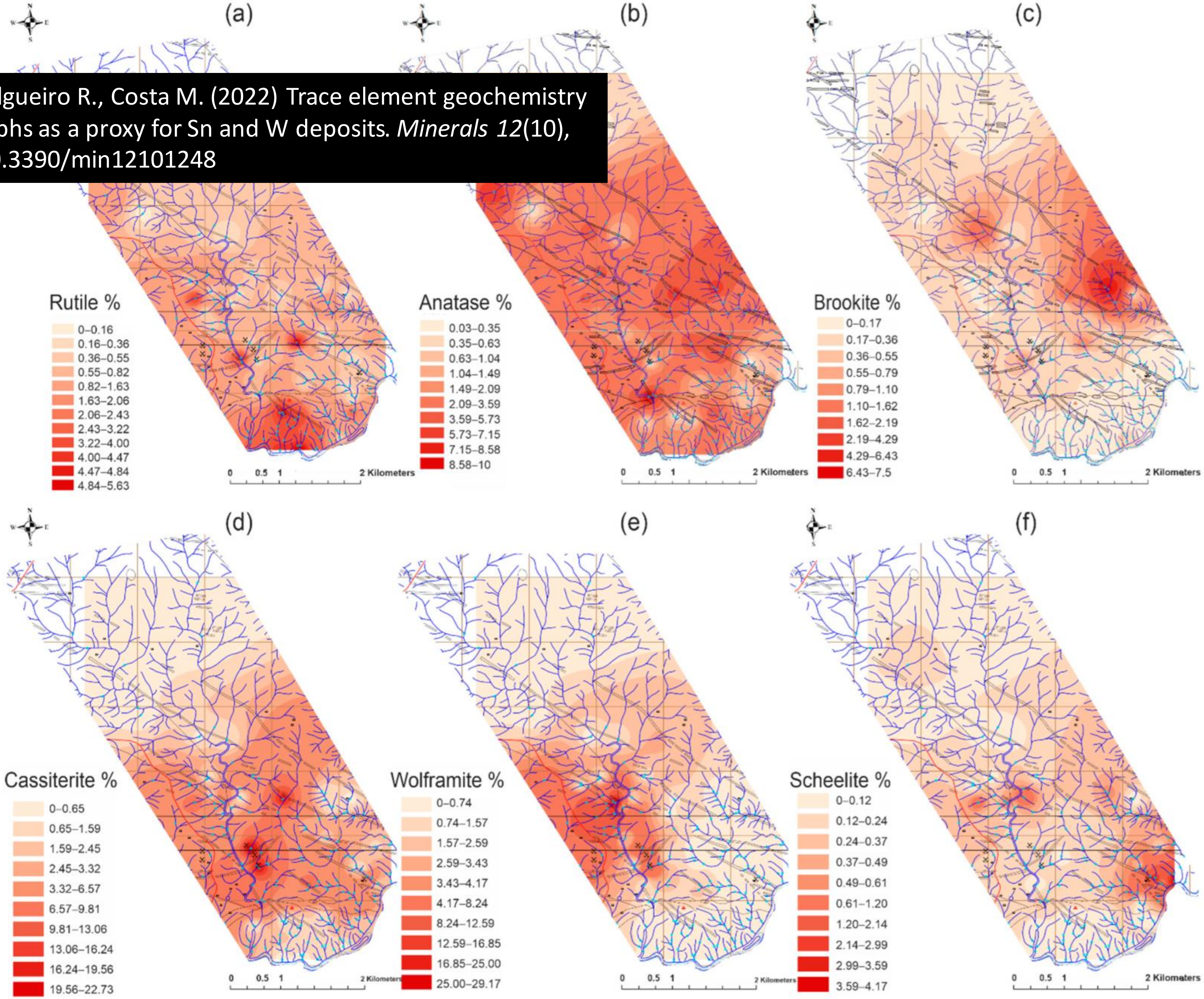
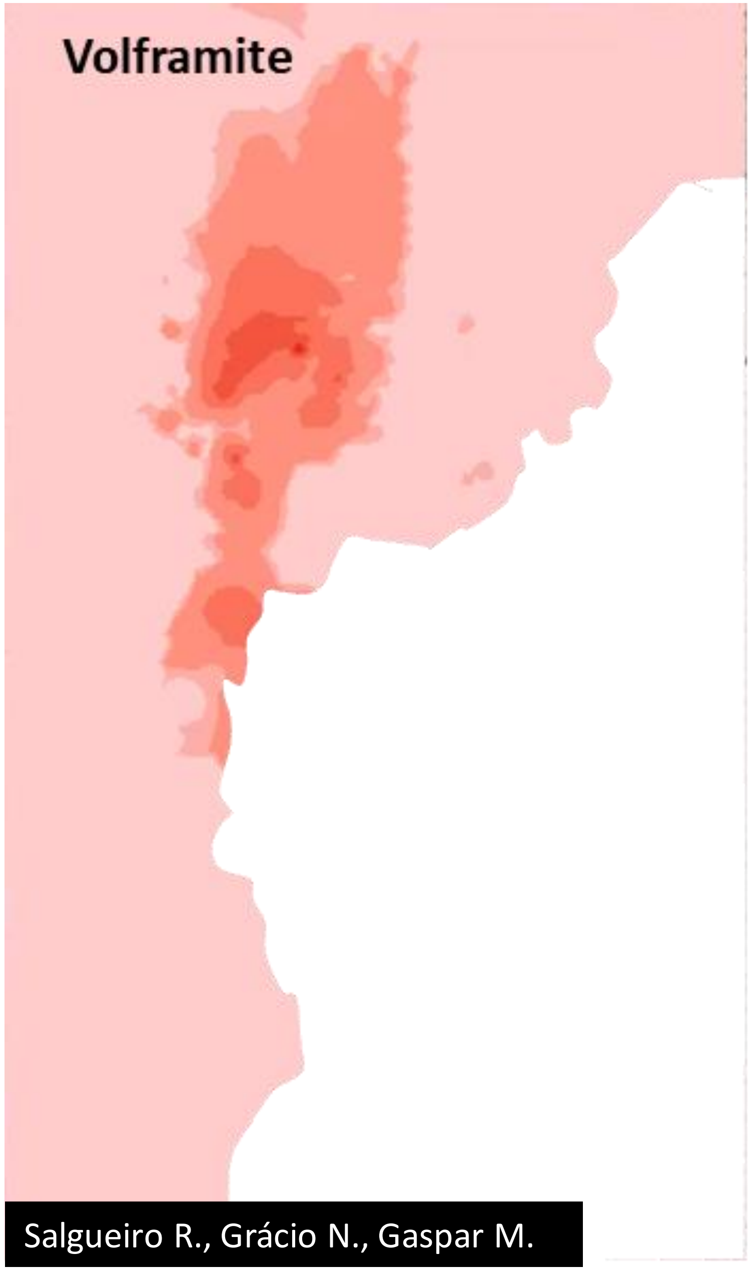
Km
Esri, Intermap, NASA, NGA, USGS

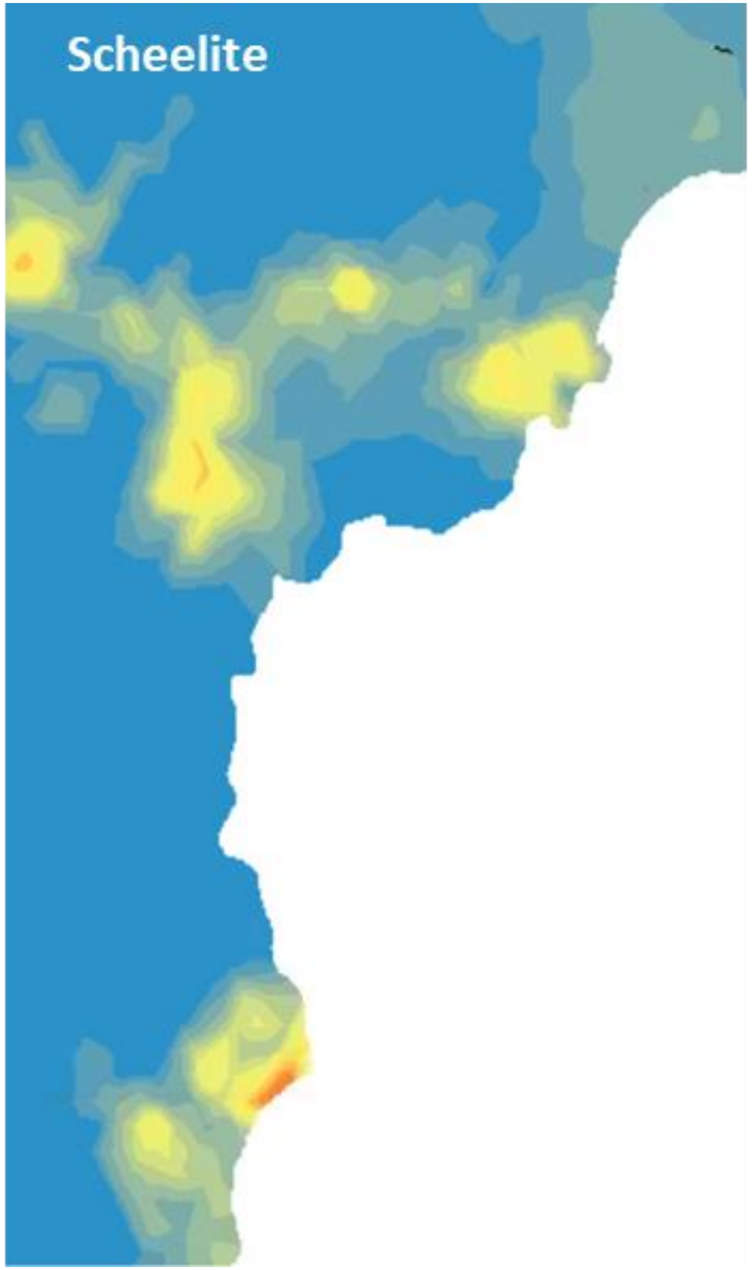
Gaspar M., Grácio N., Salgueiro R., Costa M. (2022) Trace element geochemistry of alluvial TiO2 polymorphs as a proxy for Sn and W deposits. *Minerals 12*(10), 1248. https://doi.org/10.3390/min12101248



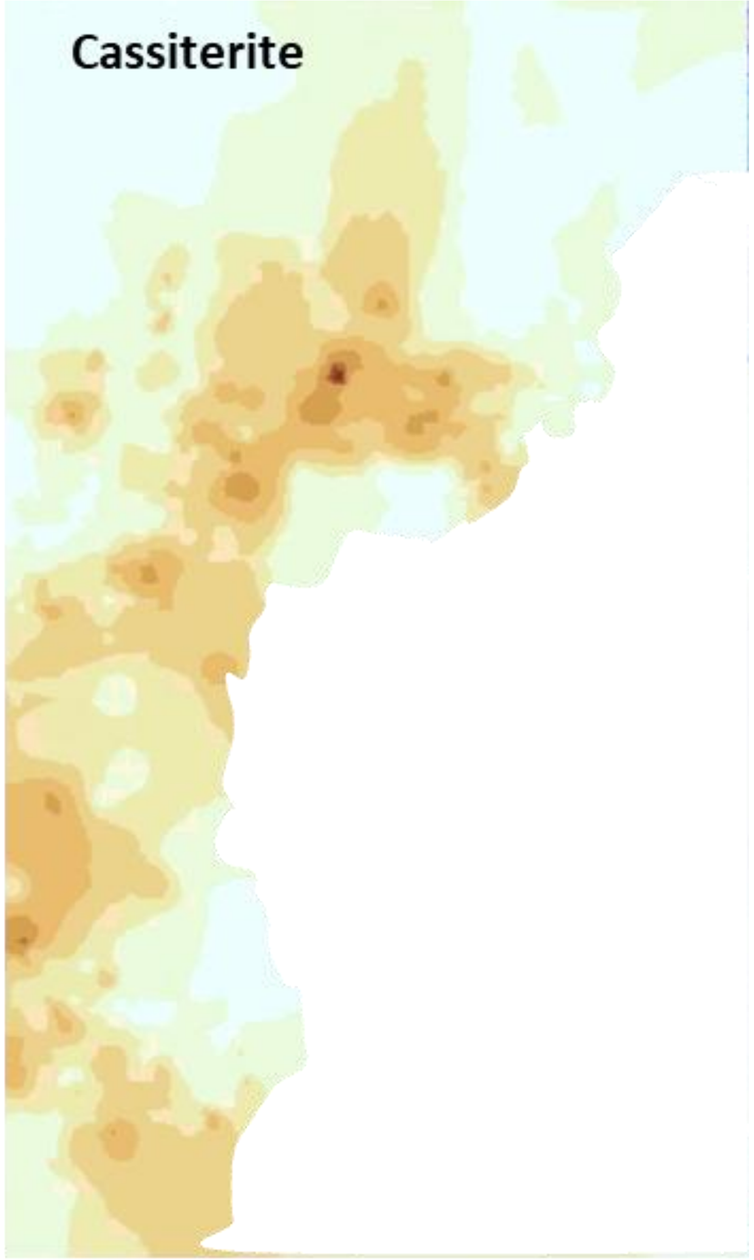


Volframite

Salgueiro R., Grácio N., Gaspar M.

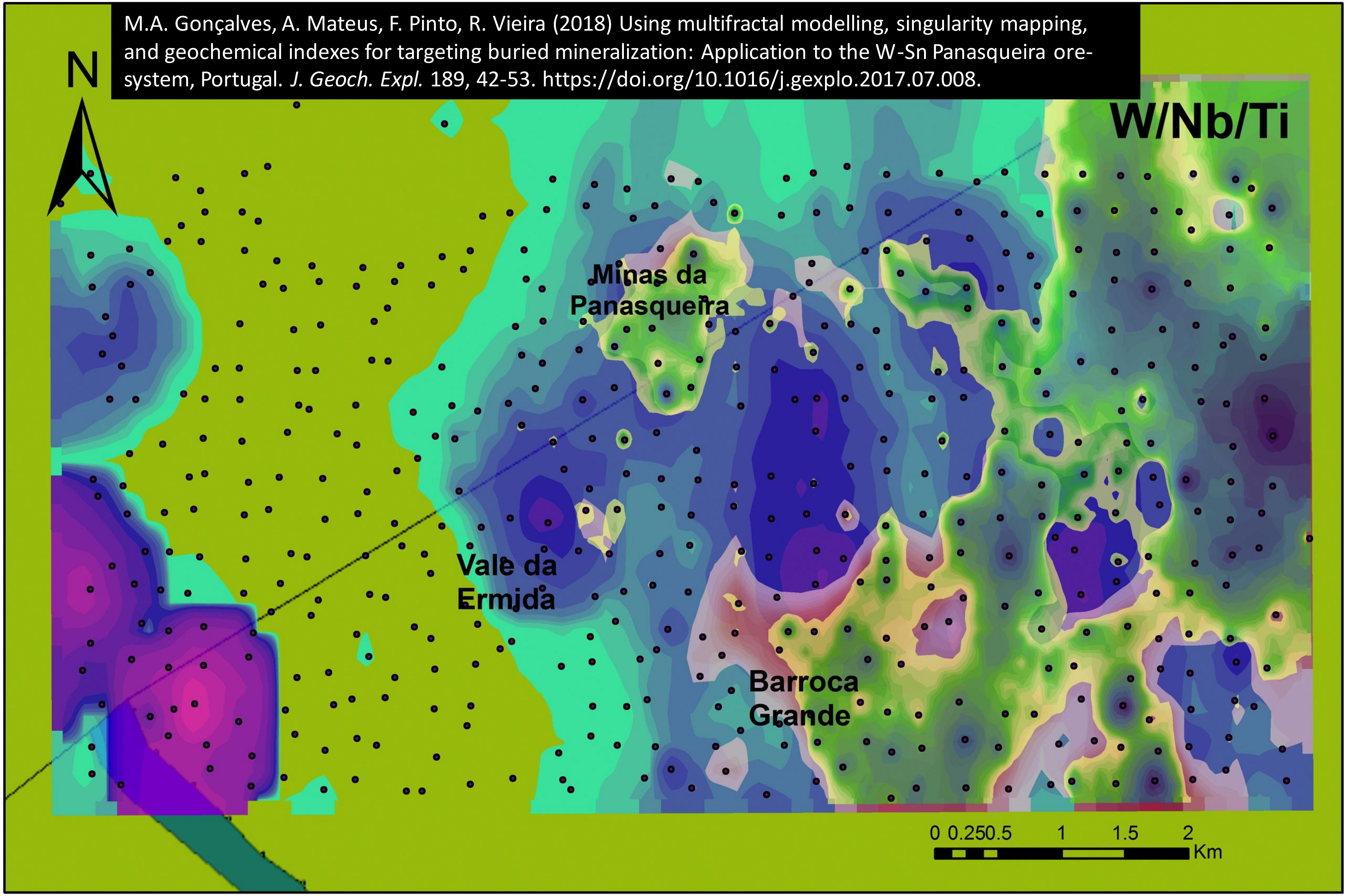


Scheelite



Cassiterite

M.A. Gonçalves, A. Mateus, F. Pinto, R. Vieira (2018) Using multifractal modelling, singularity mapping, and geochemical indexes for targeting buried mineralization: Application to the W-Sn Panasqueira ore-system, Portugal. *J. Geoch. Expl.* 189, 42-53. https://doi.org/10.1016/j.gexplo.2017.07.008.



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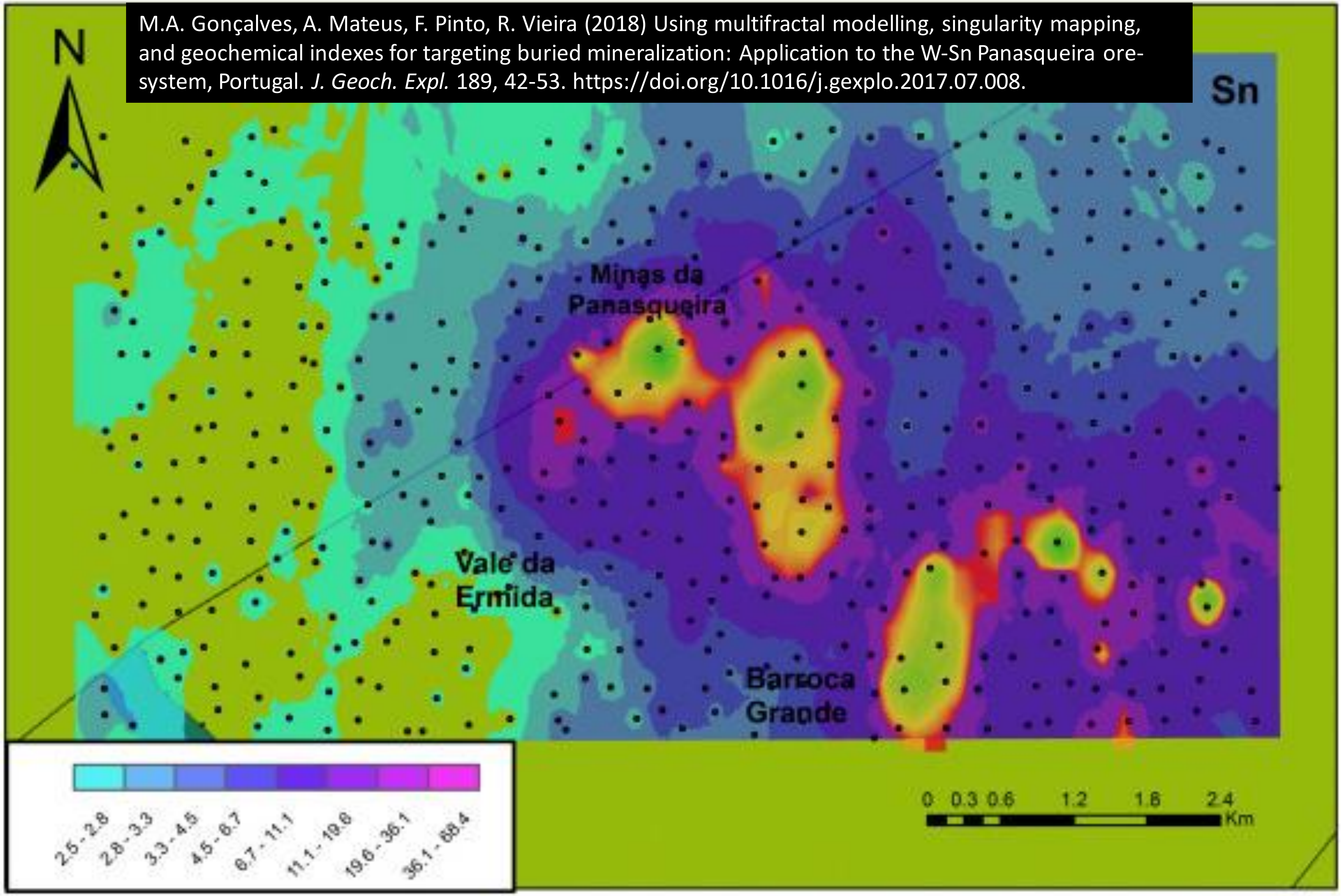

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https://mostmeg.rd.ciencias.ulisboa.pt/

Thank you for your attention!

Modified metasediment adjoining the “greisen-like” facies (Mata da Rainha)