Indications provided by compositional variations recorded in TiO_2 polymorphs and tourmaline

L. Miguel Gaspar; Nuno Grácio; Rute Salgueiro; Mafalda Costa; Isabel Ribeiro da Costa; António Mateus; Ivo Martins; Pedro Reis

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

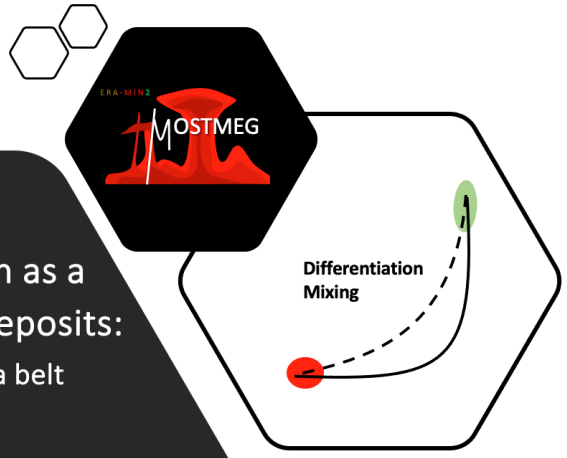
ERA-MIN Joint Call 2019 (EU Horizon 2020 ERA-NET Co-fund Project ERA-MIN2, Grant agreement Nº 730238)

Indications provided by compositional variations recorded in TiO_2 polymorphs and tourmaline

Part I

Tourmaline

SEG 2022 MINERALS FOR OUR FUTURE
August 27-30, 2022 | Denver



Assessment of Tourmaline Composition as a Vectoring Tool for Sn-W Deposits: The Góis-Panasqueira-Segura belt (Central Portugal)

Miguel **Gaspar**, Isabel R. **Costa**, António **Mateus**, Ivo **Martins**, and Pedro **Rodrigues**

Ciências ULisboa INSTITUTO DOM LUIZ

Part II

minerals MDPI

Article

Trace Element Geochemistry of Alluvial TiO_2 Polymorphs as a Proxy for Sn and W Deposits

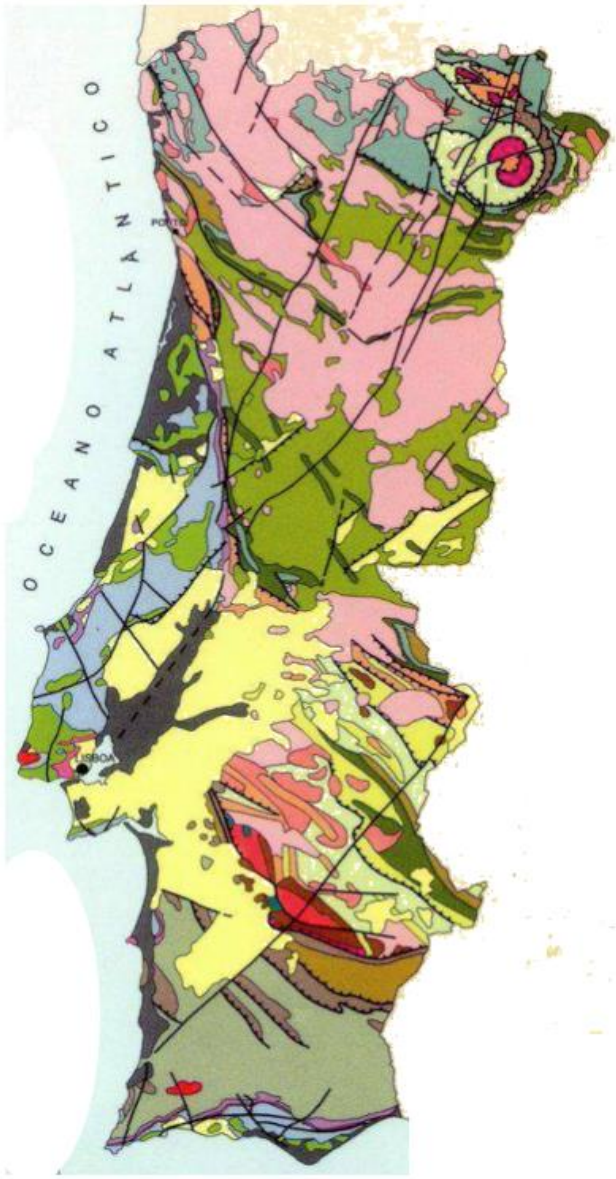
Miguel Gaspar [1,2,*], Nuno Grácio [2,3], Rute Salgueiro [3] and Mafalda Costa [4]

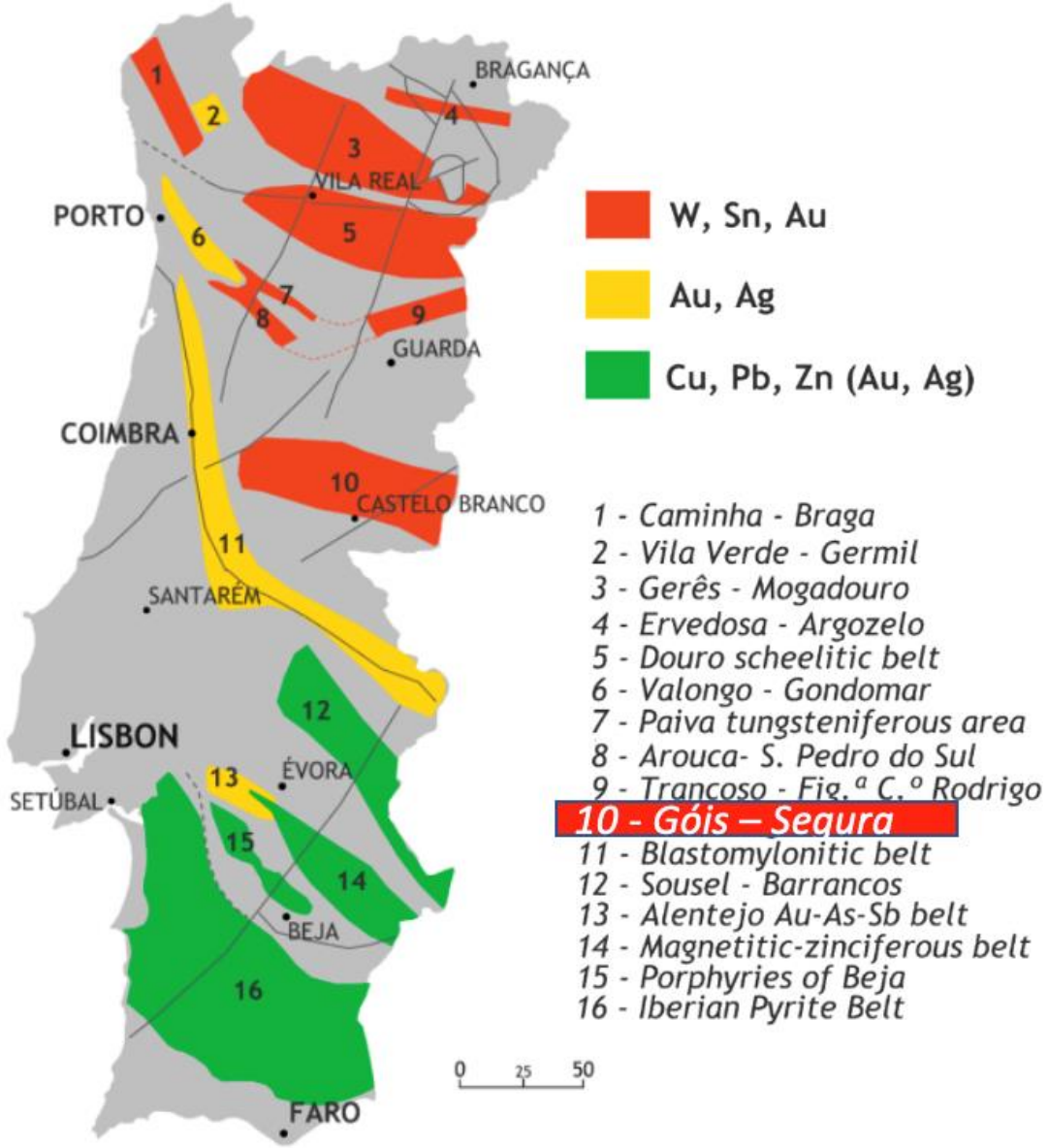
Rutile

Anatase

Brookite

Metallogenic belts



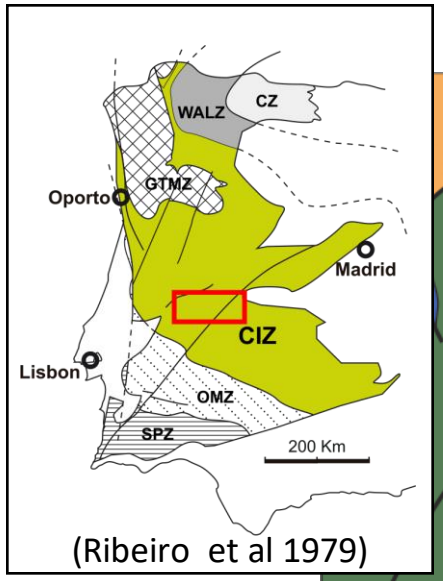


(Martins 2012, after Carvalho 1974)

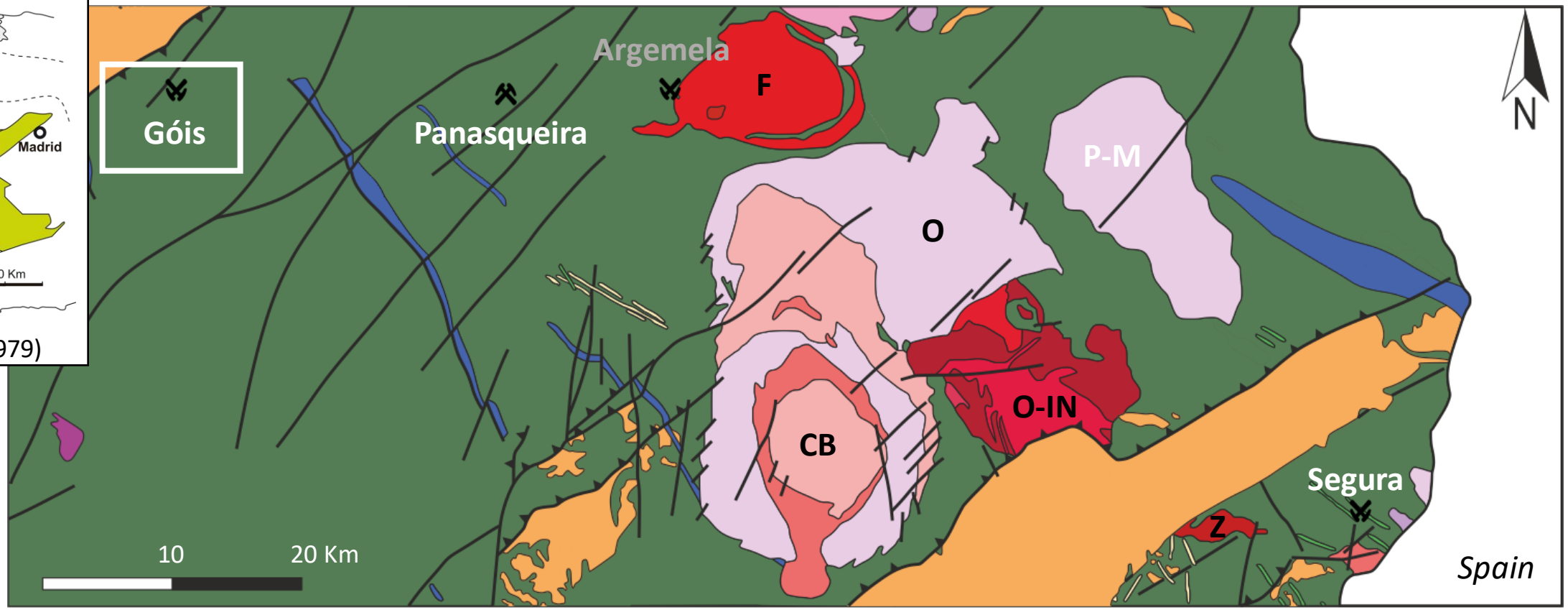
Sn-W deposits

W quartz veins
W(Sn) quartz veins
W skarns
Sn(W) quartz veins
Sn aplite-pegmatites
Sn greisen
Sn alluvial

Góis-Panasqueira-Segura Sn-W belt (Central Portugal)



(Ribeiro et al 1979)



Variscan Granites

Ordovician Granites

Cadomian Granites

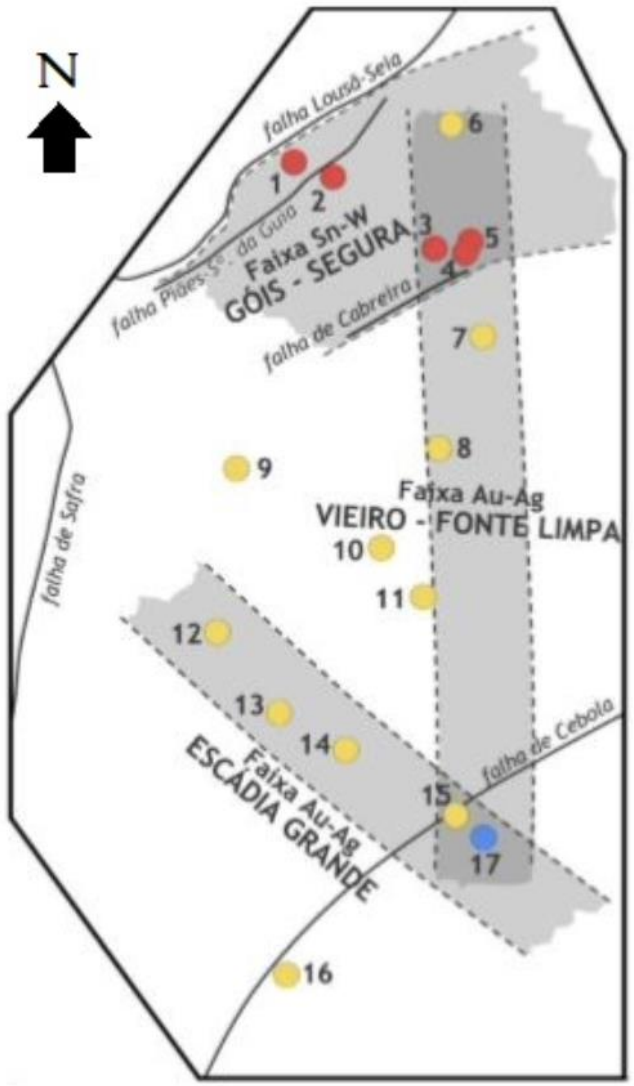
Ordovician Metasediments

Ante-Ordovician Metasediments (Beiras Group)

Tertiary deposits

(MOSTMEG 2020)

Góis – Vale Pião deposit



(Manuel et al. 2017)

Mineral ocurrences

(Sn-W)

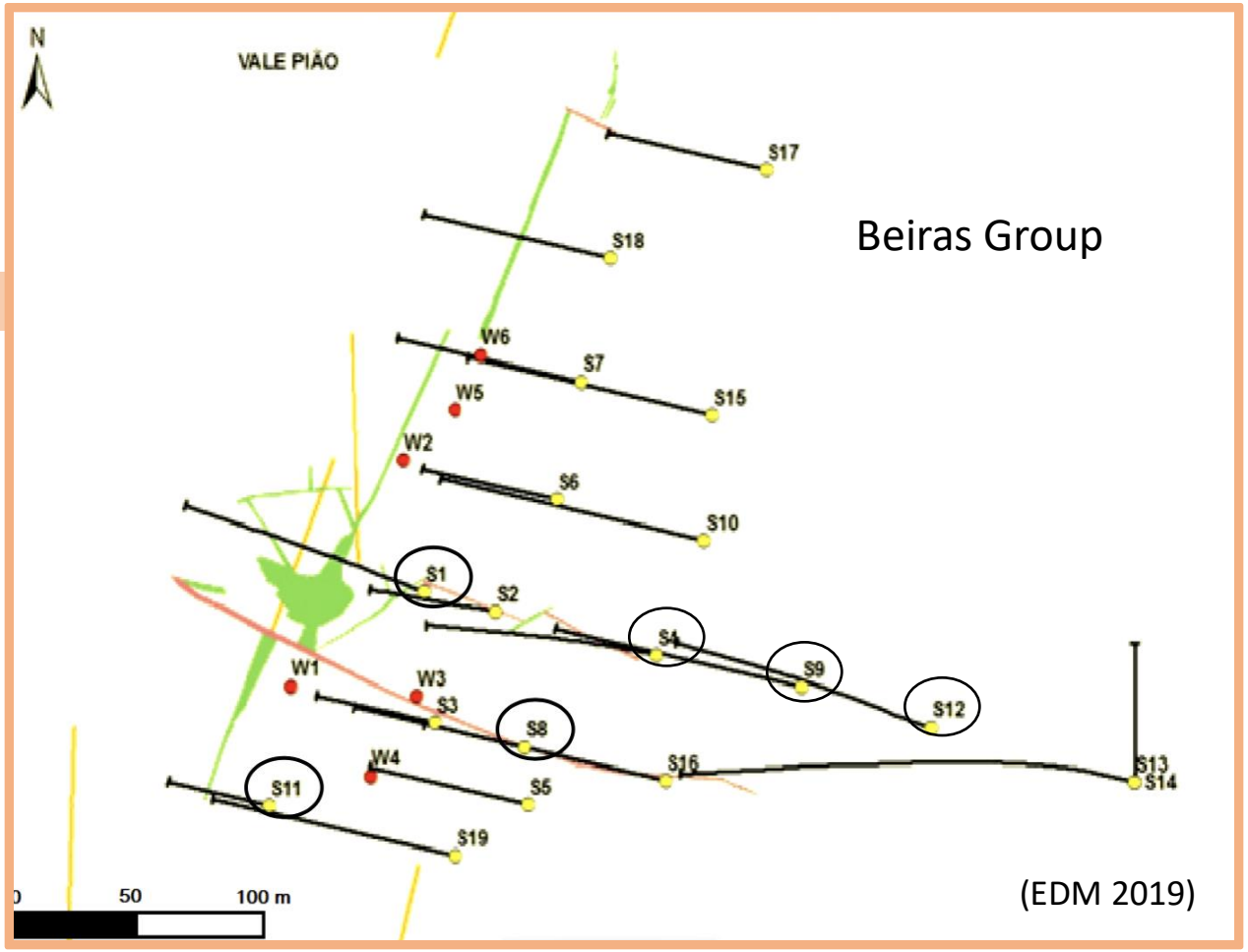
1 – Vale Moreiro – Casal Loureiro
2 – Senhora da Guia
3 – Rabadão
4 – Vale Pião
5 – Barroca de Amiães

(Au-Ag)

6 – Vieiro
7 – Cadafaz
8 – Corterredor
9 – Cerdeira
10 – Mestras
11 – Cabeçadas
12 – Escádia Grande
13 – Roda Cimeira
14 – Roda Fundeira
15 – Fonte Limpa
16 - Alvares

(Sb-Au)

17 – Vale Torto

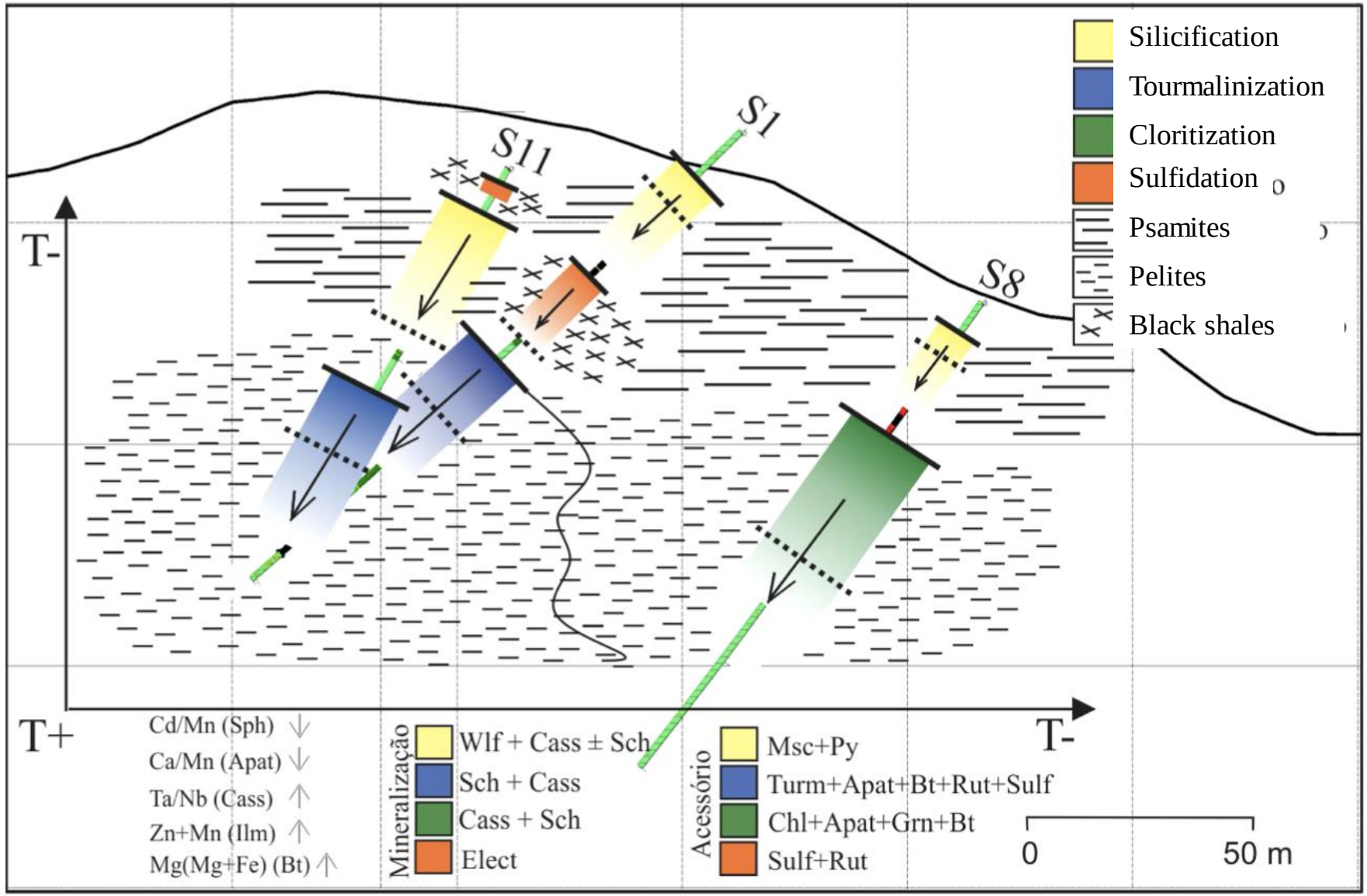


Breccias – Woframite/Scheelite

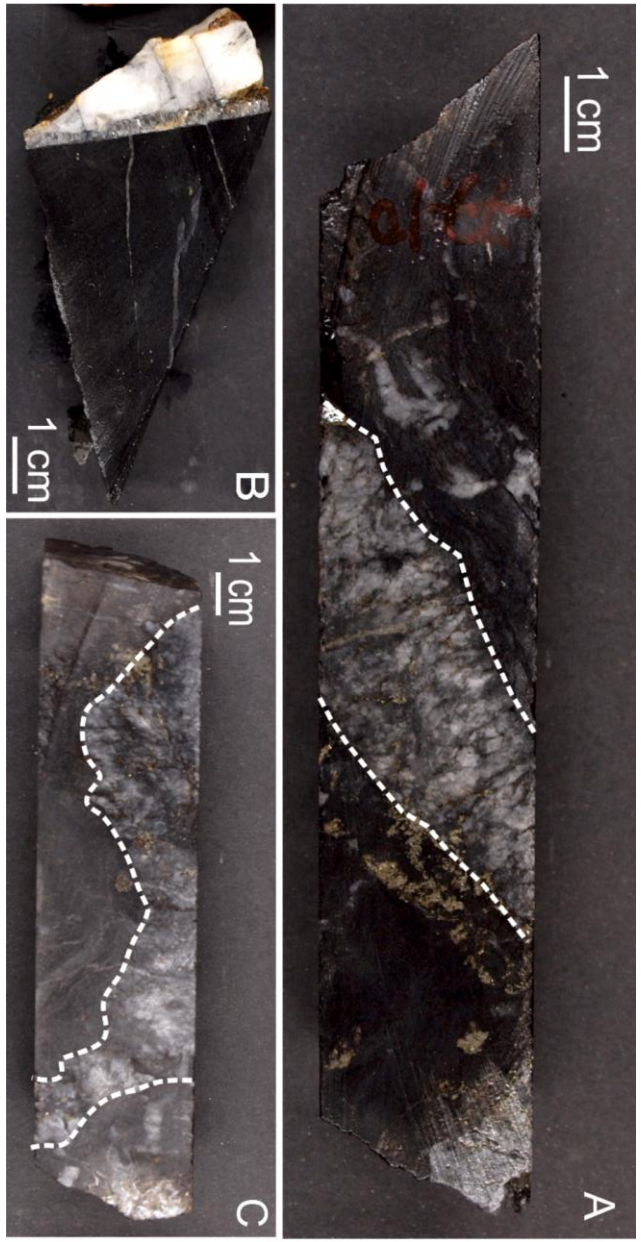
Quartz – Wolframite – Cassiterite veins

Studied core

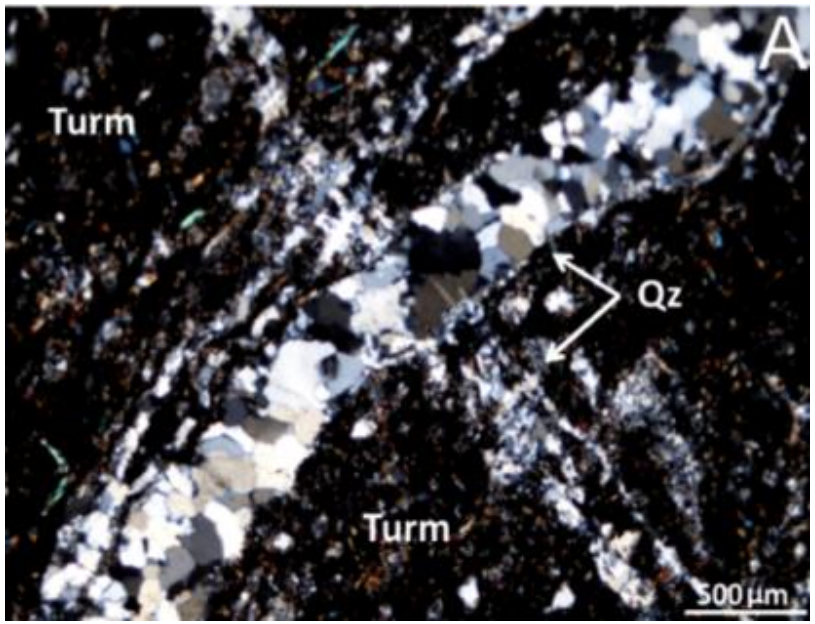
Góis – Vale Pião deposit

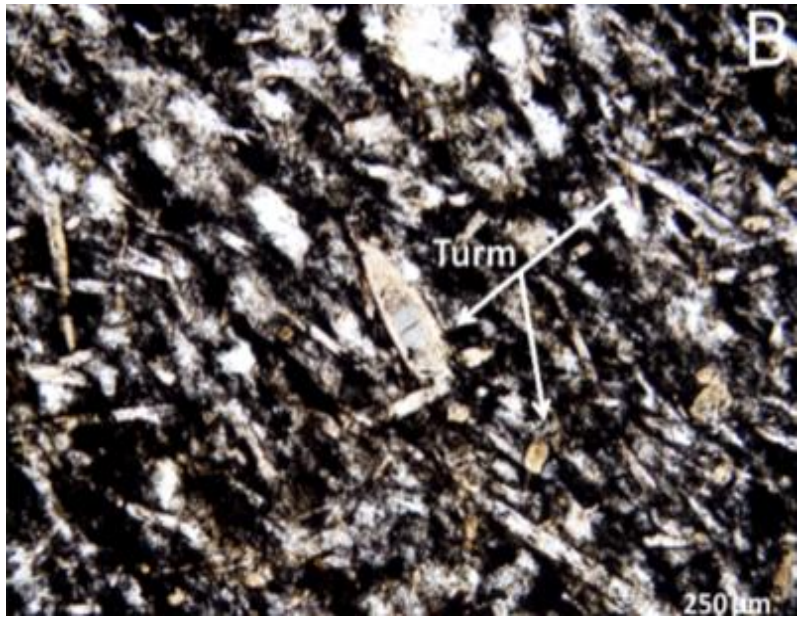


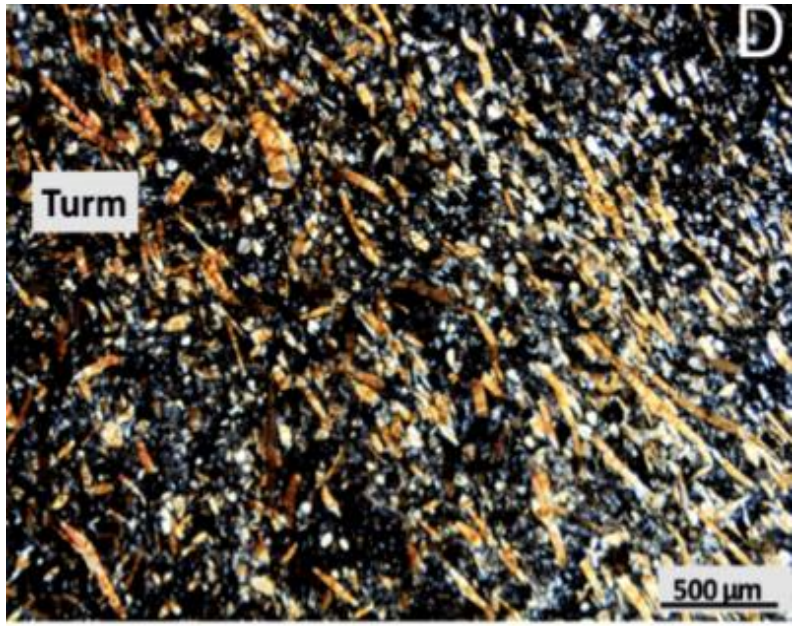
(I. Fernandes 2020)

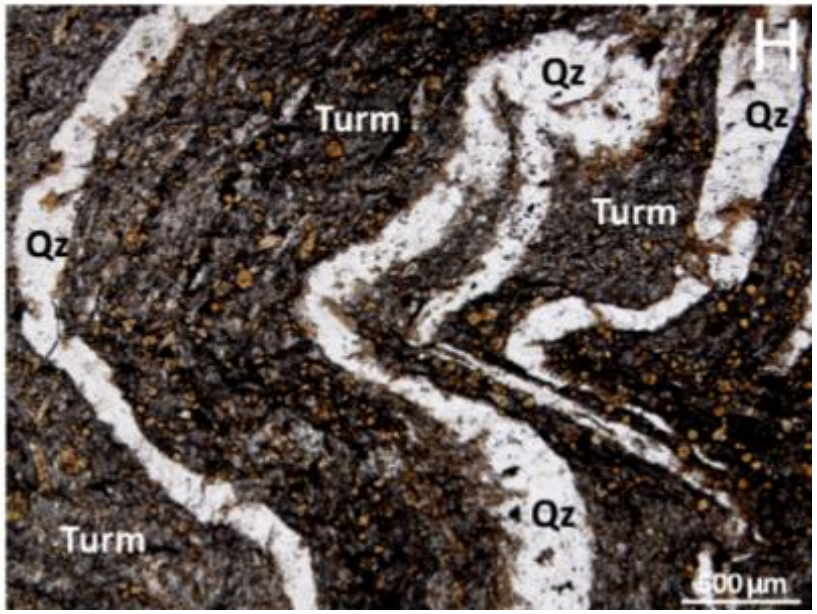


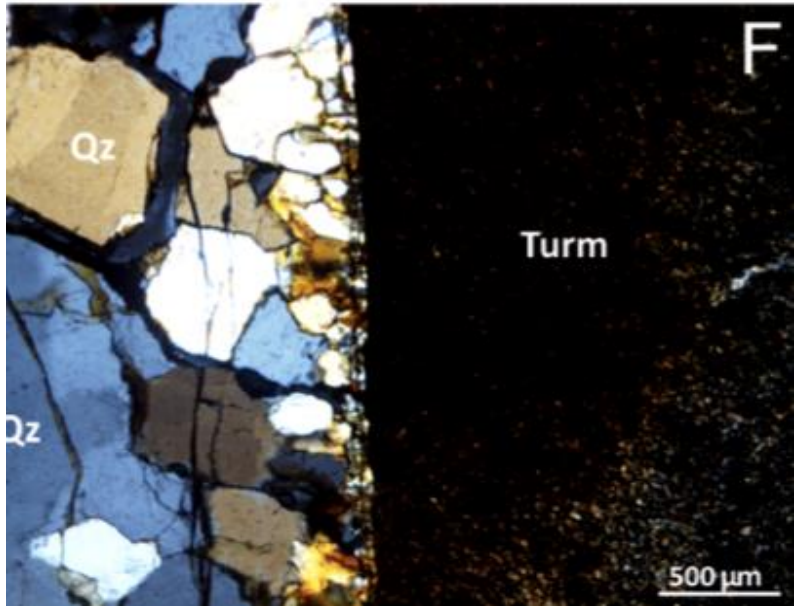
Góis – Vale Pião Tourmaline

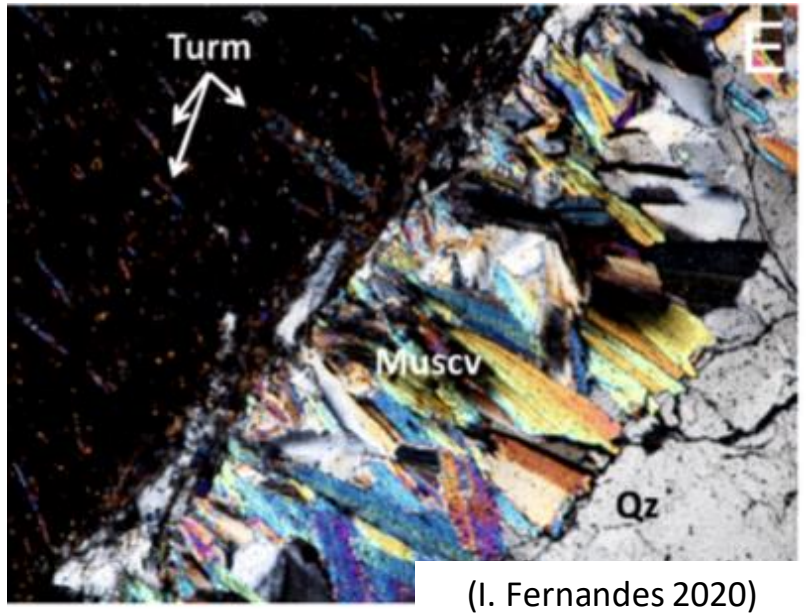








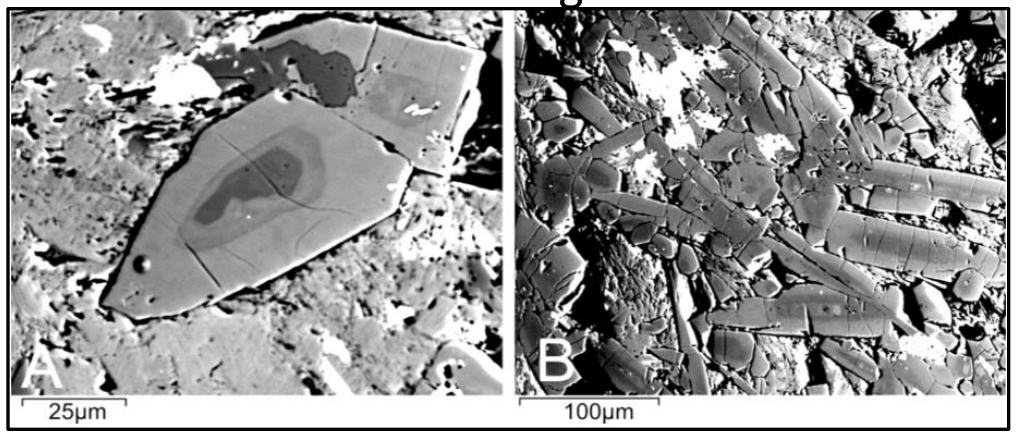


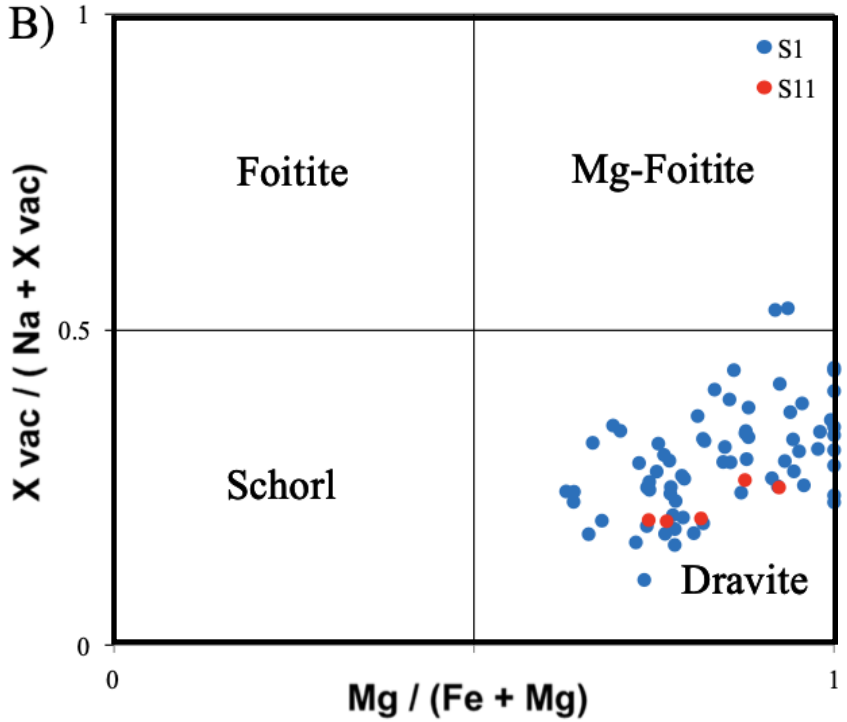


(I. Fernandes 2020)

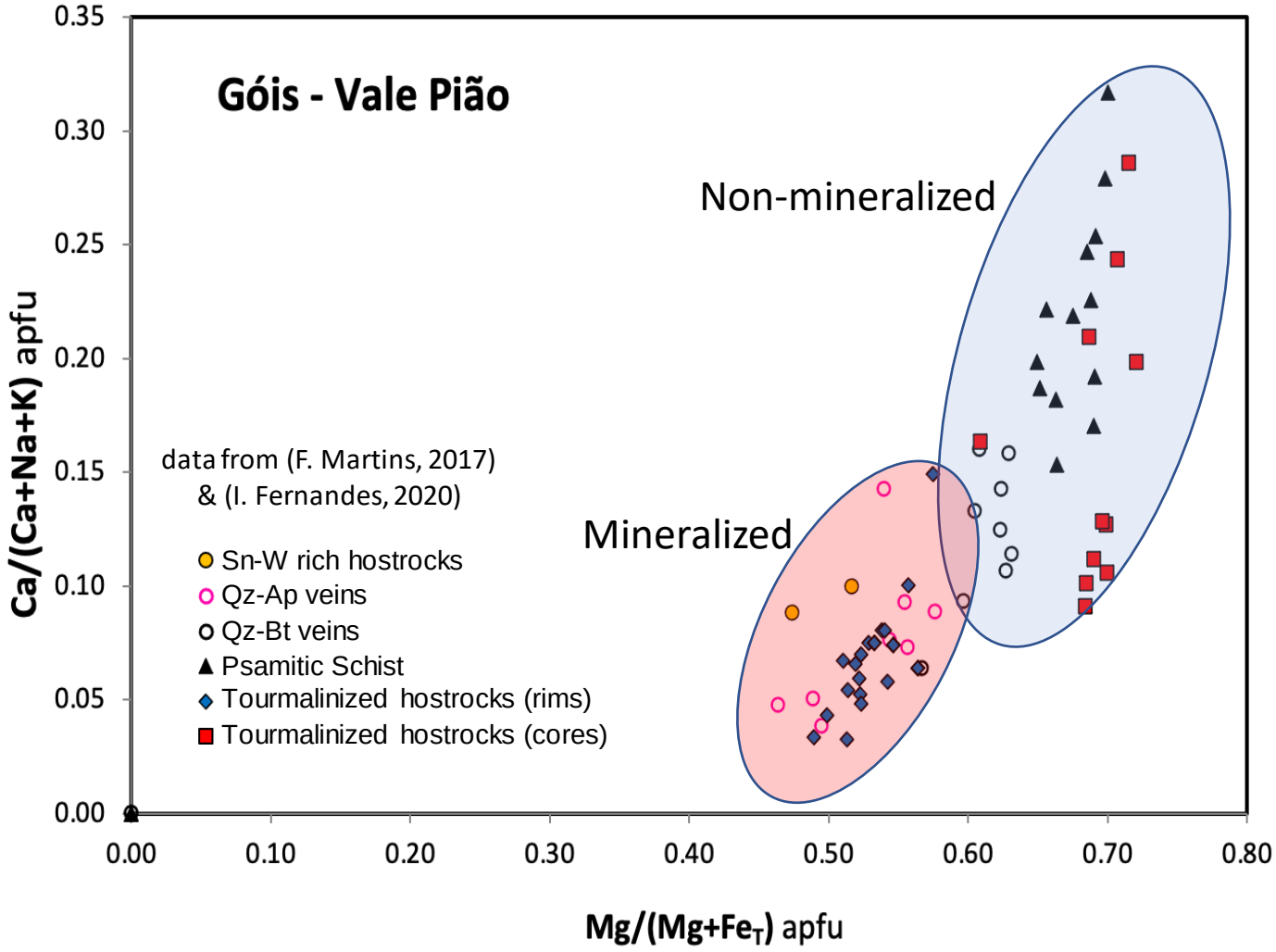
Góis – Vale Pião Tourmaline

BSE images

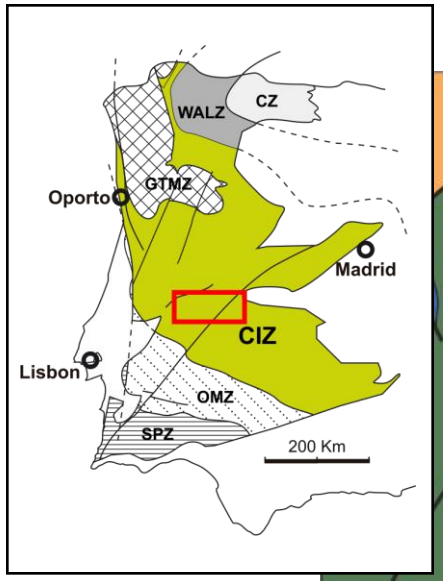


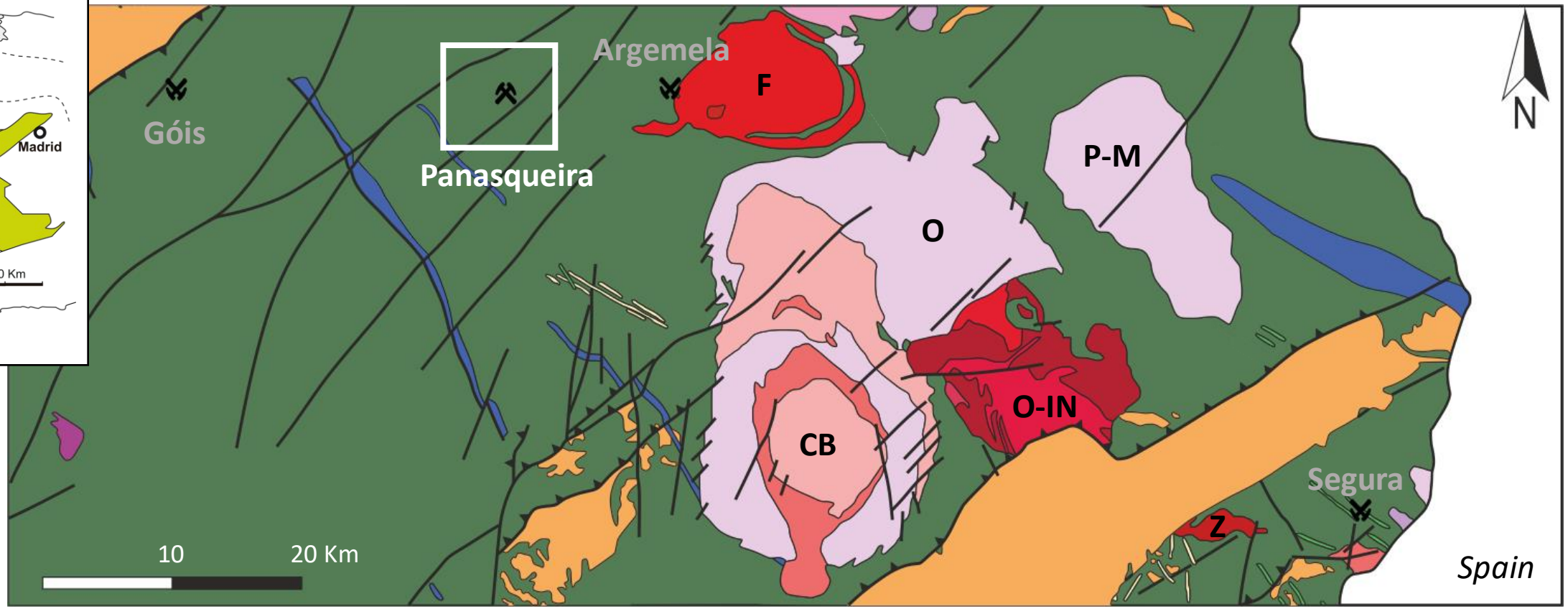


Tourmaline Composition



Góis-Panasqueira-Segura Sn-W belt (Central Portugal)





Variscan Granites

Ordovician Granites

Cadomian Granites

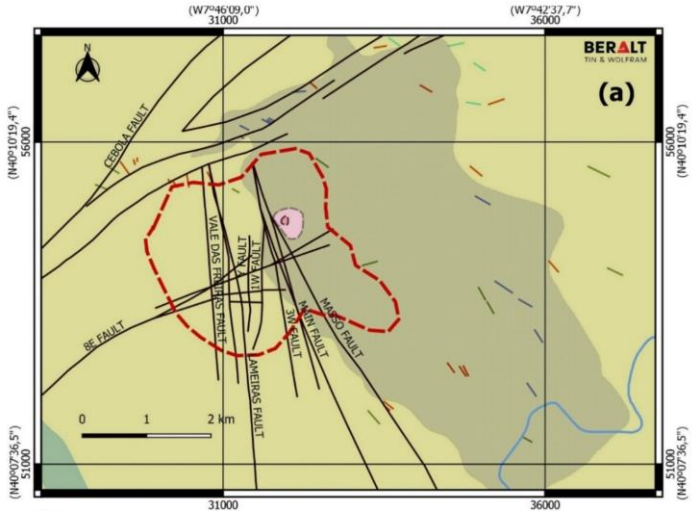
Ordovician Metasediments

Ante-Ordovician Metasediments (Beiras Group)

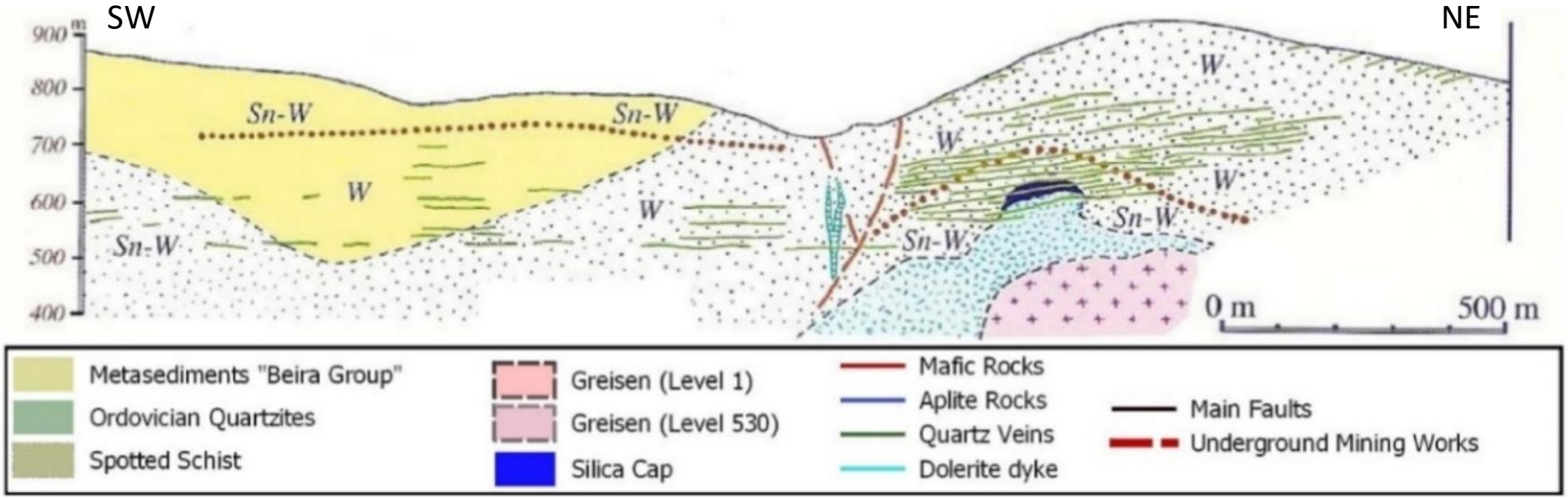
Tertiary deposits

(MOSTMEG 2020)

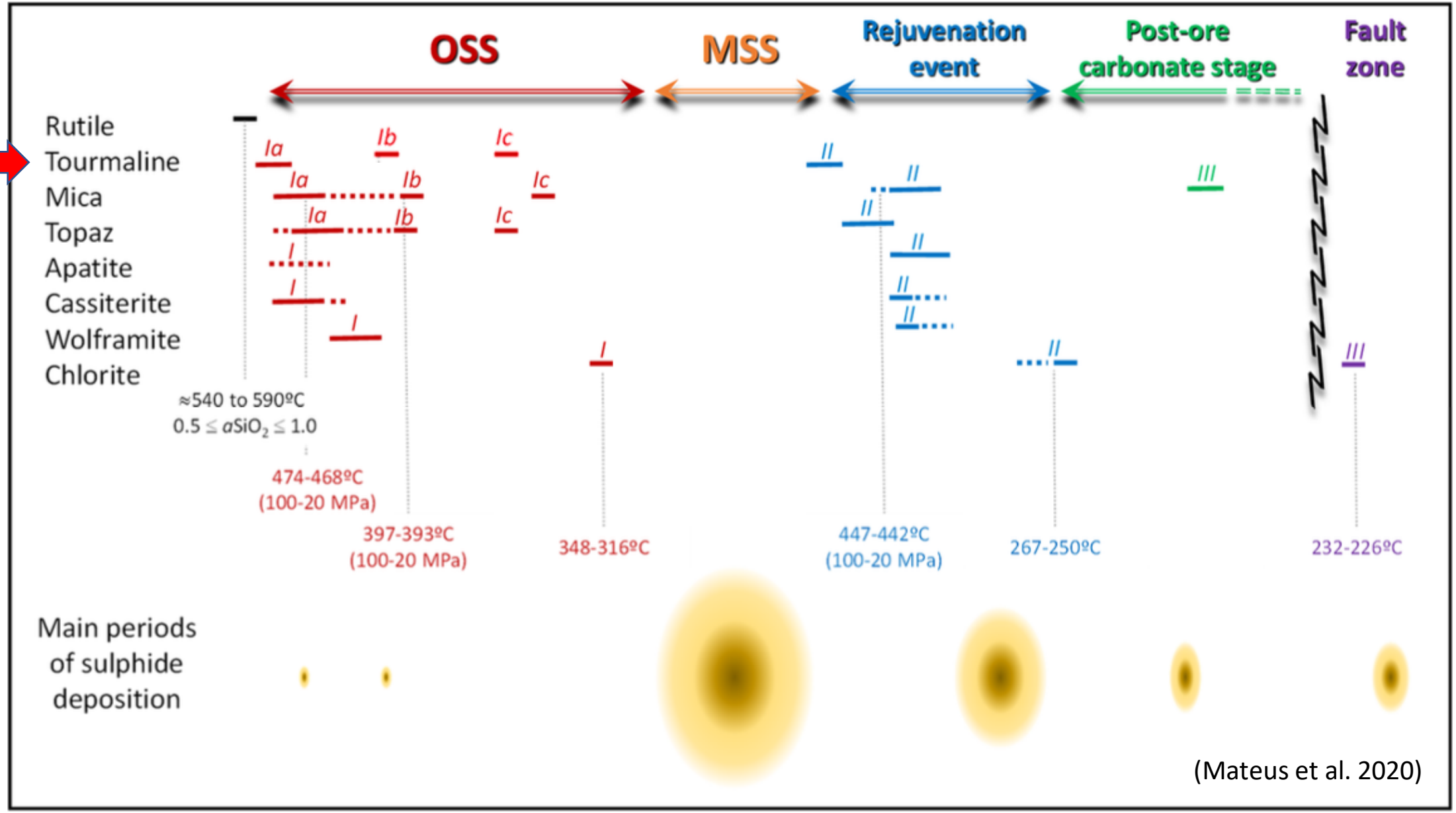
Panasqueira W-Sn-(Cu) deposit



- W quartz veins
- W(Sn) quartz veins
- Sn(W) quartz veins
- Sn greisen

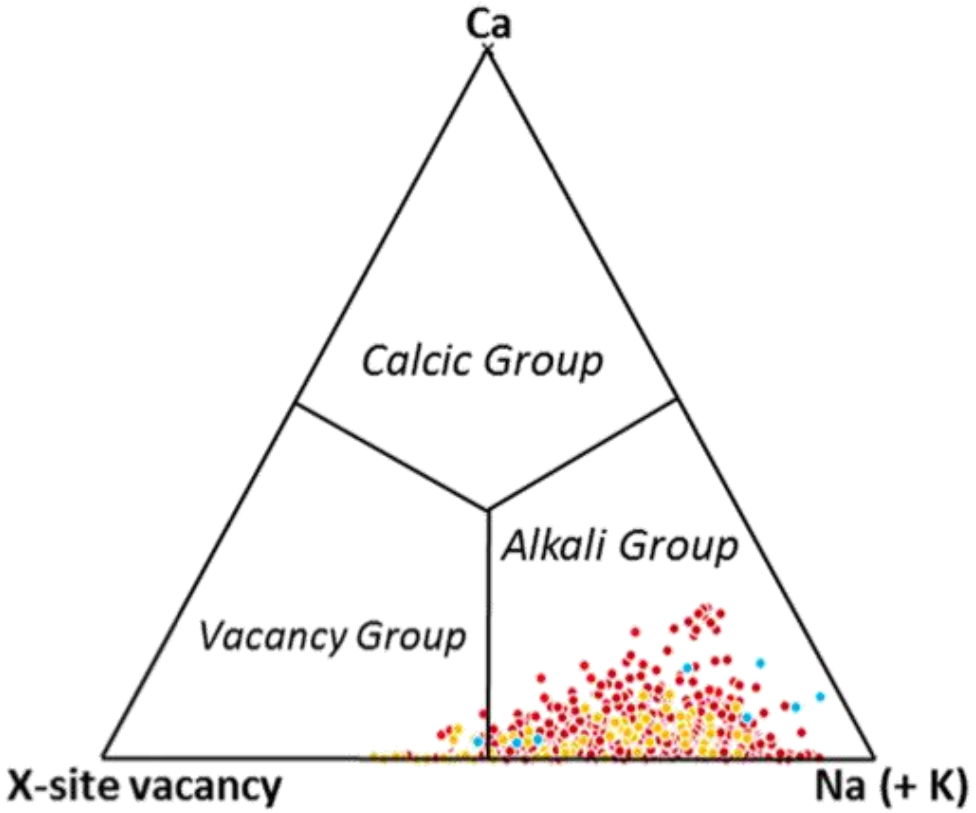


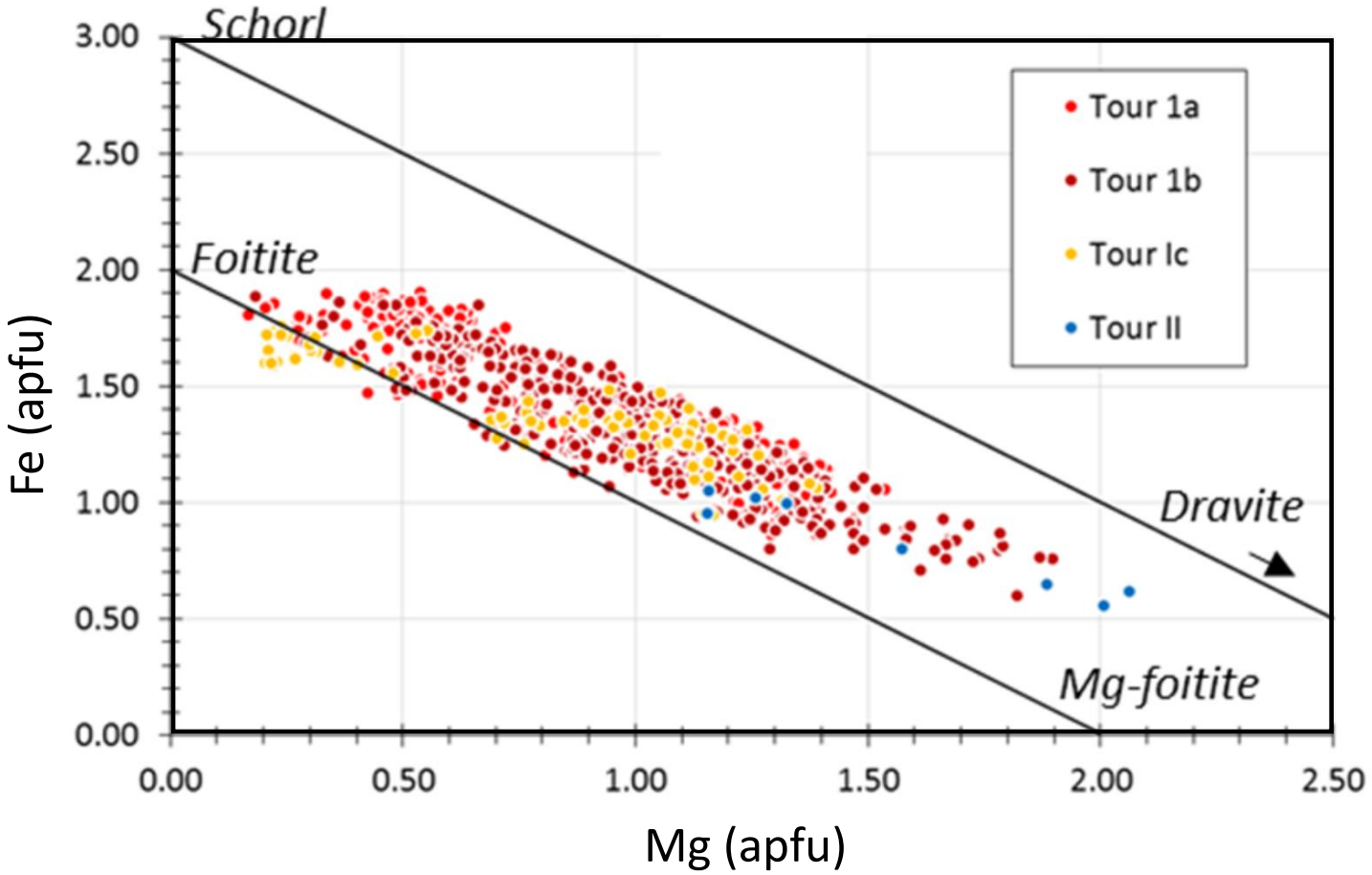
Simplified paragenitic sequence of Panasqueira deposit



(Mateus et al. 2020)

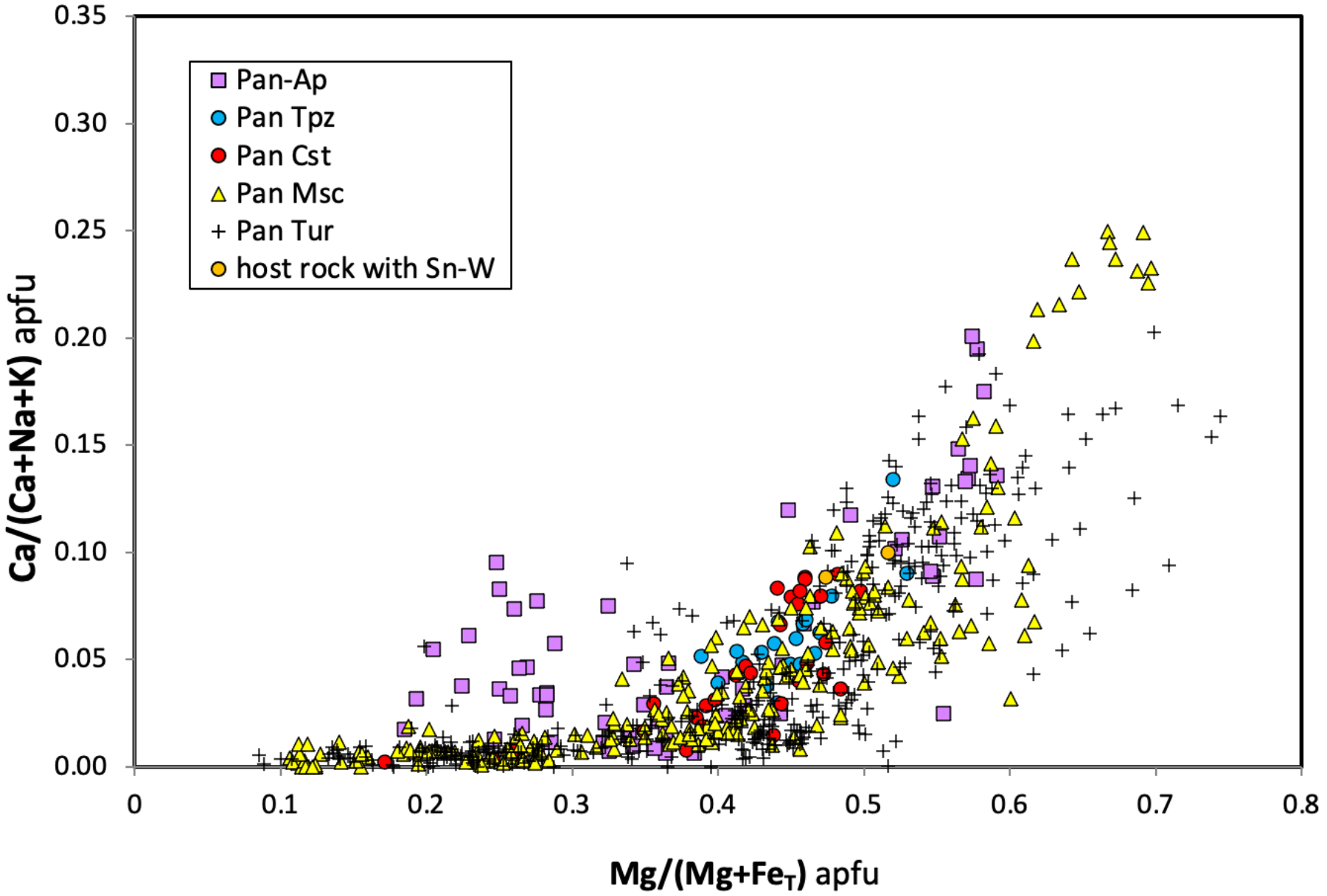
Panasqueira tourmaline



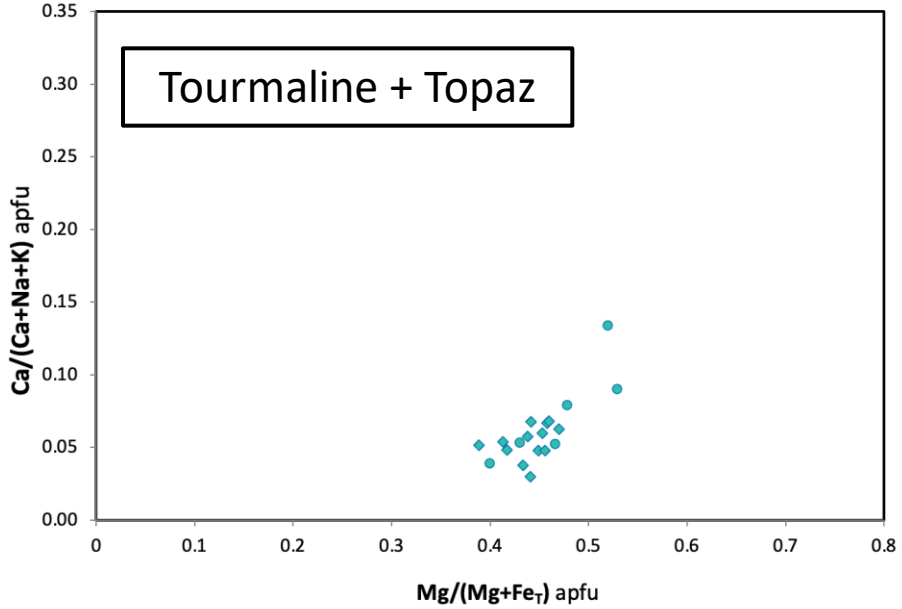


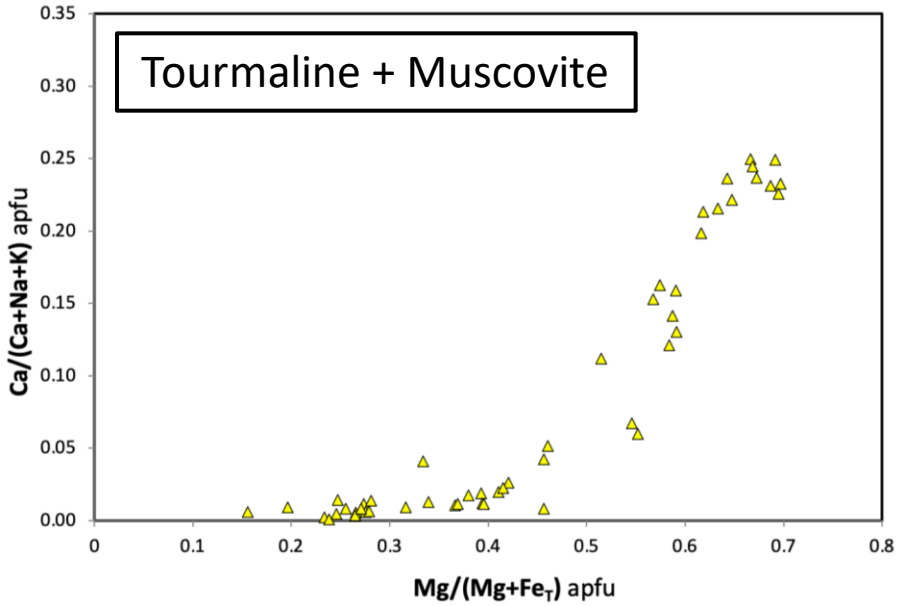
(Mateus et al. 2020)

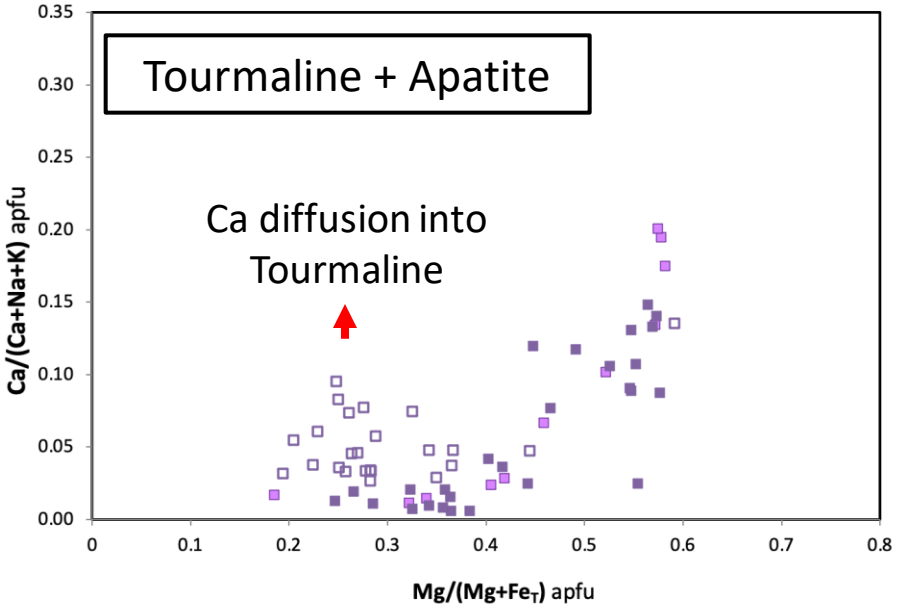
Panasqueira tourmaline

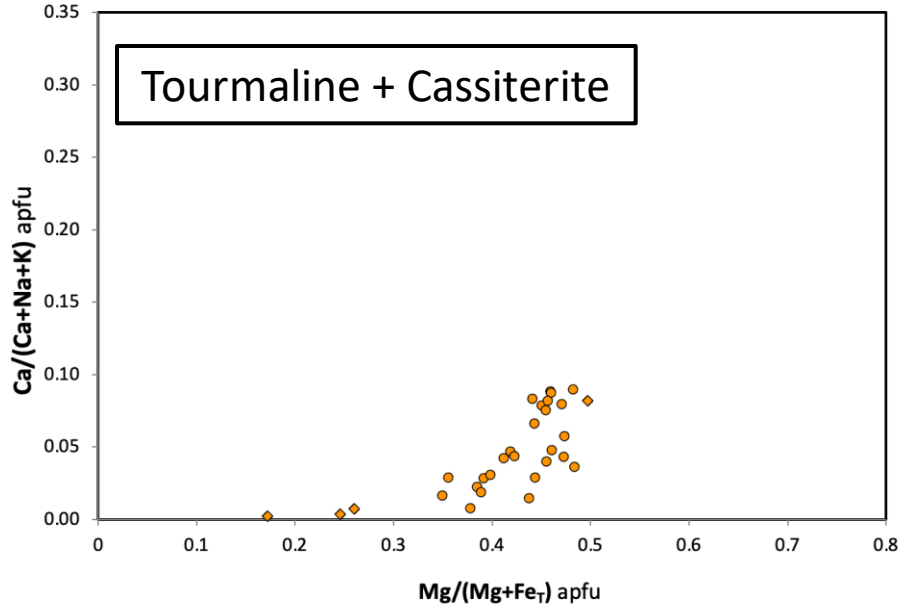


Panasqueira tourmaline

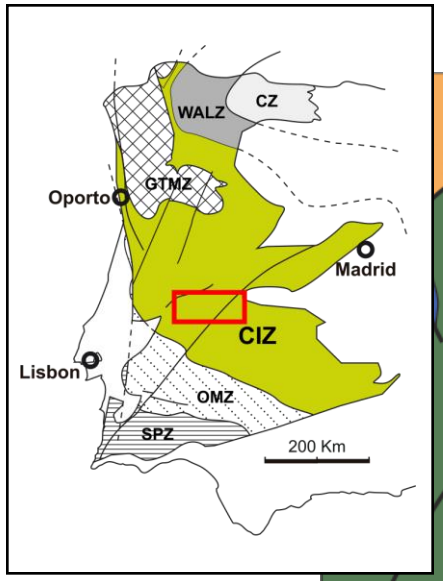


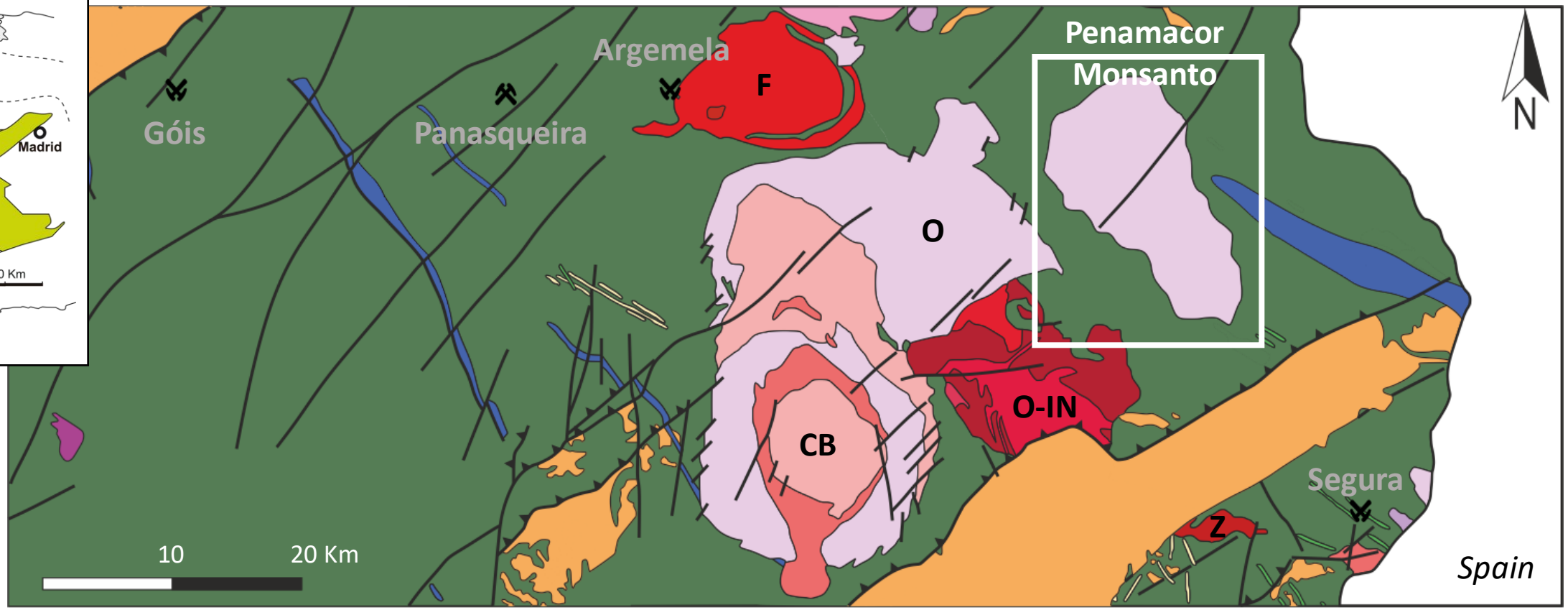






Góis-Panasqueira-Segura Sn-W belt (Central Portugal)





Variscan Granites

Ordovician Granites

Cadomian Granites

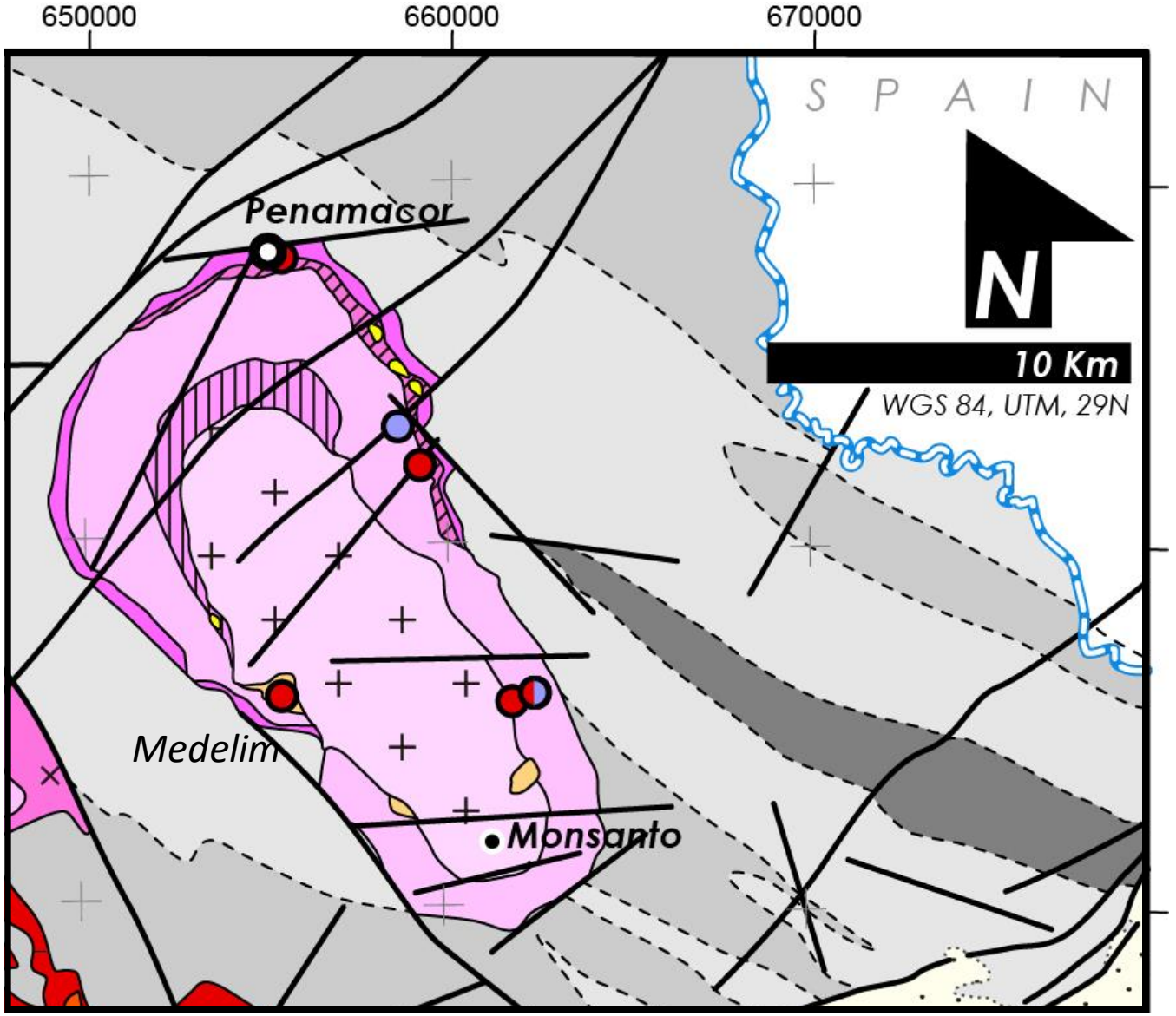
Ordovician Metasediments

Ante-Ordovician Metasediments (Beiras Group)

Tertiary deposits

(MOSTMEG 2020)

Penamacor-Monsanto-Medelim



Variscan

Penamacor-Monsanto

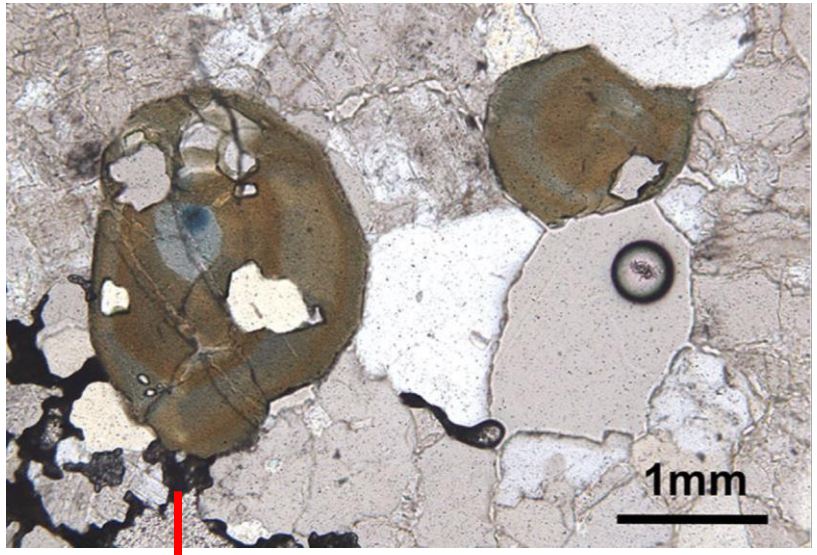
- $G_{PM}1$: Medium- to coarse-grained muscovite-biotite granite
- $G_{PM}2$: Medium-grained muscovite-biotite granite
- $G_{PM}3$: Coarse- to medium-grained porphyritic biotite-muscovite granite
- $G_{PM}4$: Medium-grained porphyritic biotite-muscovite granite
- $G_{PM}5$: Coarse-grained porphyritic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

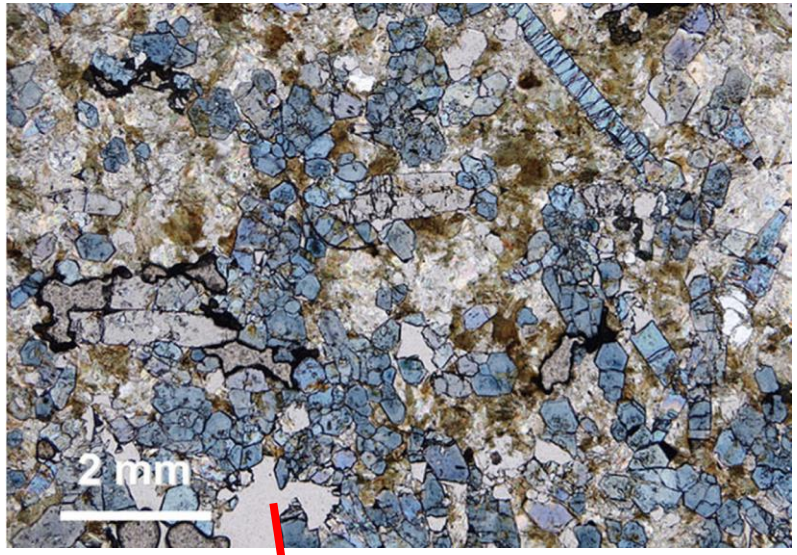
(MOSTMEG 2022)

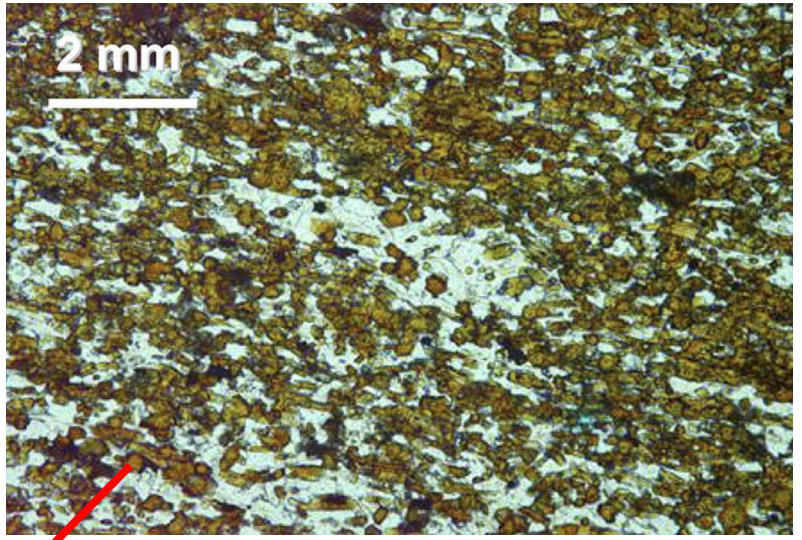
Granite

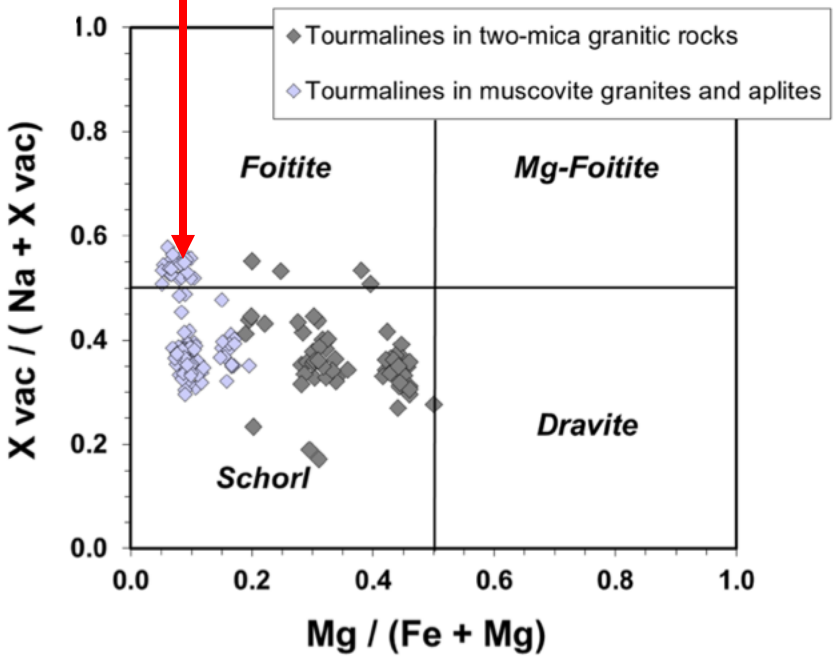
Qz vein/breccia

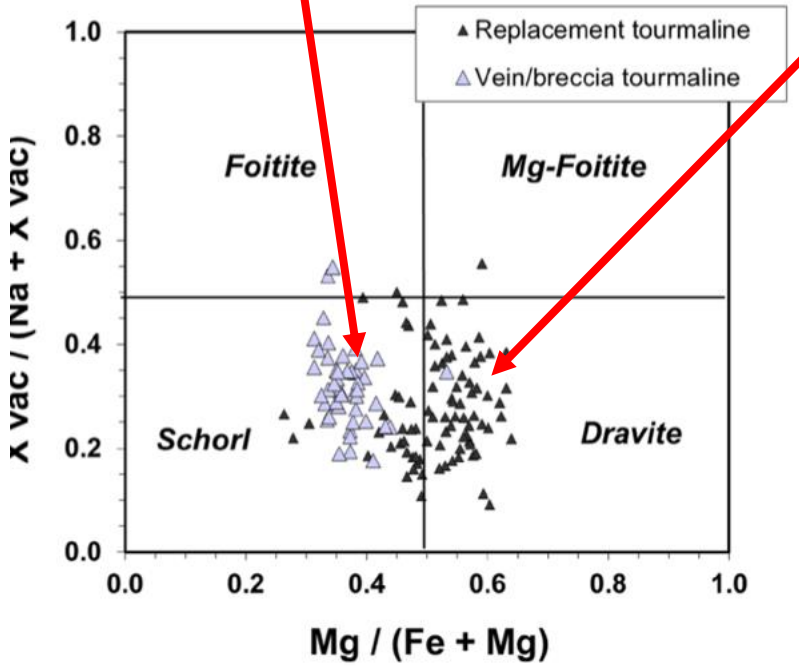
Tourmalinite

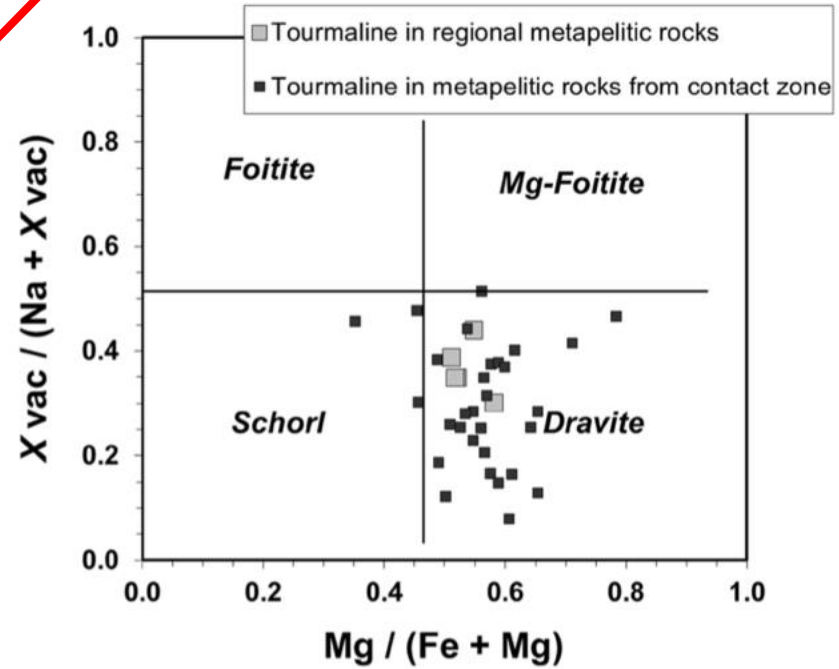






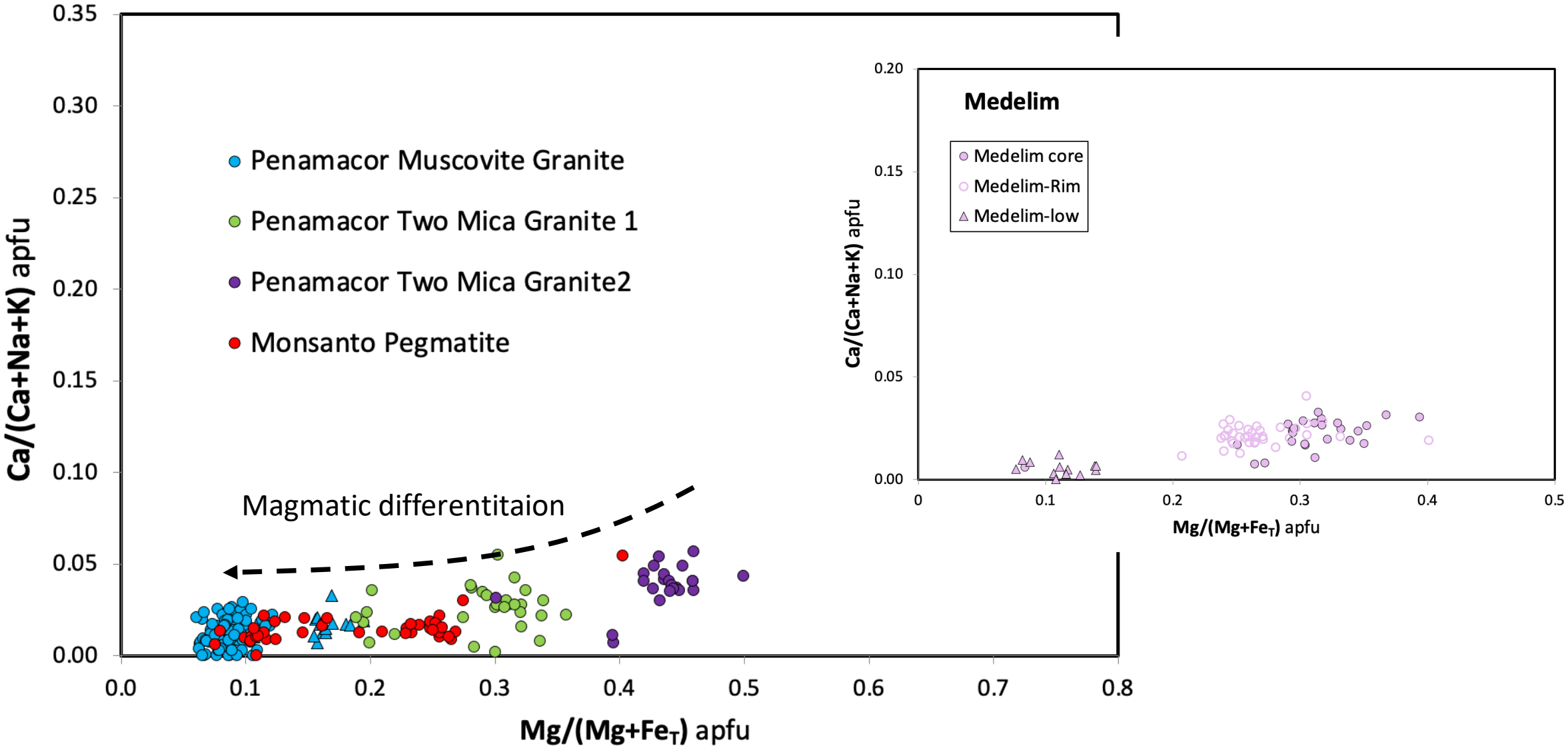




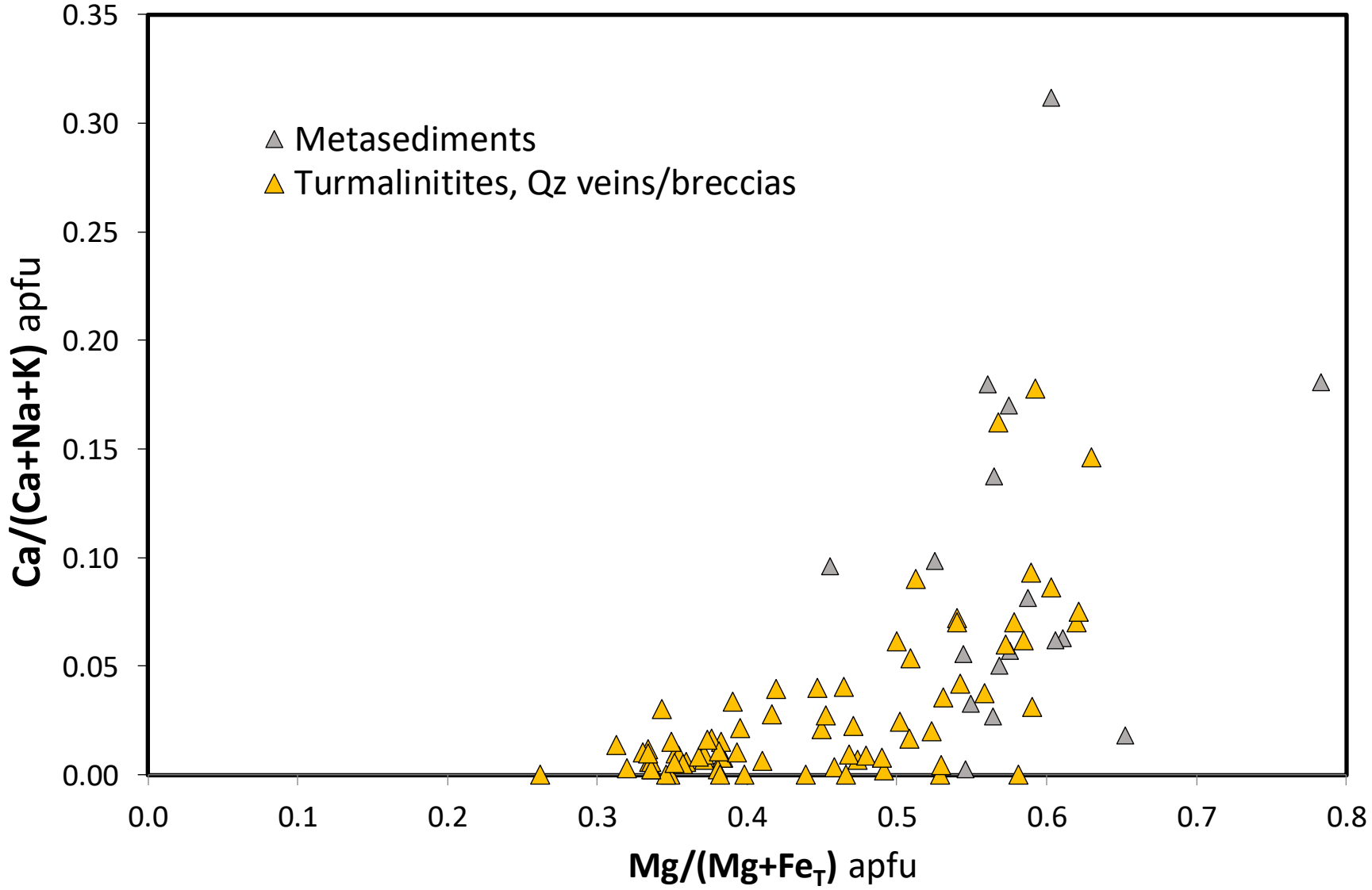


(Ribeiro da Costa et al. 2014)

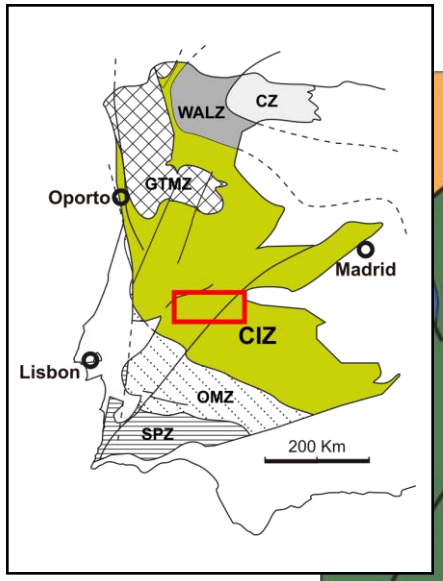
Tourmaline from magmatic rocks

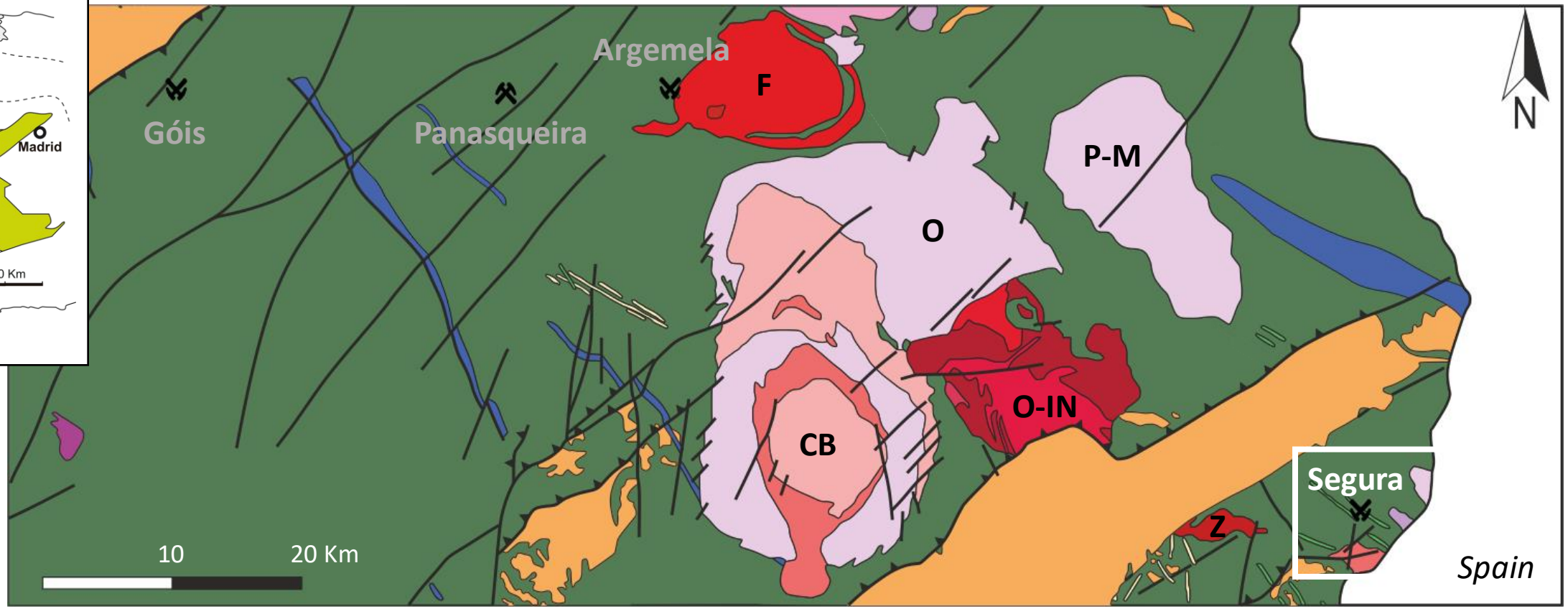


Tourmaline from metasediments, toumalinite & breccias



Góis-Panasqueira-Segura Sn-W belt (Central Portugal)





Variscan Granites

Ordovician Granites

Cadomian Granites

Ordovician Metasediments

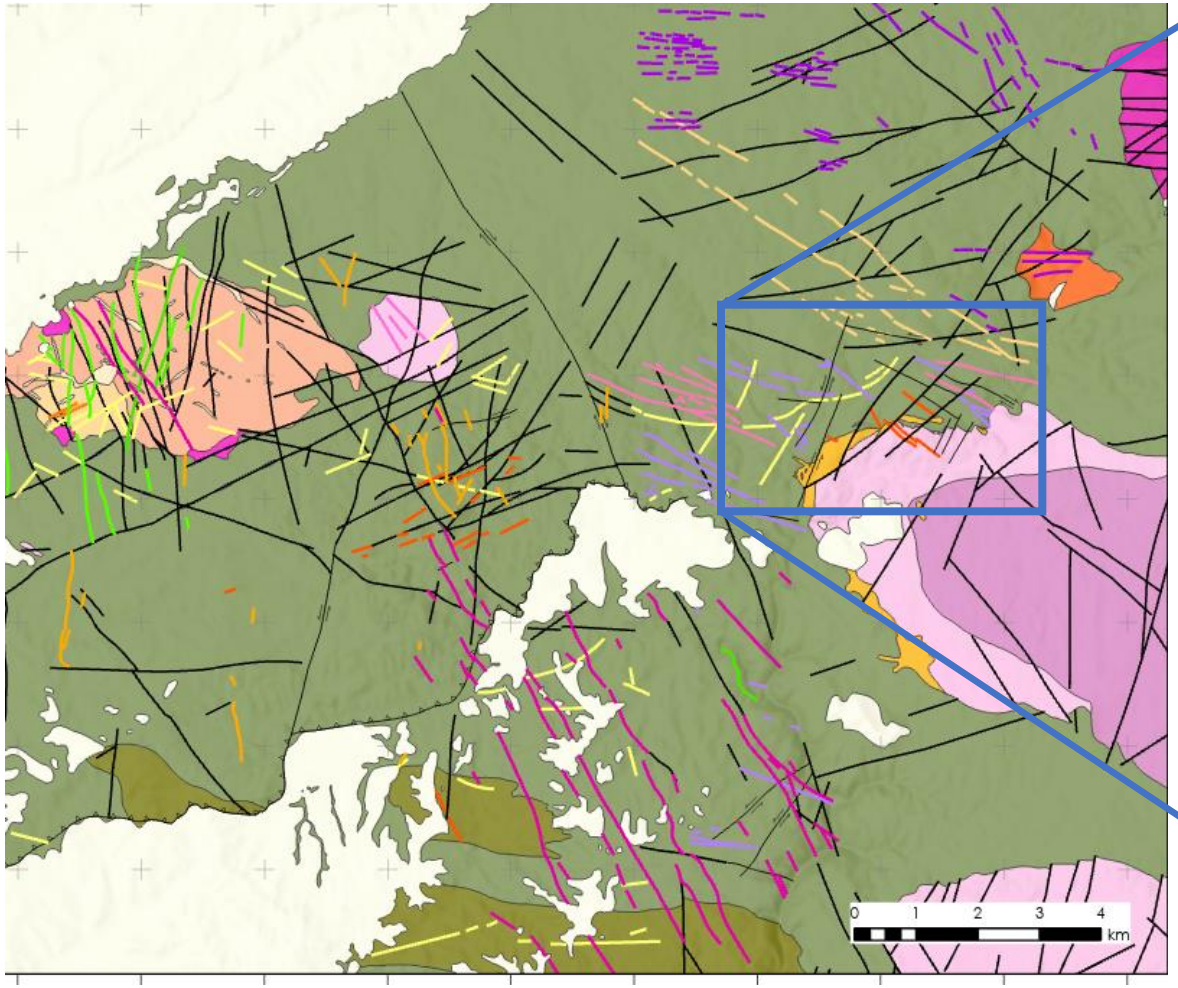
Ante-Ordovician Metasediments (Beiras Group)

Tertiary deposits

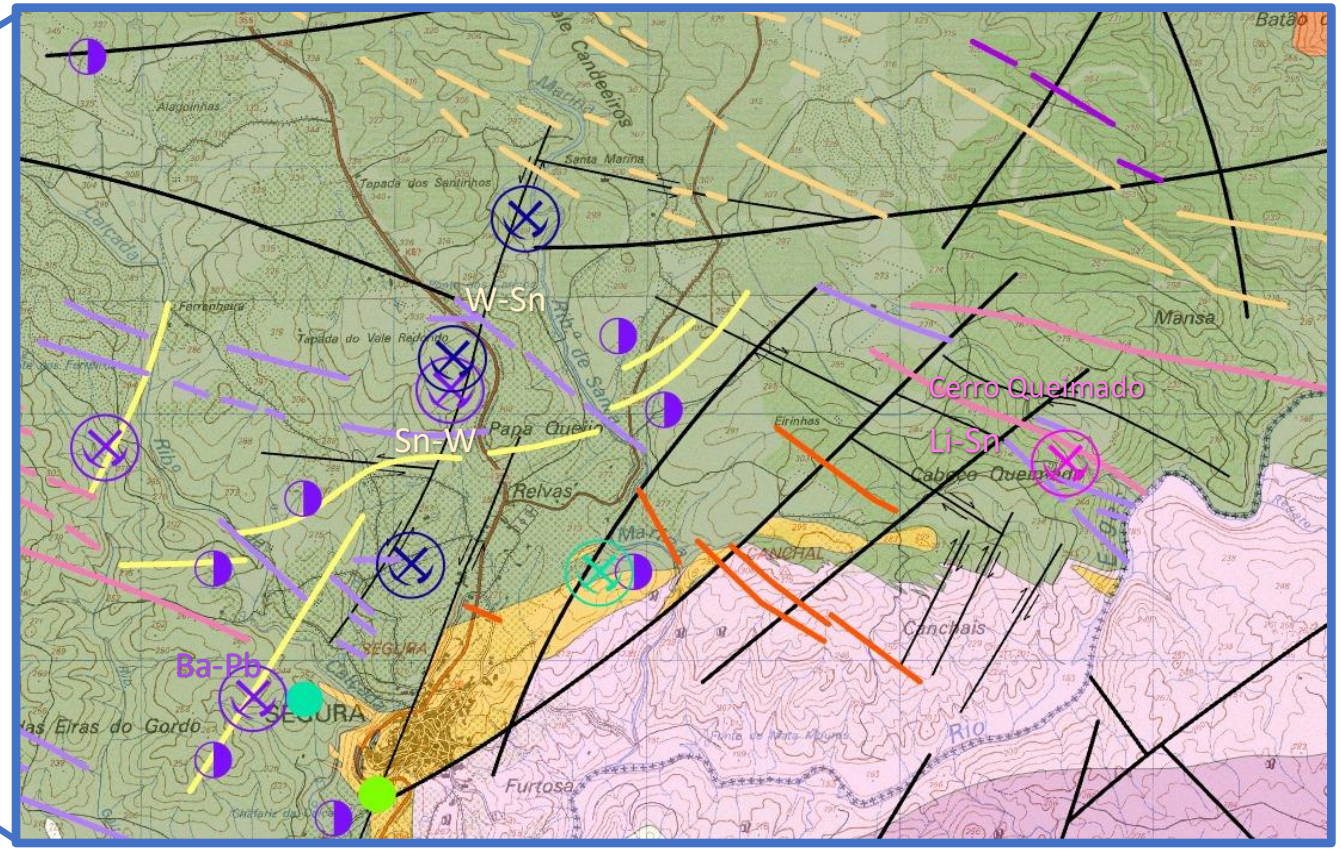
(MOSTMEG 2020)

Segura-Zebreira-Salvaterra do Extremo

New data (MOSTMEG)



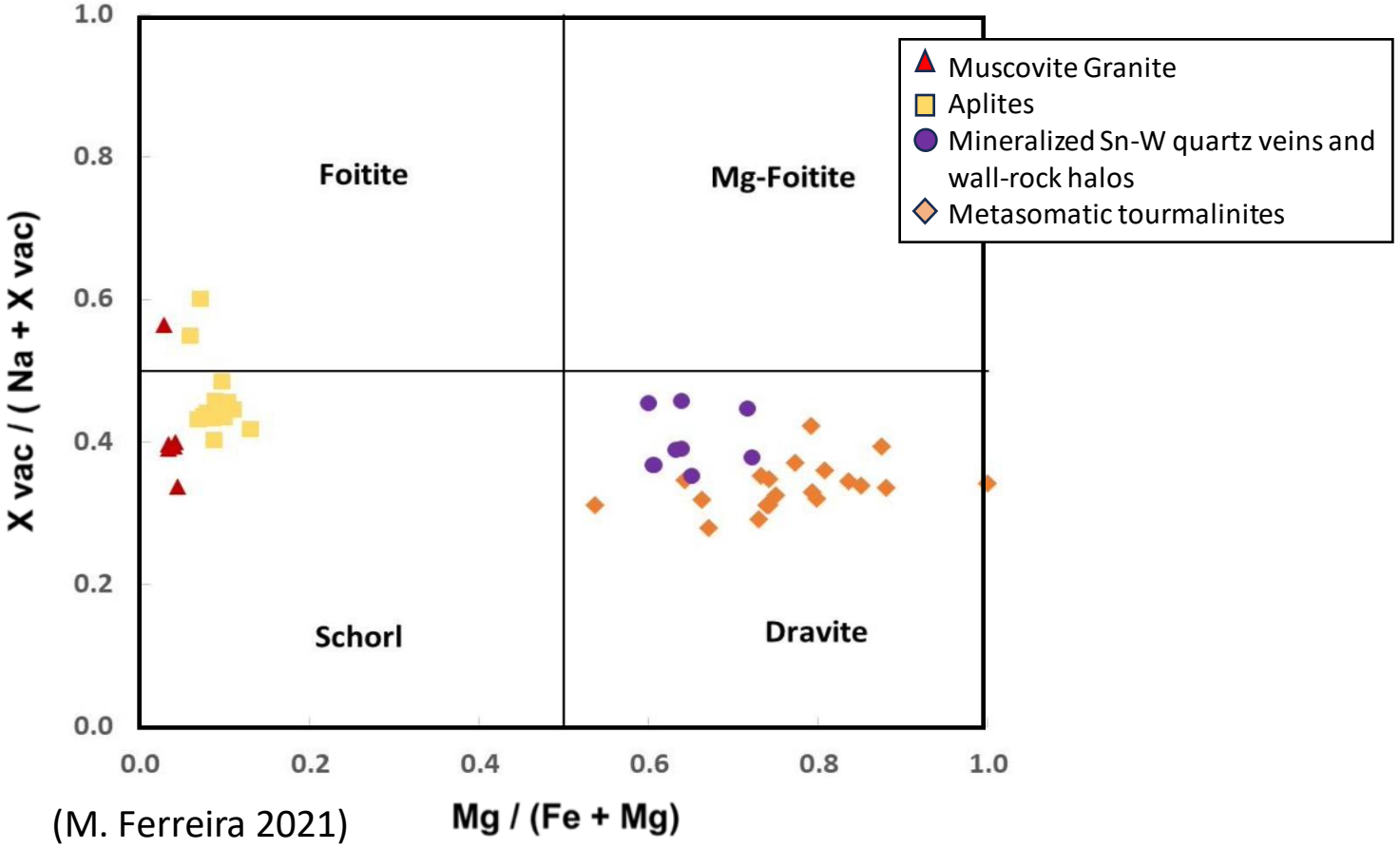
(MOSTMEG 2023)



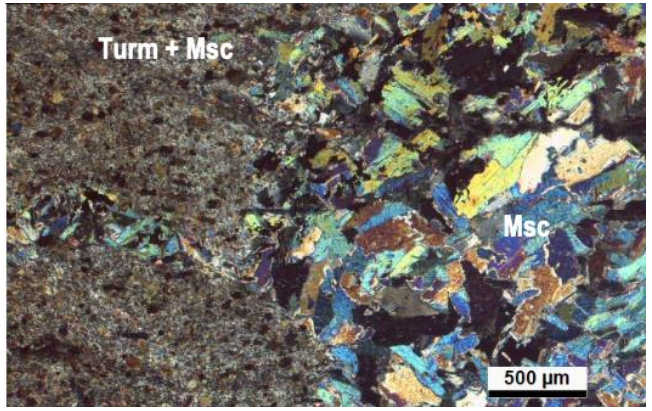
(MOSTMEG 2023)

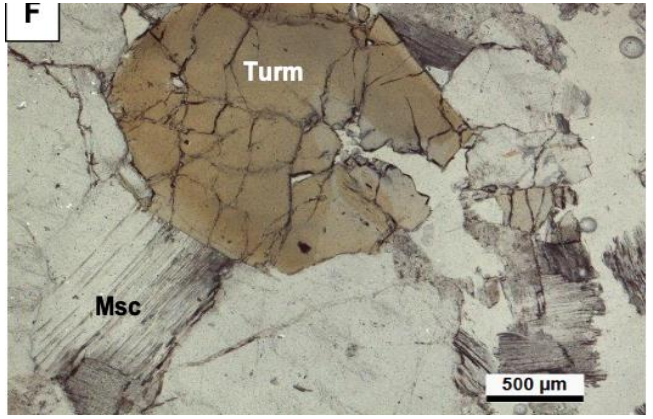
Segura

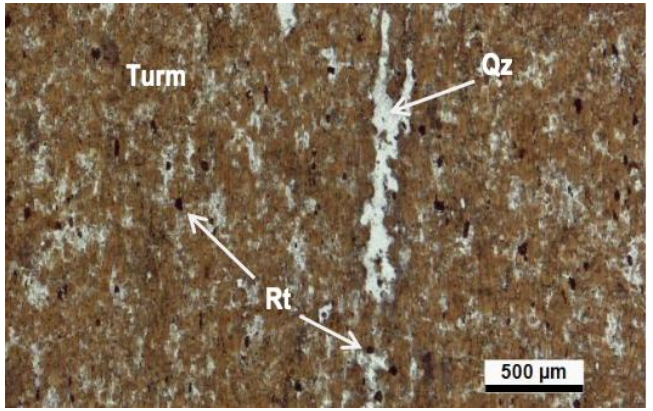
Sub-horizontal Sn-W quartz vein system similar to Panasqueira



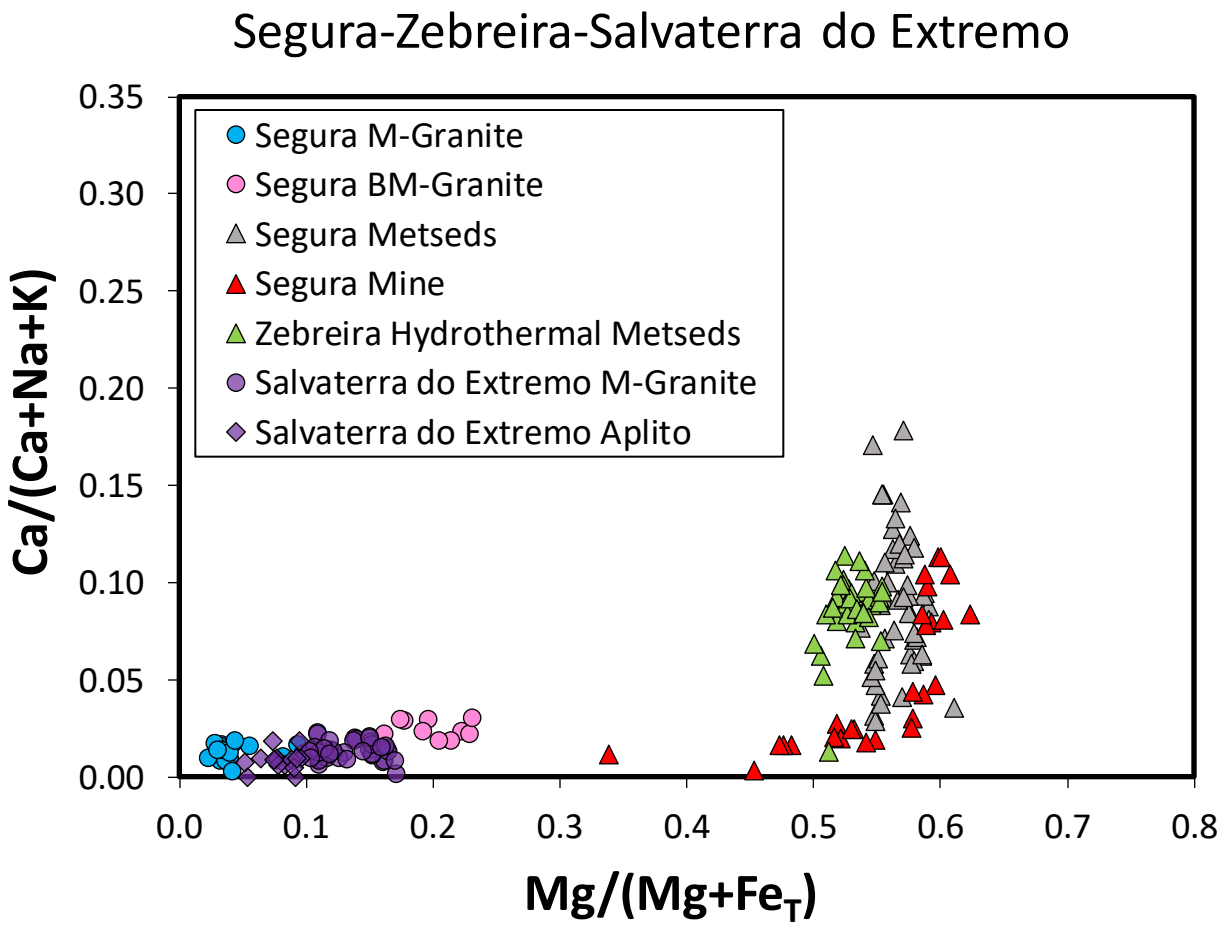
(M. Ferreira 2021)

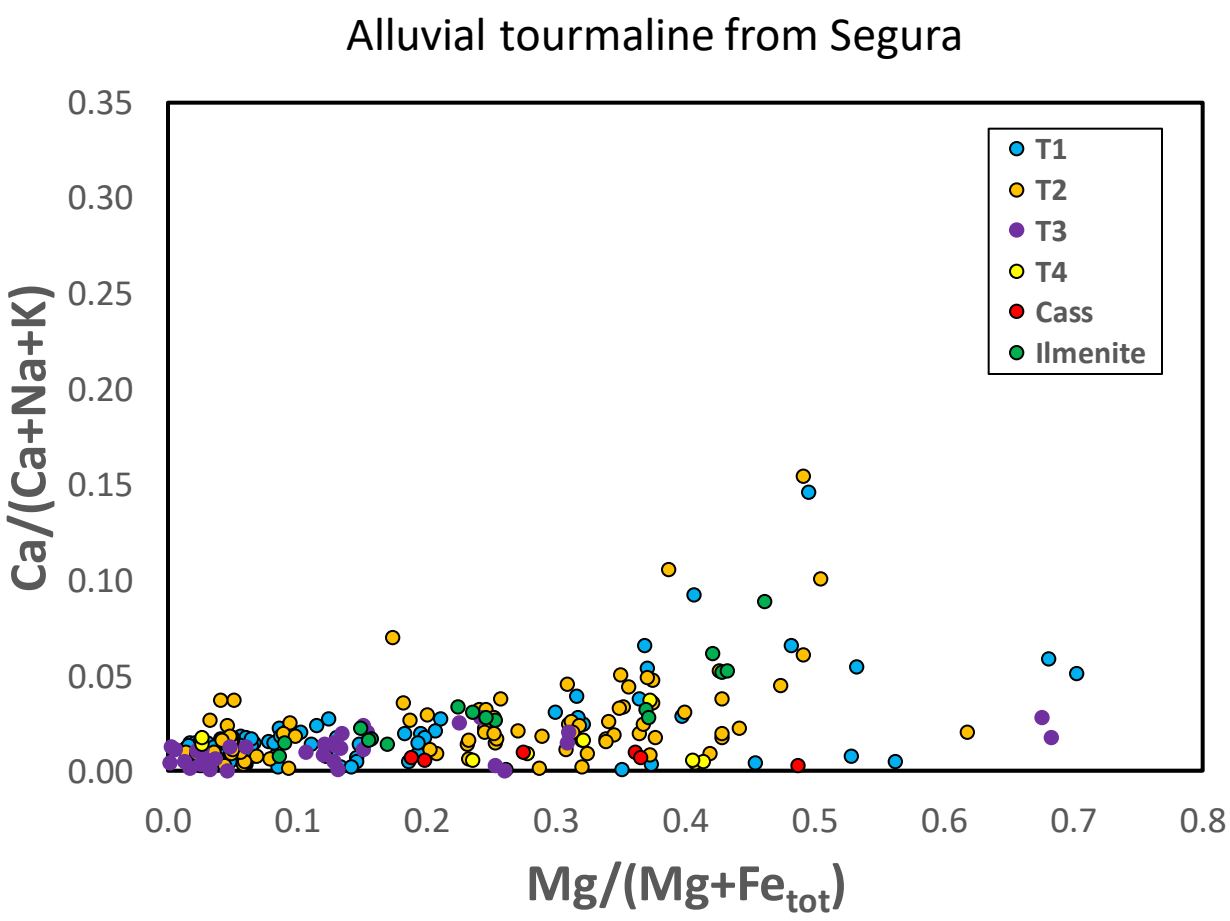




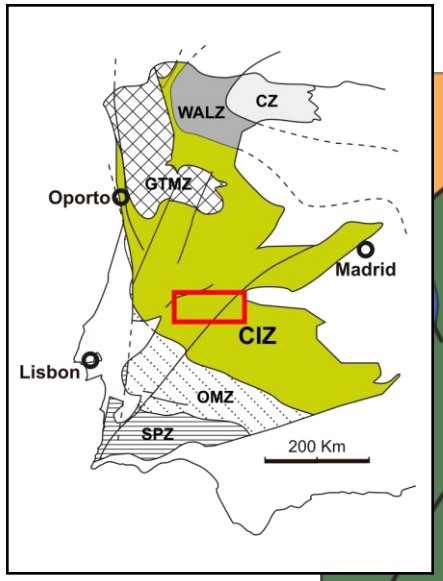


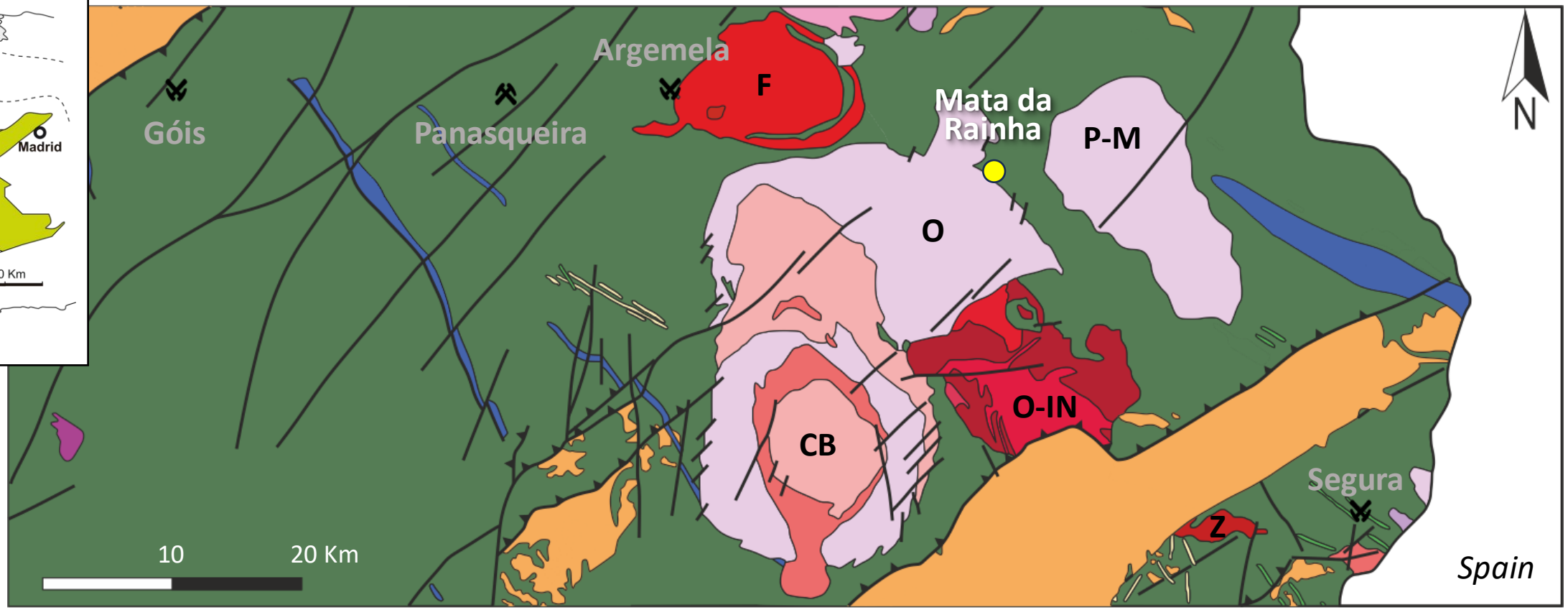
Segura-Zebreira-Salvaterra do Extremo





Góis-Panasqueira-Segura Sn-W belt (Central Portugal)





Variscan Granites

Ordovician Granites

Cadomian Granites

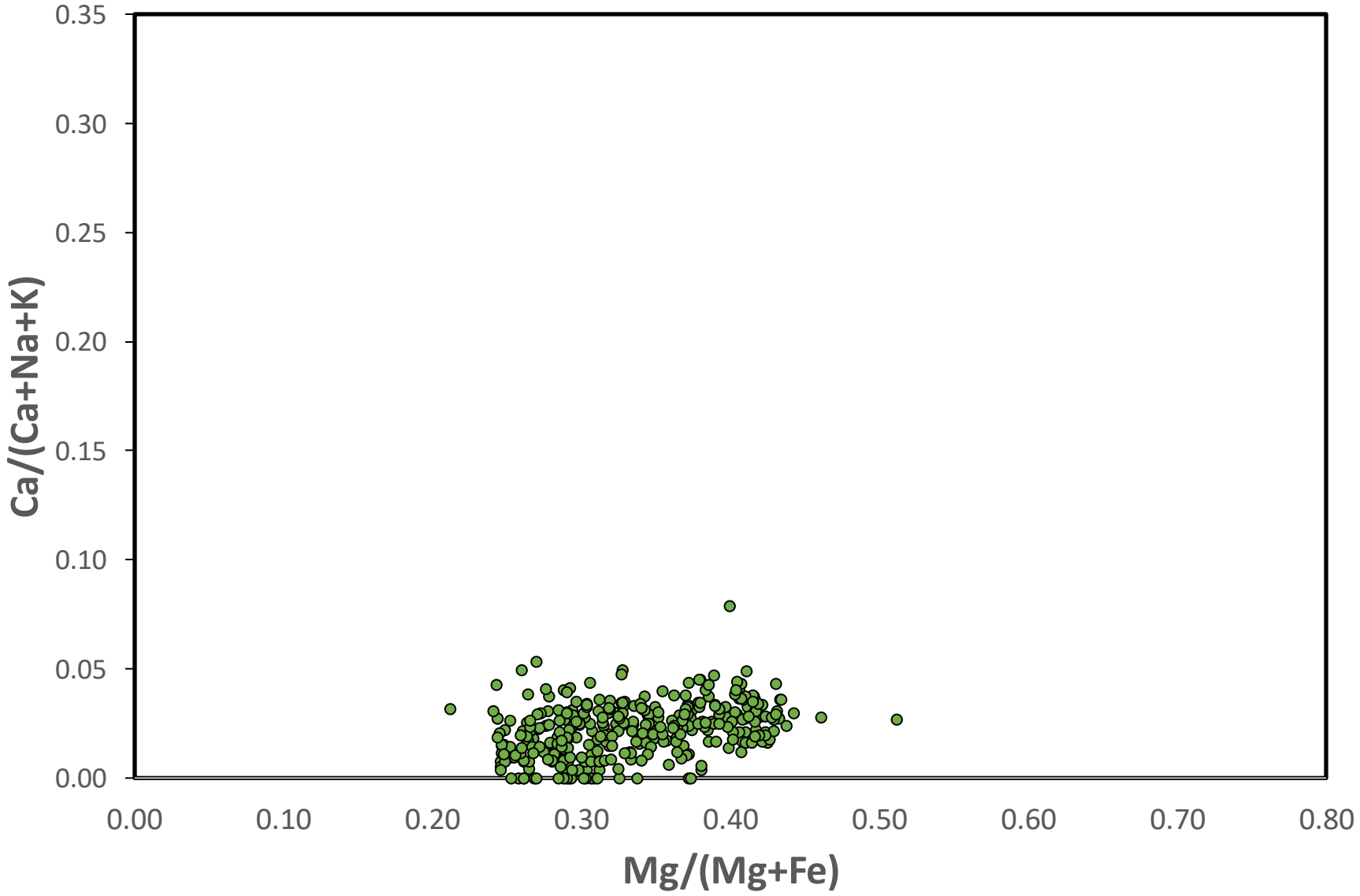
Ordovician Metasediments

Ante-Ordovician Metasediments (Beiras Group)

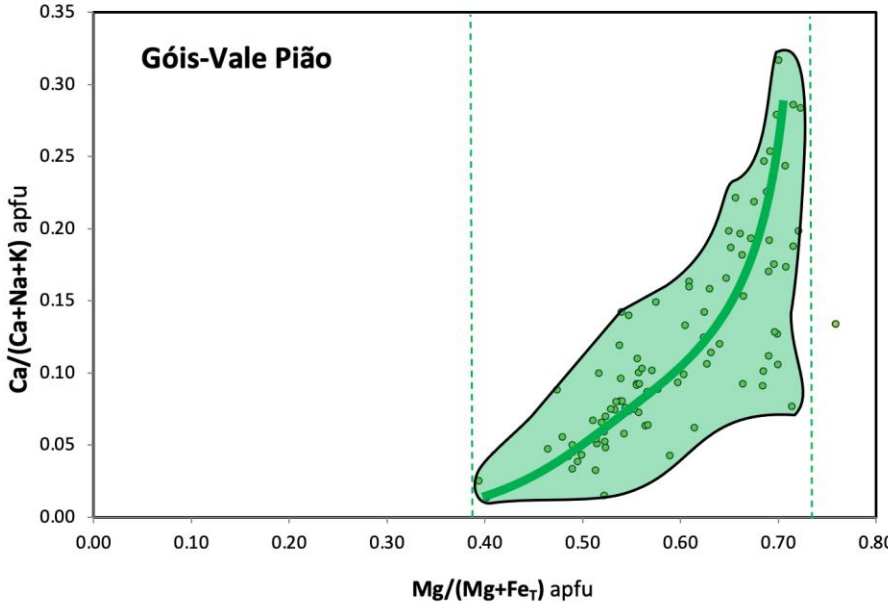
Tertiary deposits

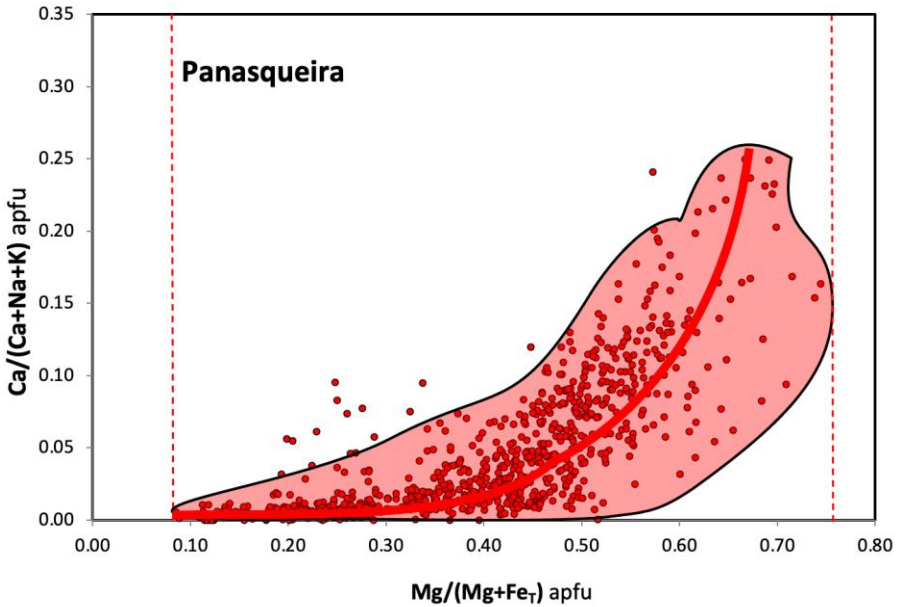
(MOSTMEG 2020)

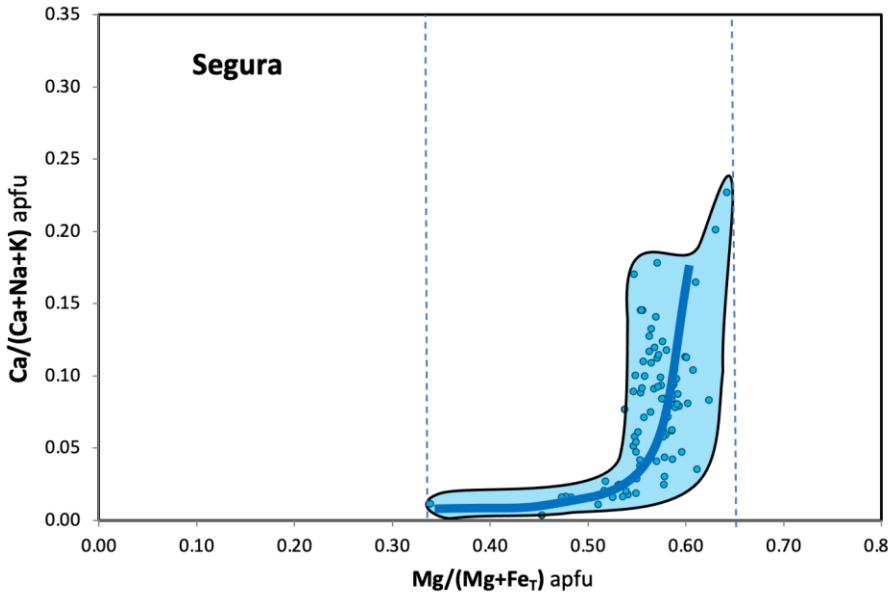
Mata da Rainha

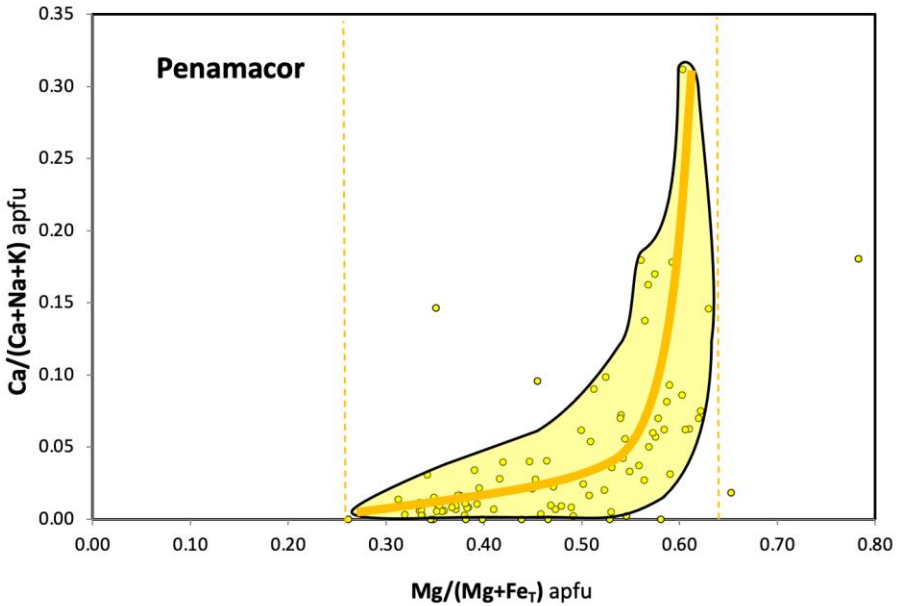


Summarizing

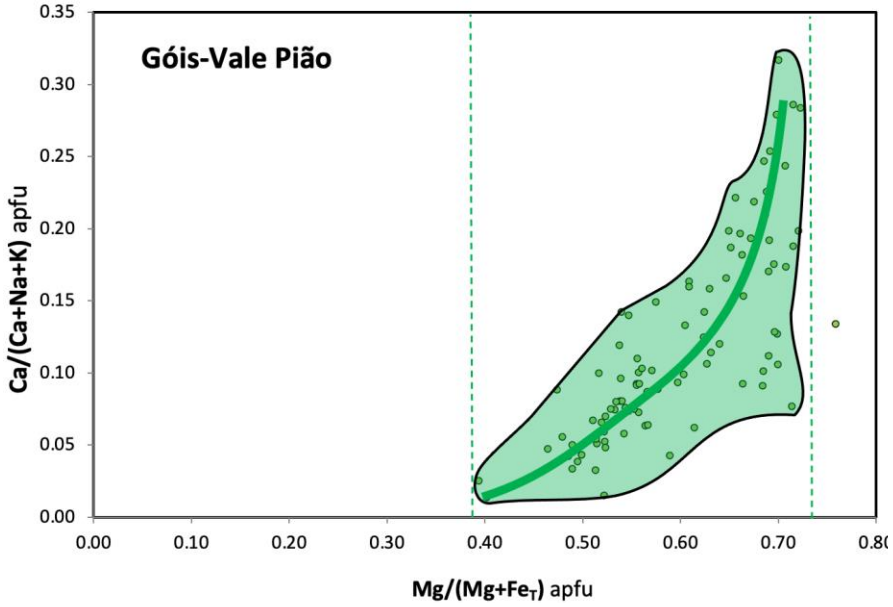


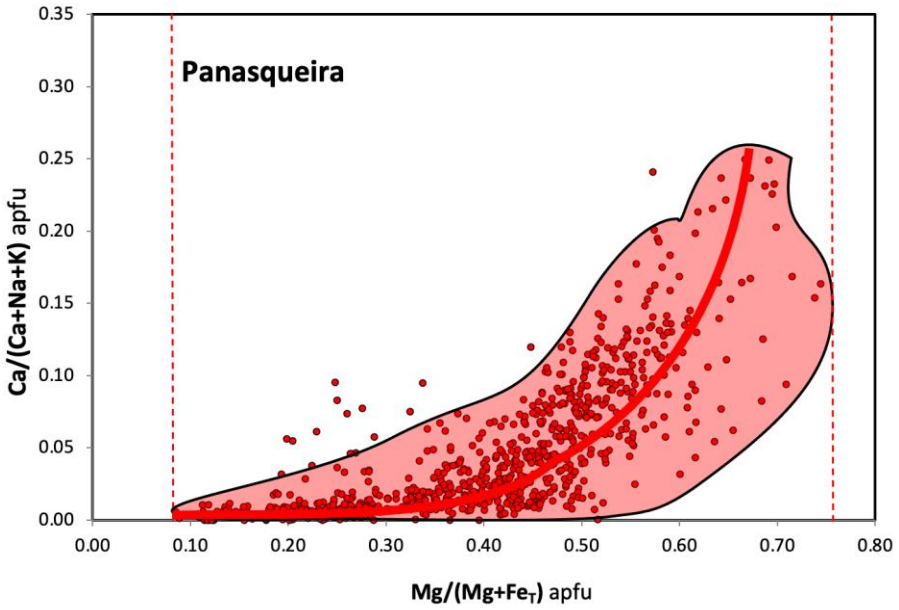


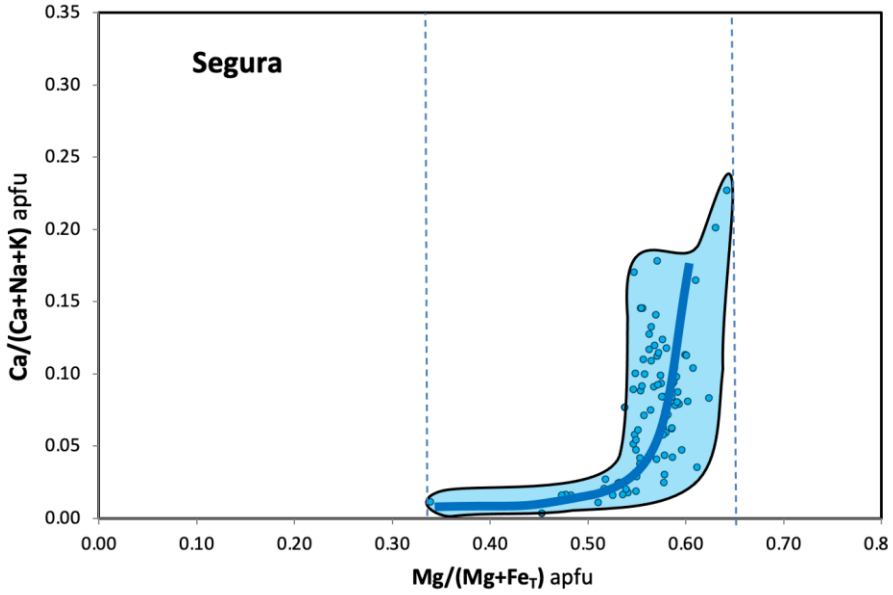


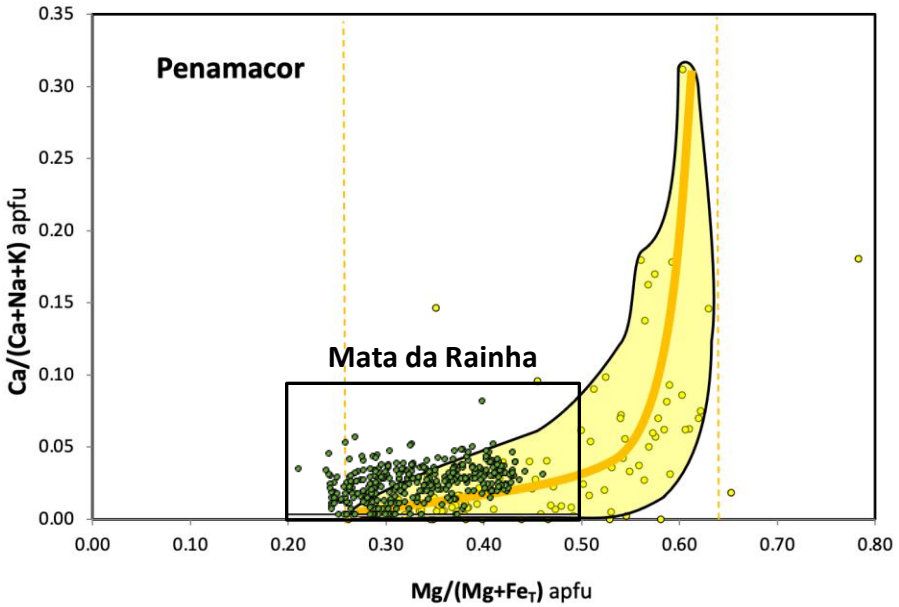


Summarizing

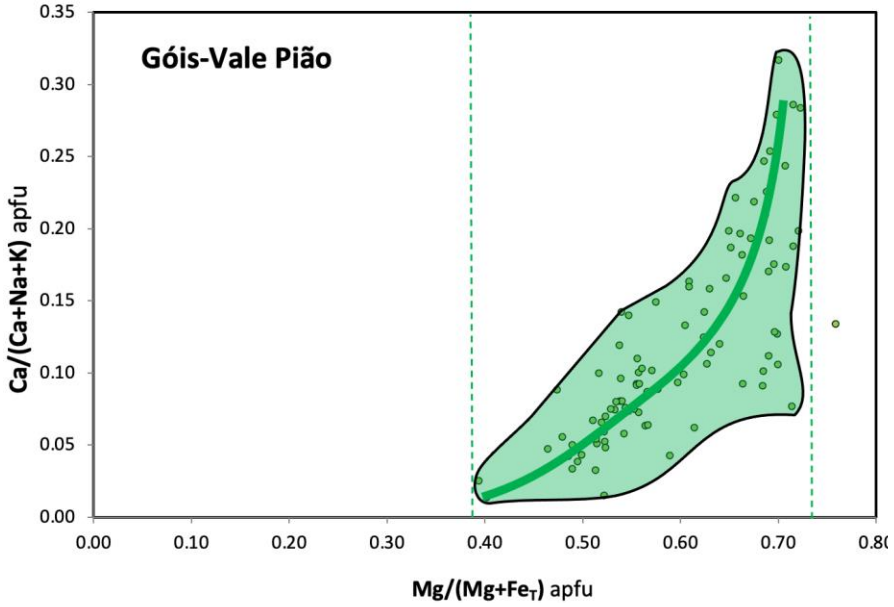


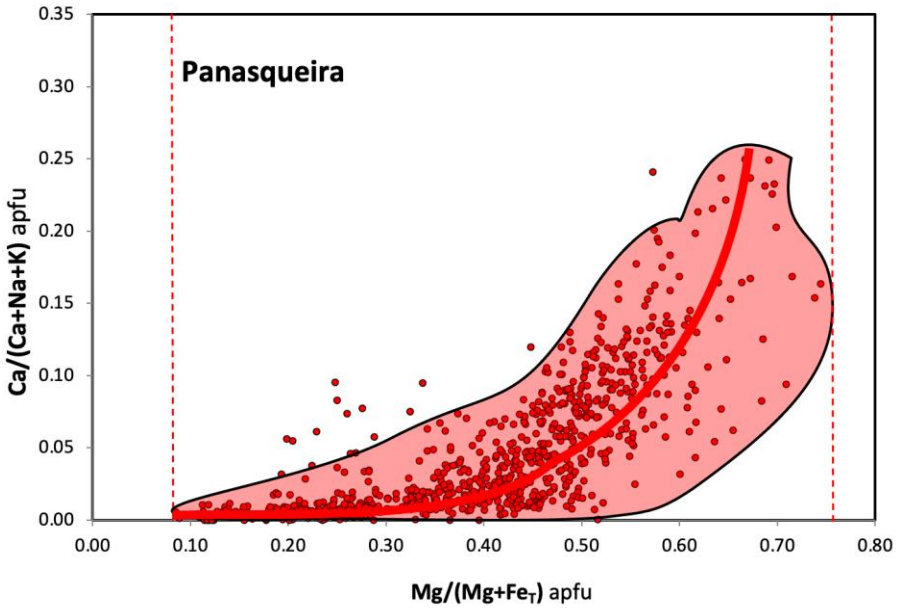


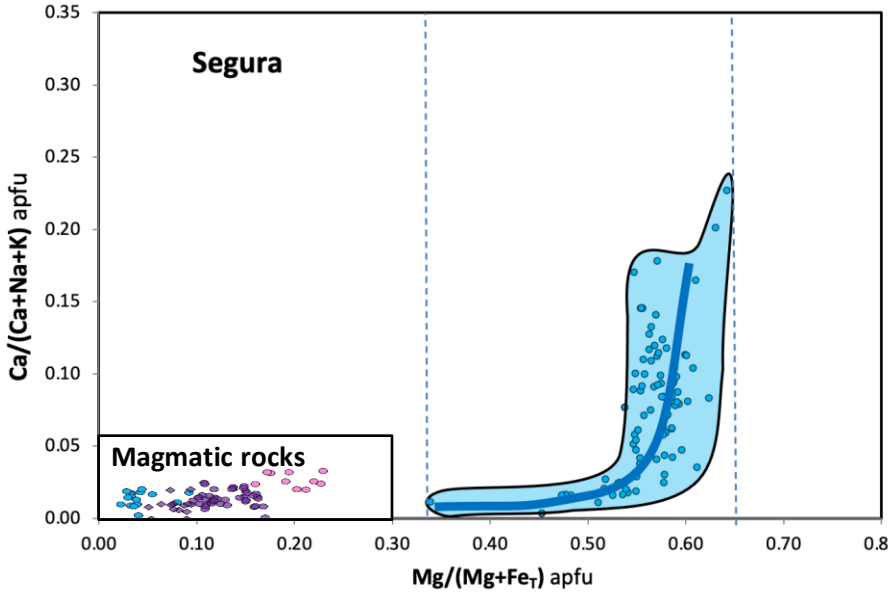


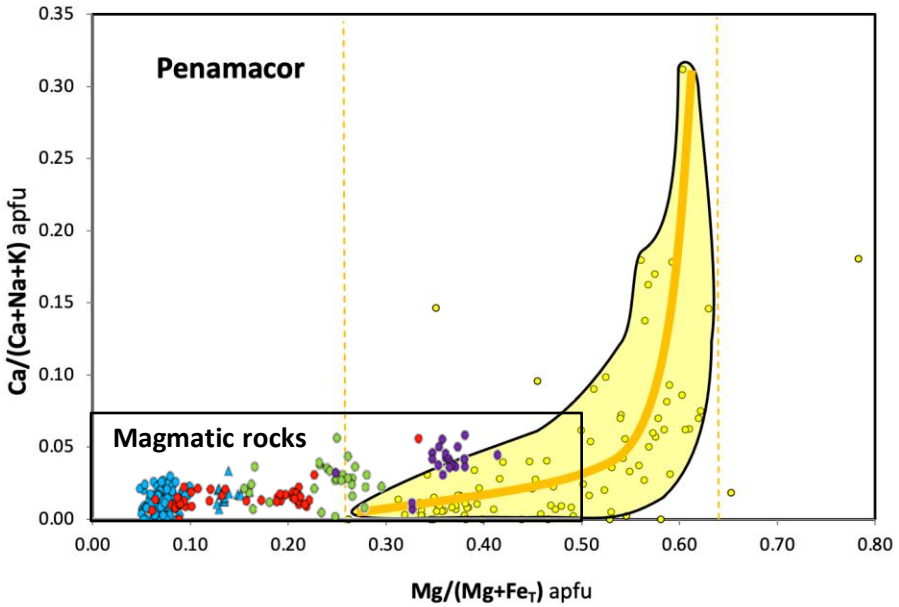


Summarizing

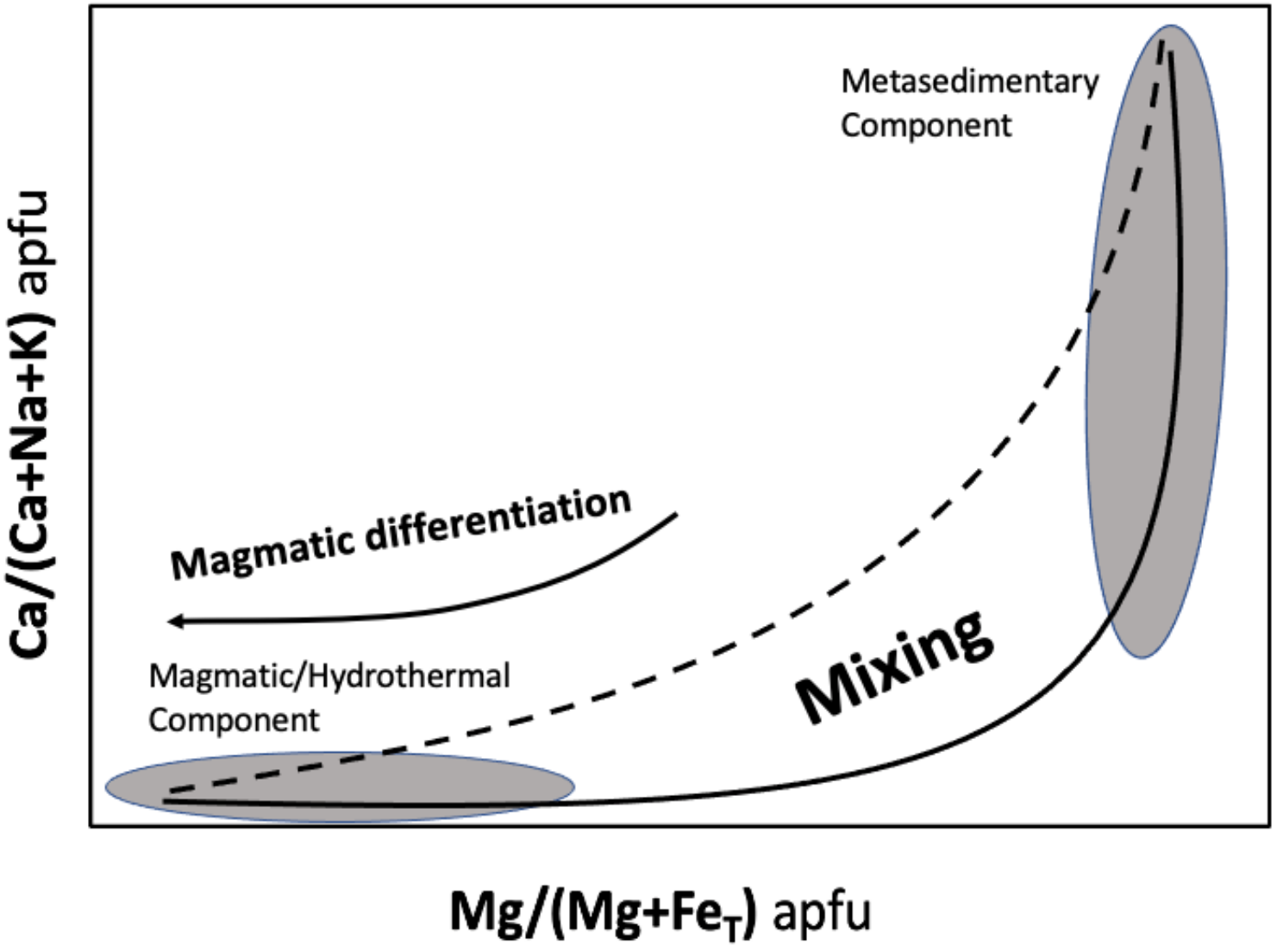








Assessment of Tourmaline Composition as a Vectoring Tool for Sn-W Deposits



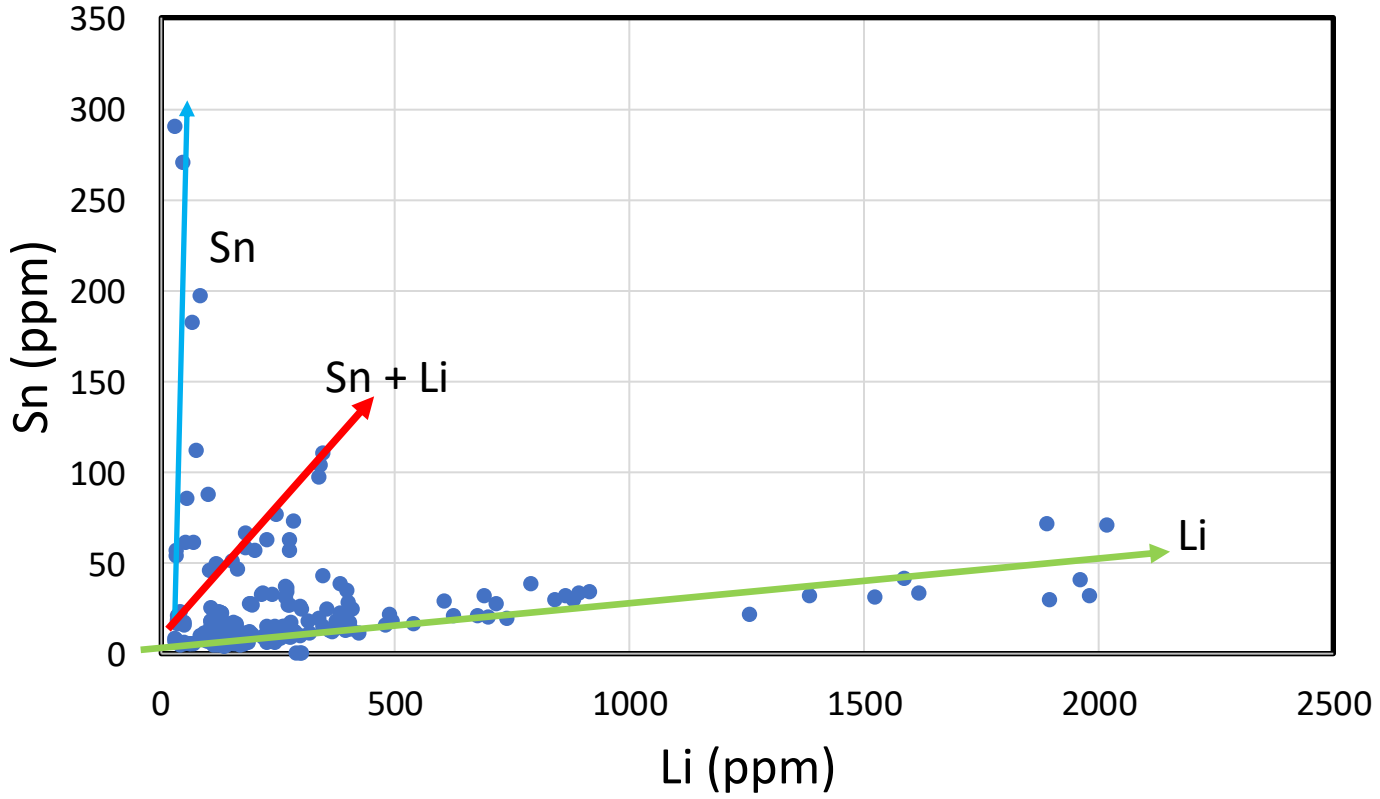
Assessment of Tourmaline Composition as a Vectoring Tool for Sn-W Deposits

What about minor and trace elements?

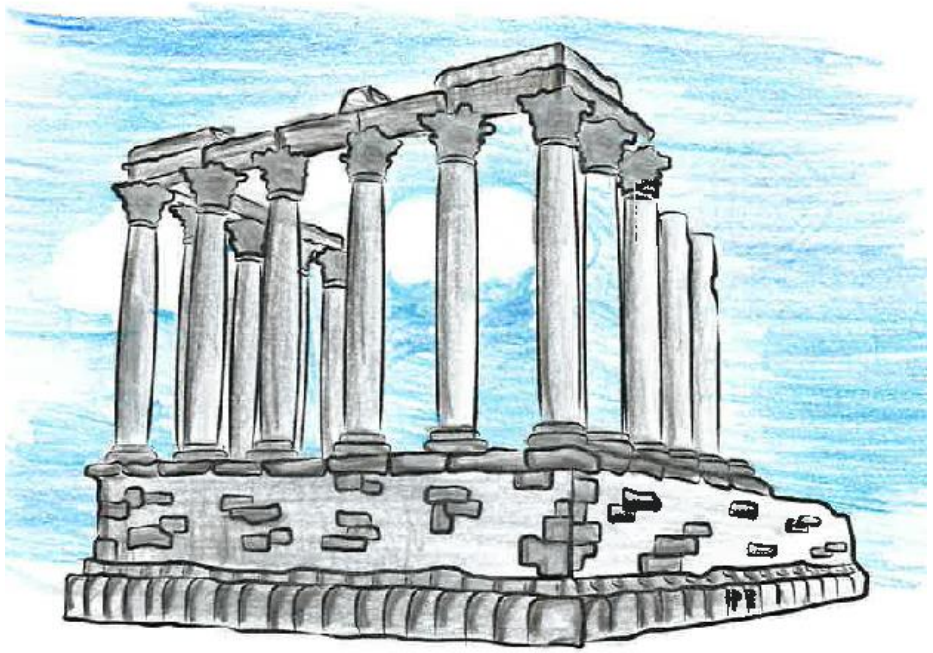
Assessment of Tourmaline Composition as a Vectoring Tool for Sn-W Deposits

What about minor and trace elements?

Alluvial Tourmaline from Segura (LA-ICPMS)

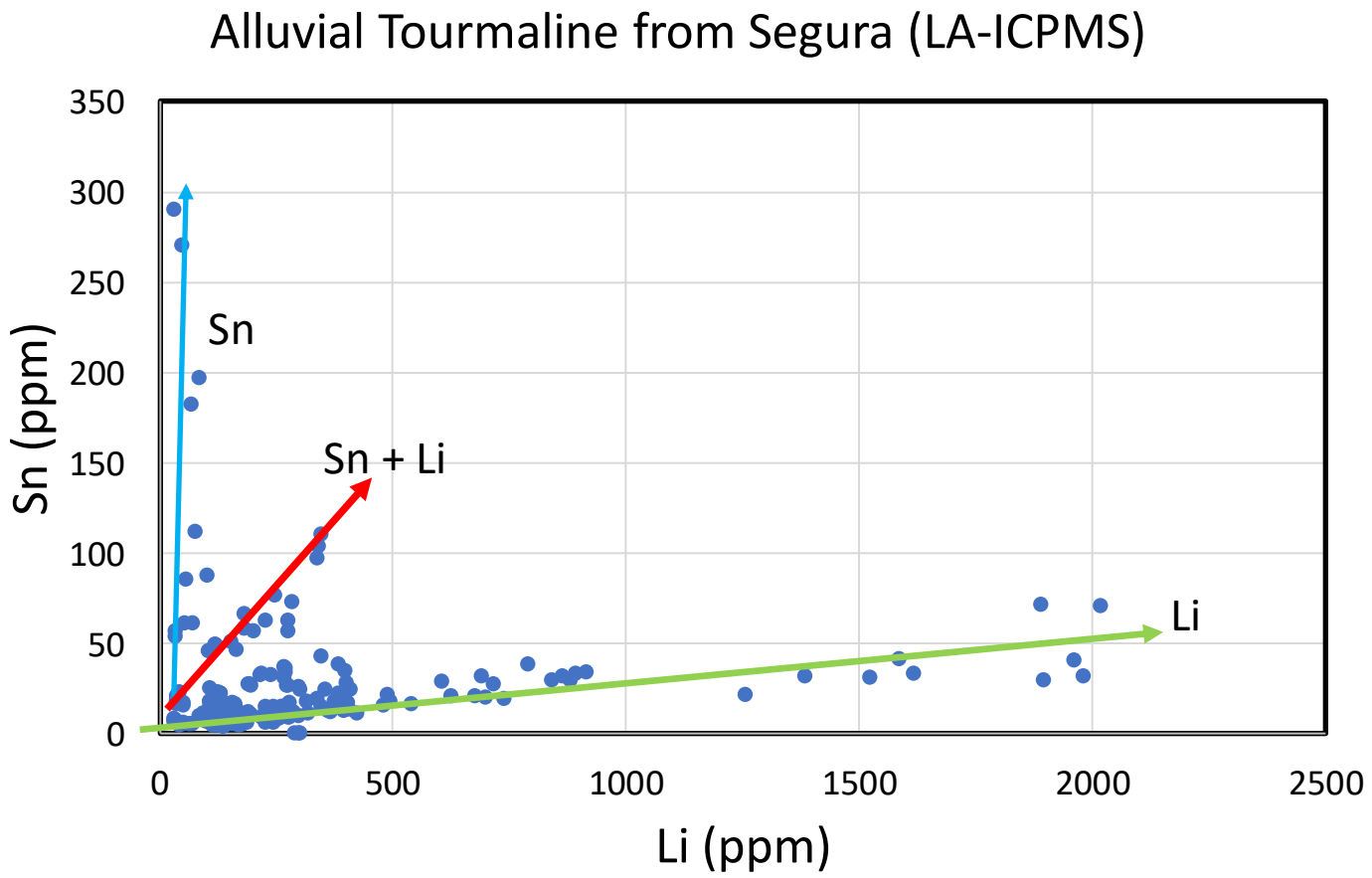


Comeback in June!



Assessment of Tourmaline Composition as a Vectoring Tool for Sn-W Deposits

What about minor and trace elements?



Part II – TiO_2 polymorphs

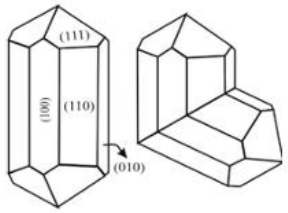
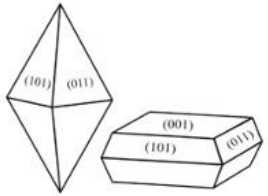
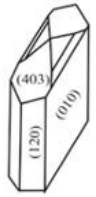
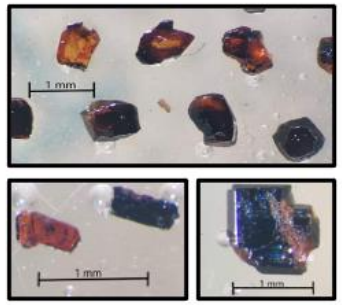
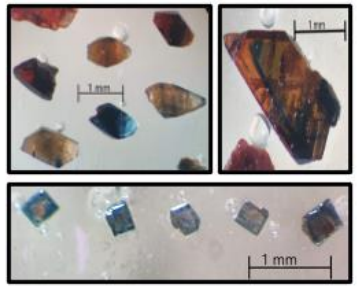
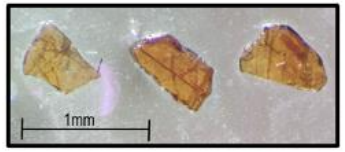
minerals

MDPI

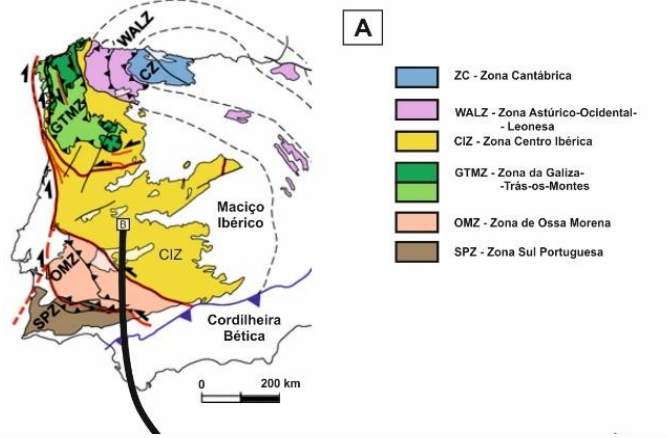
Article

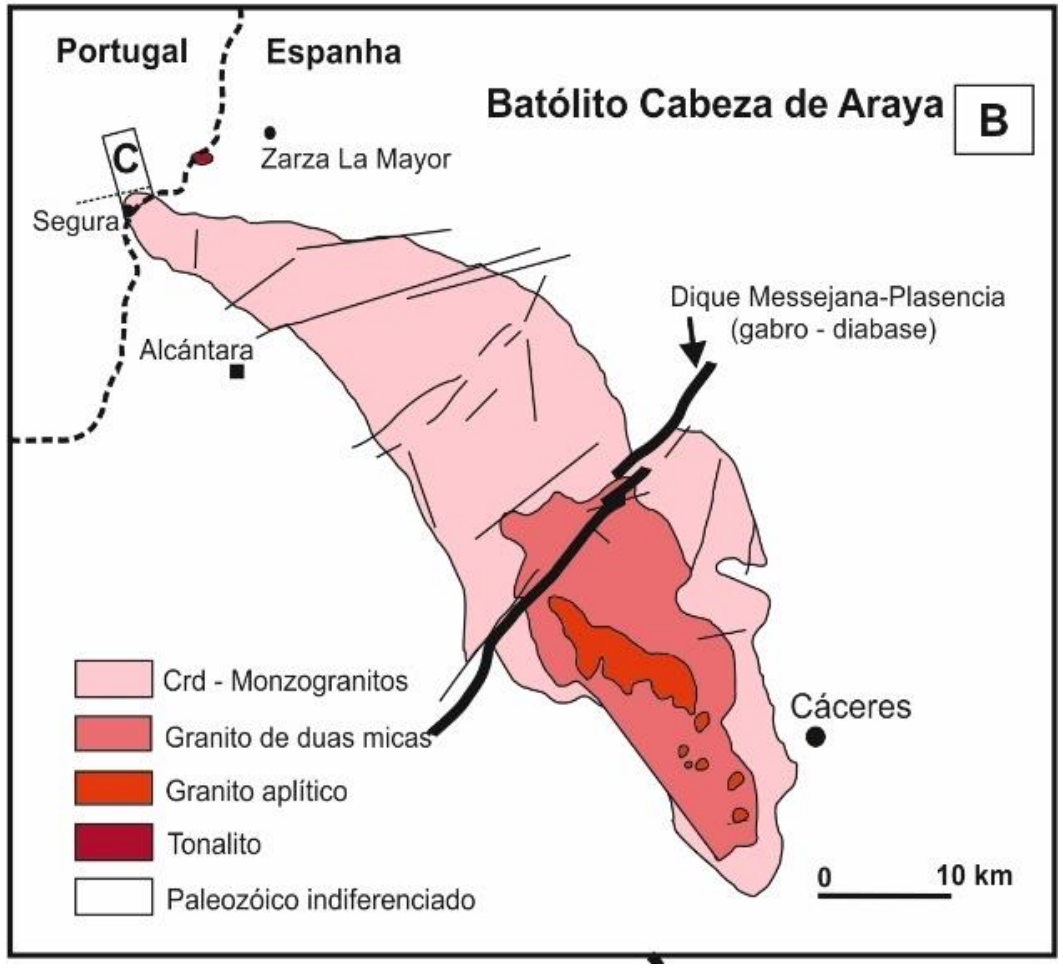
Trace Element Geochemistry of Alluvial TiO_2 Polymorphs as a Proxy for Sn and W Deposits

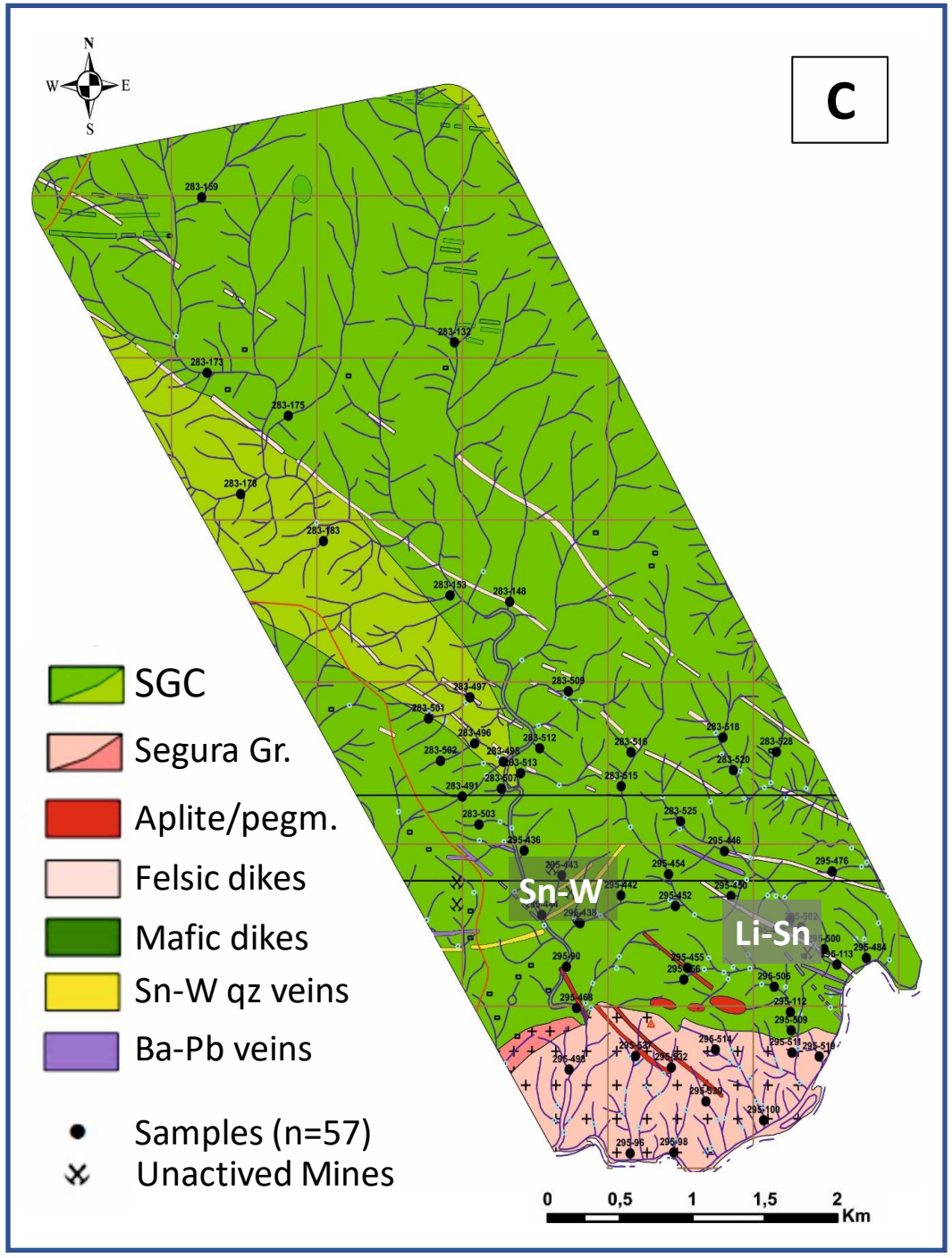
Miguel Gaspar [1,2,*], Nuno Grácio [2,3], Rute Salgueiro [3] and Mafalda Costa [4]

Rutile	Anatase	Brookite
(4/m2/m2/m)	(4/m2/m2/m)	(2/m2/m2/m)
		
		
n=695	n=1125	n=295

Geological Setting

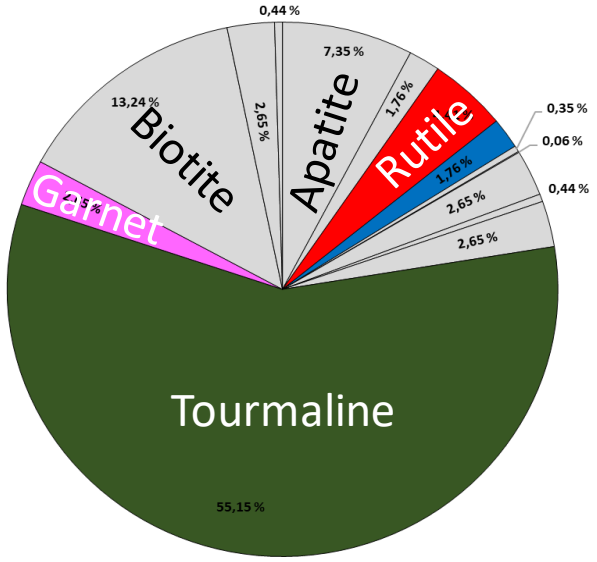




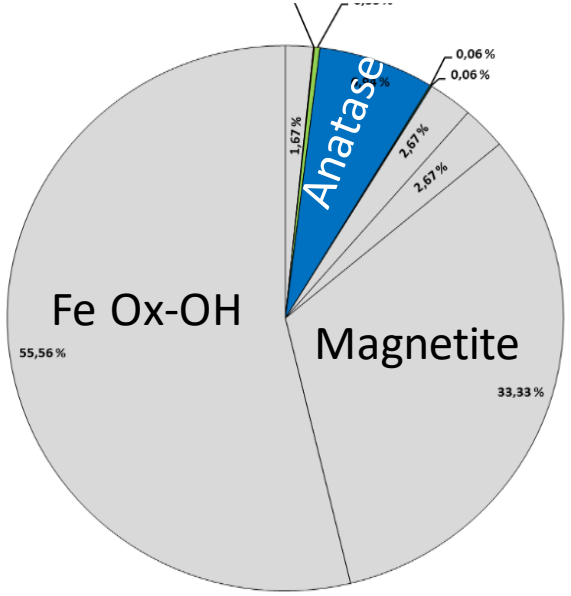


Alluvial Heavy Mineral Associations

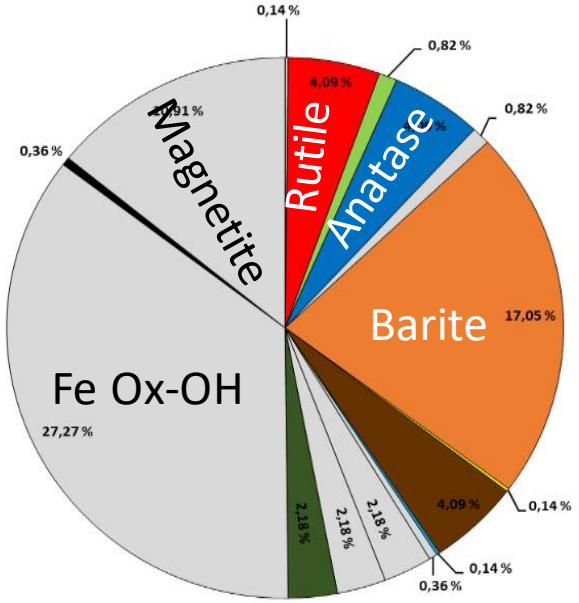
Granite



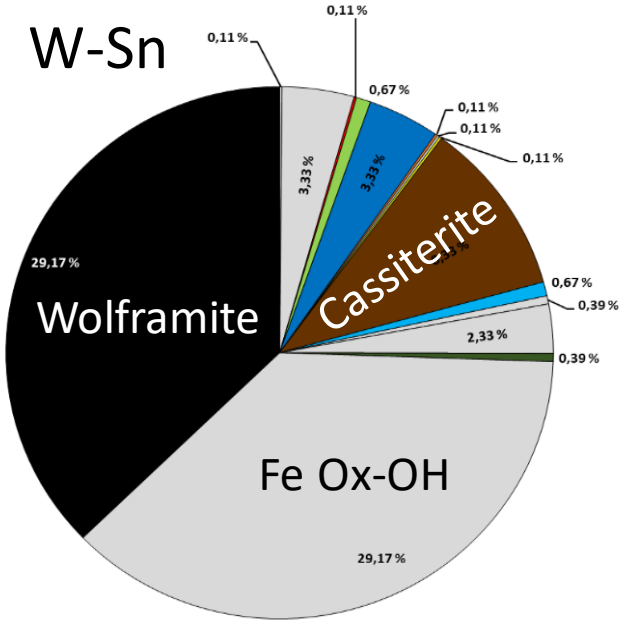
SGC metasediments



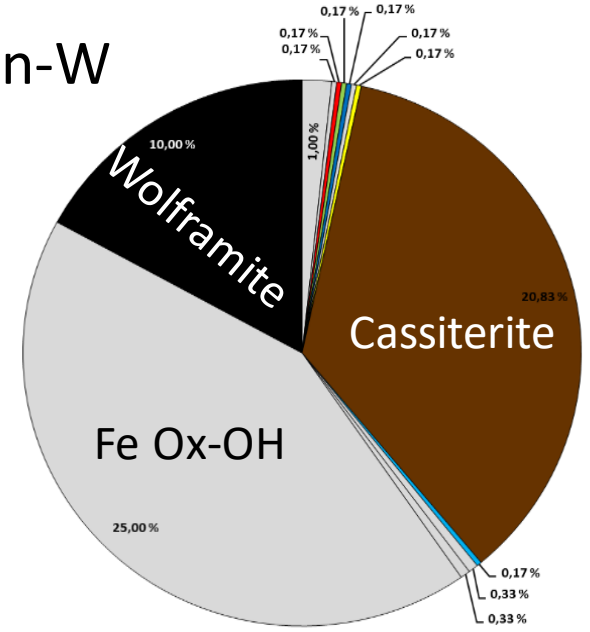
Ba-Pb



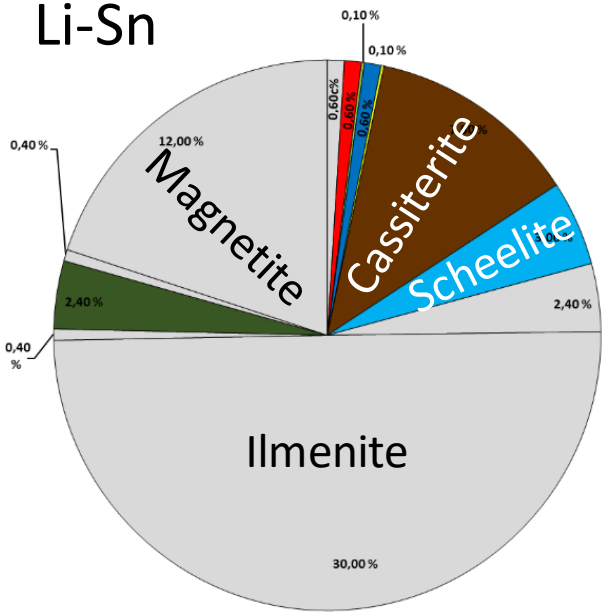
W-Sn



Sn-W

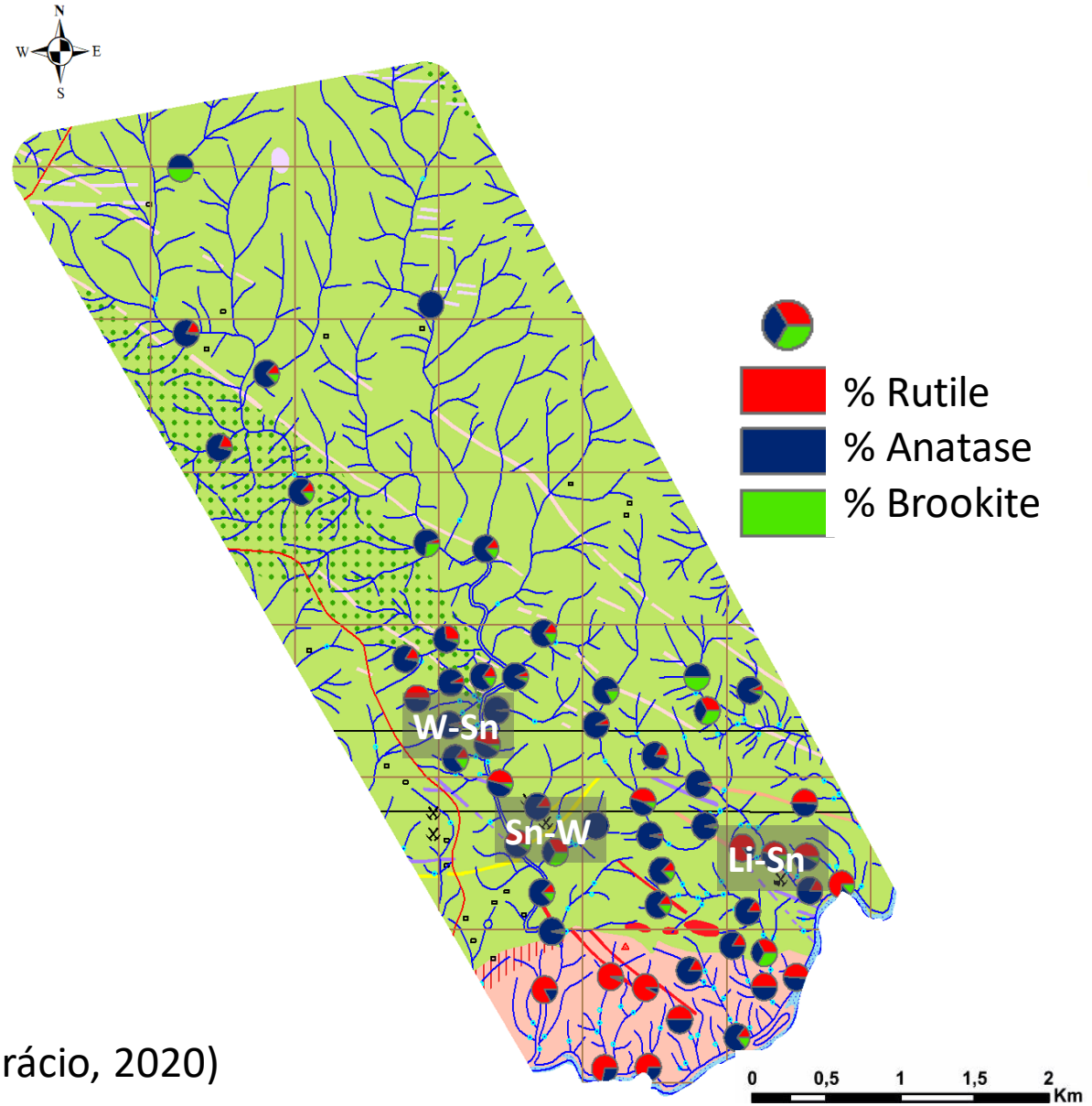


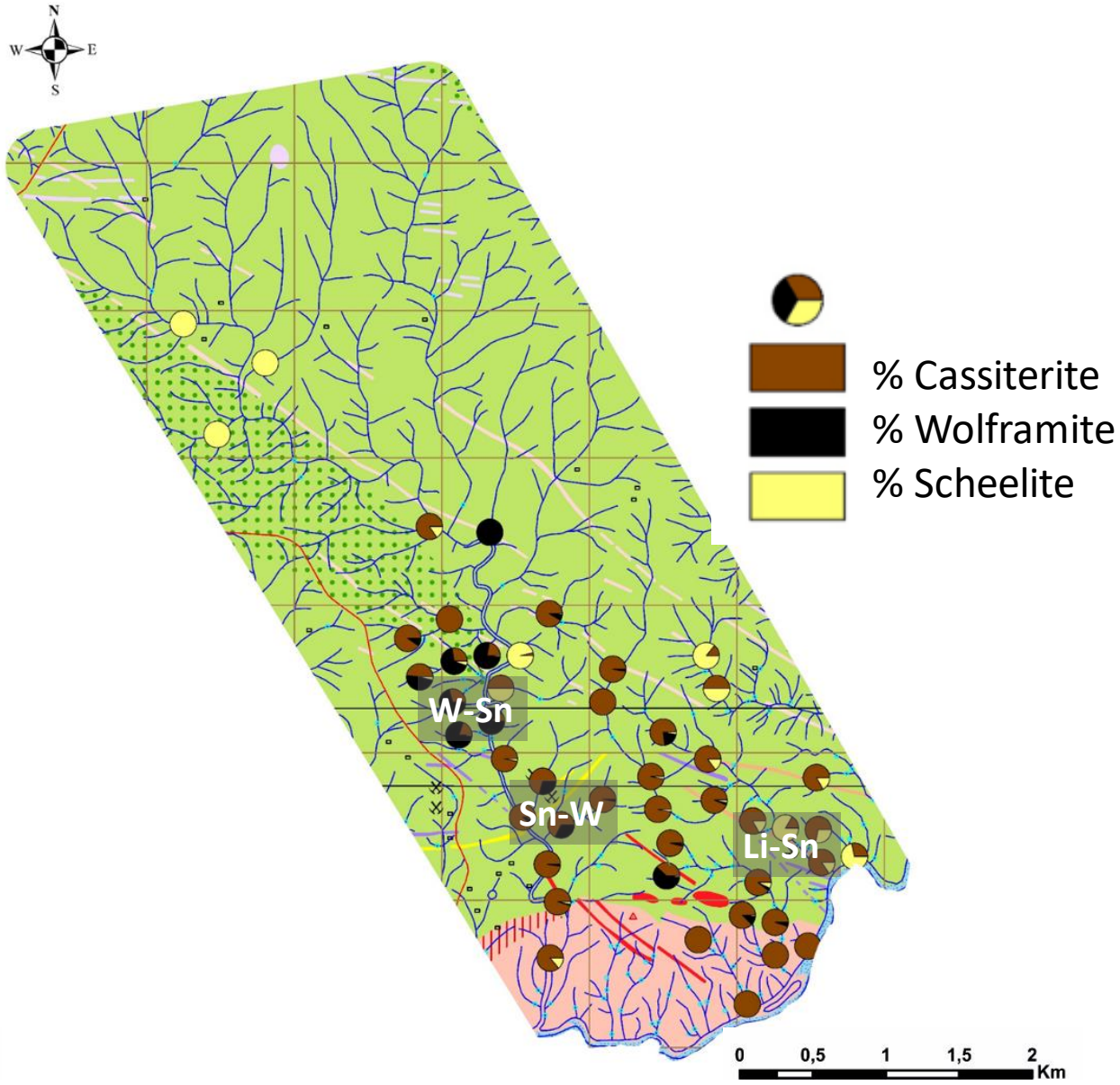
Li-Sn



(Grácio, 2020)

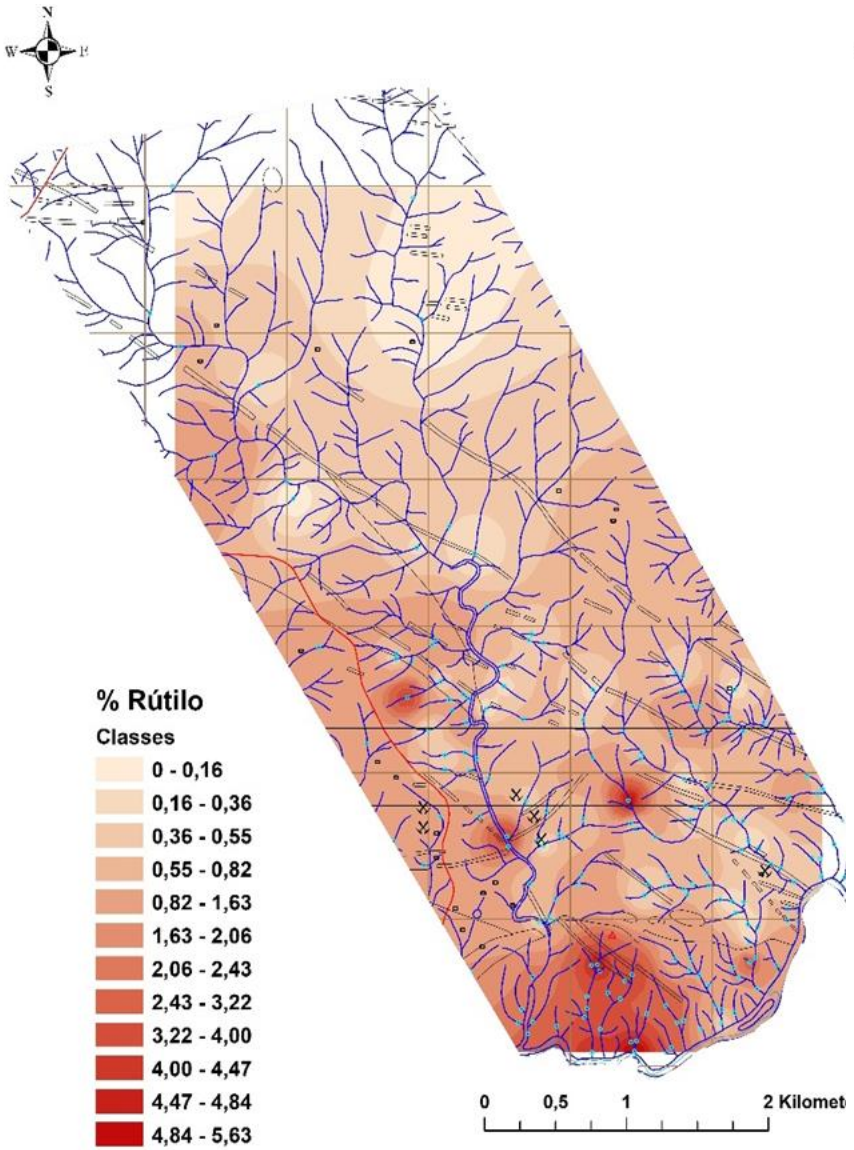
Alluvial heavy mineral relative abundance maps

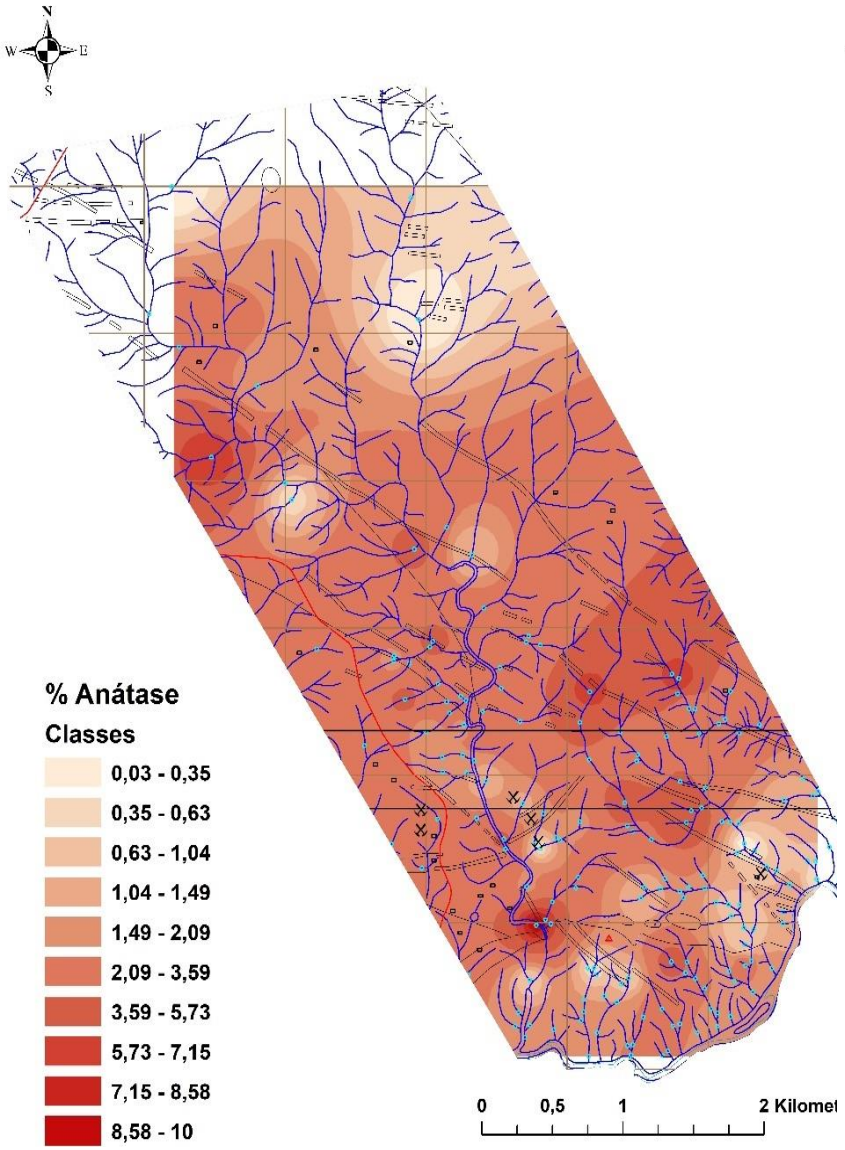


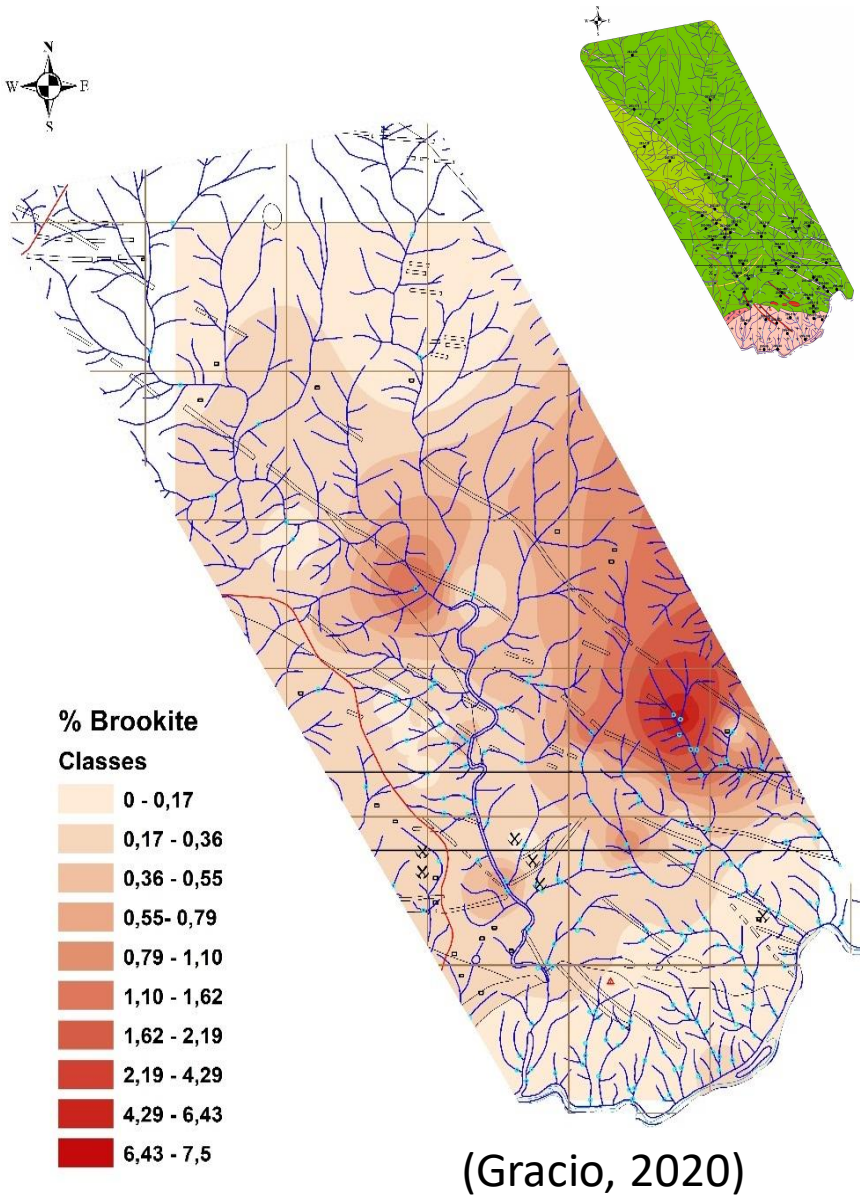


(Grácio, 2020)

Alluvial heavy mineral relative abundance maps







(Gracio, 2020)

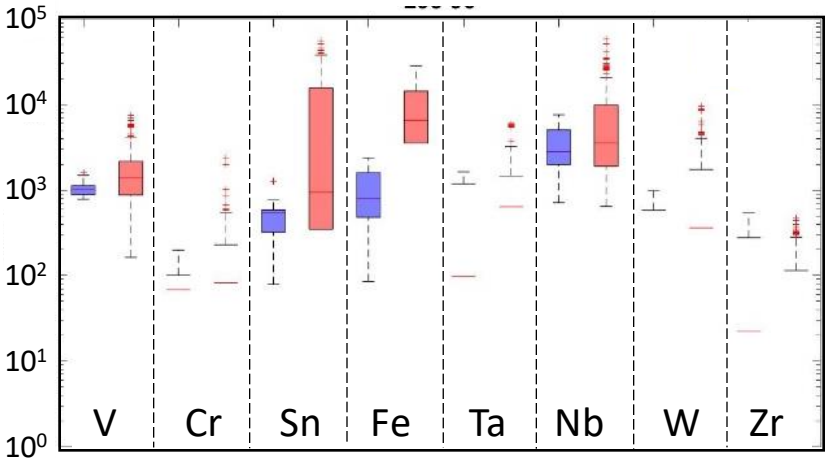
Trace elements in TiO_2 minerals – EMP data

Trace element geochemistry of rutile and anatase EMP data

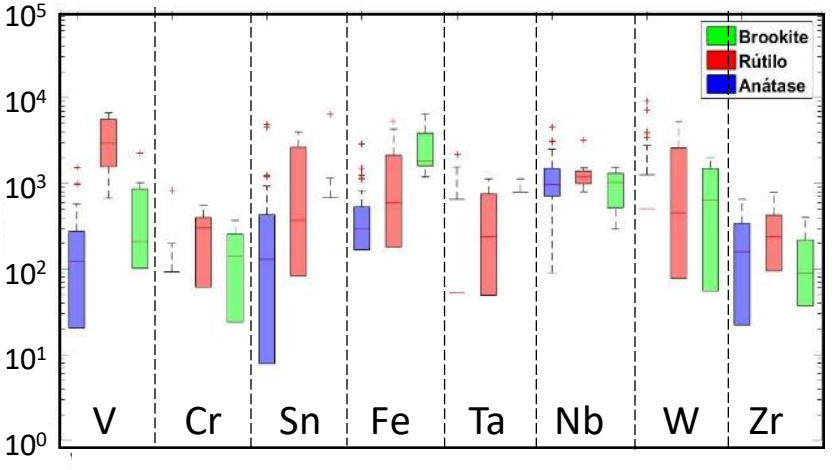
	V	Cr	Fe	Sn	Nb	Ta	W	Zr
Rútilo (ppm)								
Mínimo	< 205	< 196	< 194	< 350	< 312	< 1199	< 1212	< 279
Máximo	10937	4201	29258	55665	85347	19139	57173	1577
Média	1712	168	5882	4462	5723	890	5126	68
Mediana	1271	0	4508	882	3845	0	1491	0
Desvio Padrão	1388	370	5196	7900	6269	1990	8898	163
Anátase (ppm)								
Mínimo	< 198	< 196	< 188	< 354	< 302	< 1143	< 1103	< 270
Máximo	5289	1006	17699	4892	12296	16895	10523	992
Média	754	23	472	85	1575	261	694	99
Mediana	877	0	894	0	1139	0	0	0
Desvio Padrão	545	88	280	387	1510	833	1566	193

(Grácio, 2020)

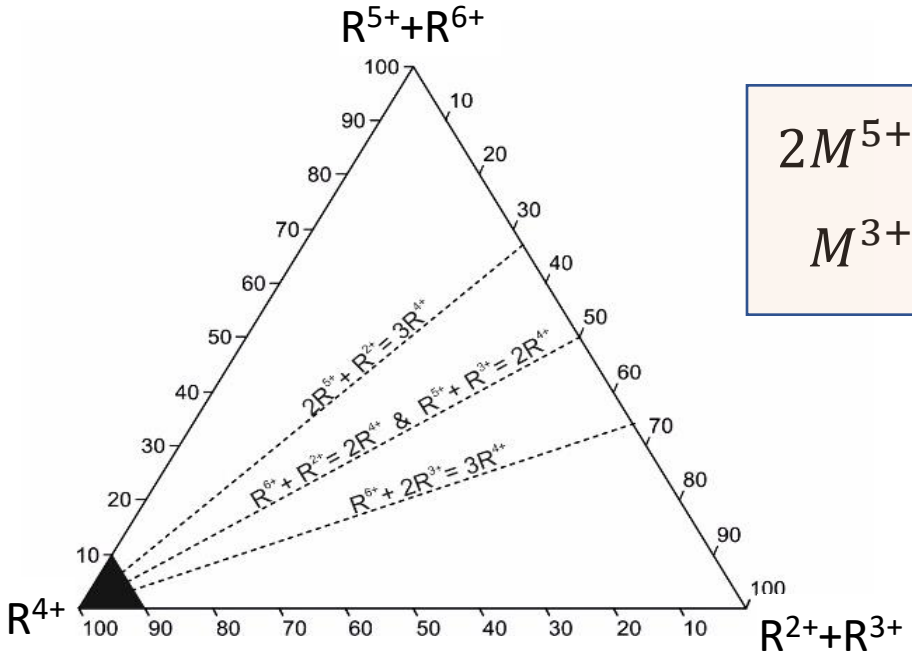
Granites



Mineralized Zones



Trace ElementSubstitution Mechanisms



$$2M^{5+} + M^{2+} \leftrightarrow 3Ti^{4+}$$

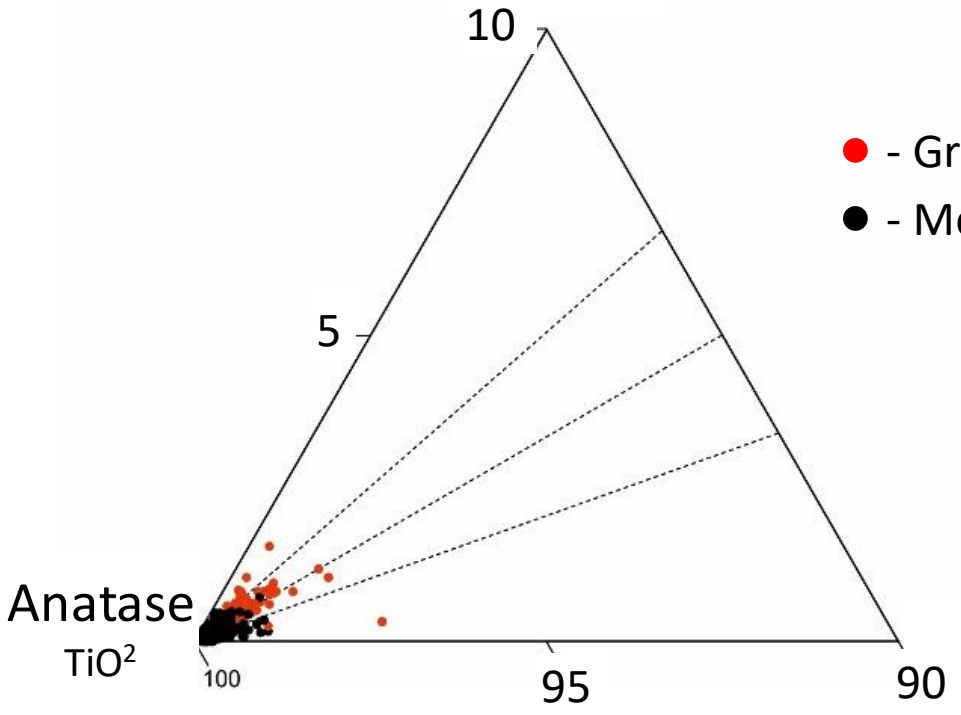
$$M^{3+} + M^{5+} \leftrightarrow 2Ti^{4+}$$

$$M^{6+} + M^{2+} \leftrightarrow 2Ti^{4+}$$

$$2M^{3+} + M^{6+} \leftrightarrow 3Ti^{4+}$$

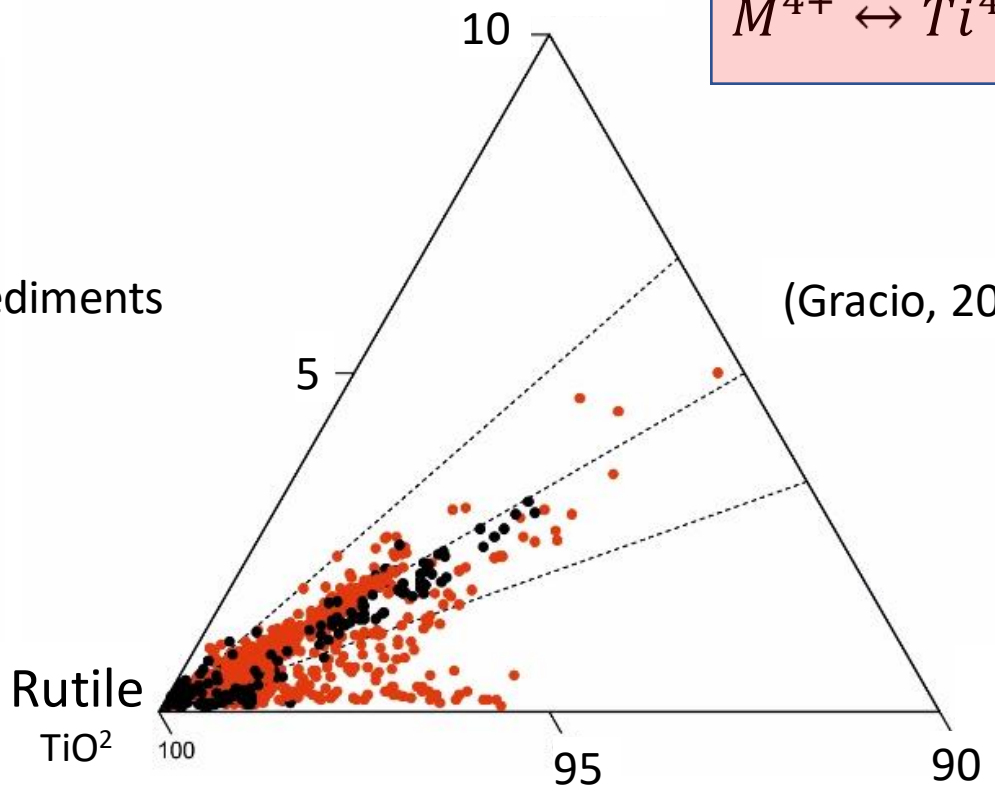
$$2M^{3+} \leftrightarrow Ti^{4+} + \square$$

$$M^{4+} \leftrightarrow Ti^{4+}$$



● - Granite

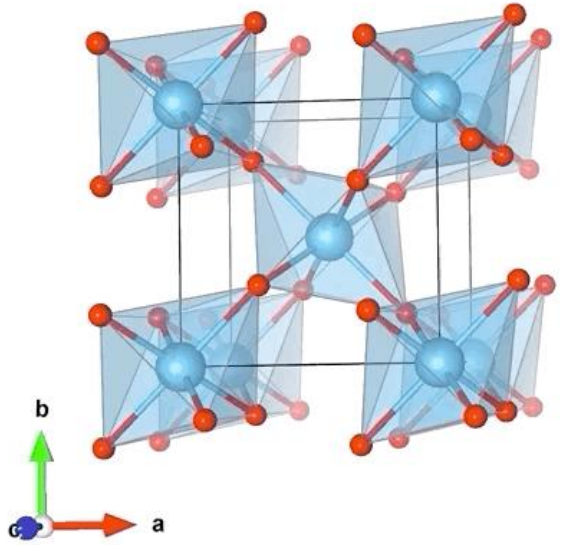
● - Metasediments



(Gracio, 2020)

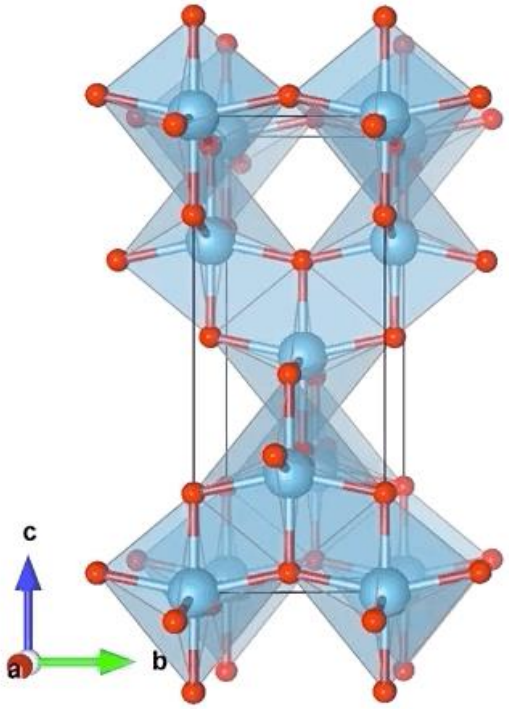
TiO_2 Polymorph structures

Rutile



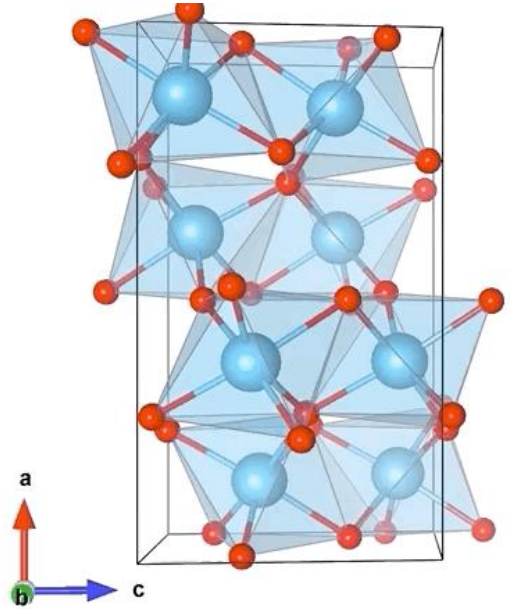
2 OSE

Anatase

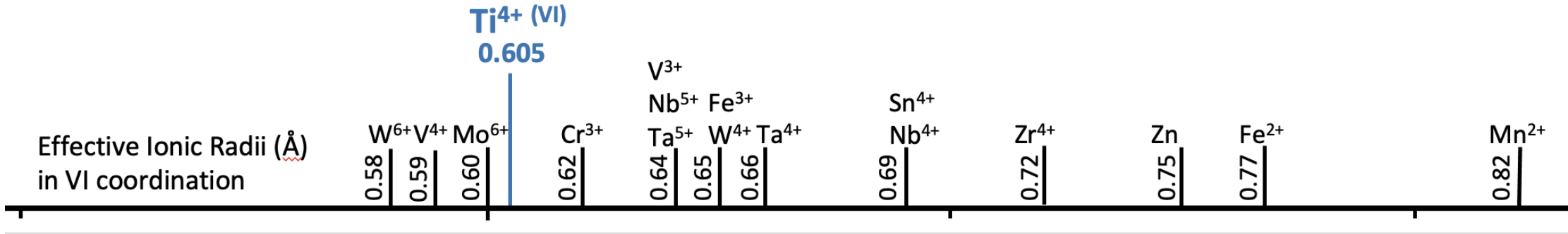


4 OSE

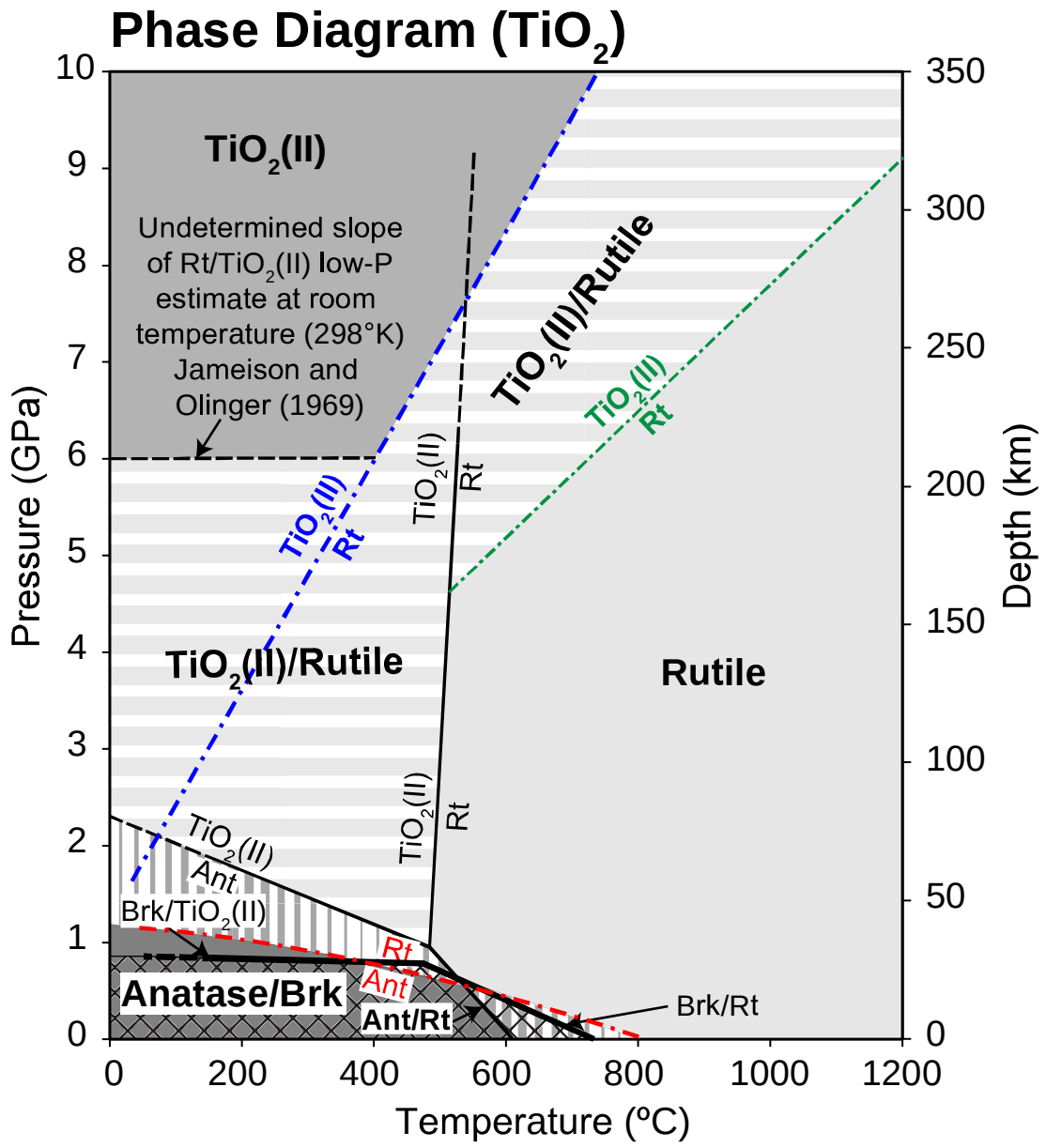
Brookite



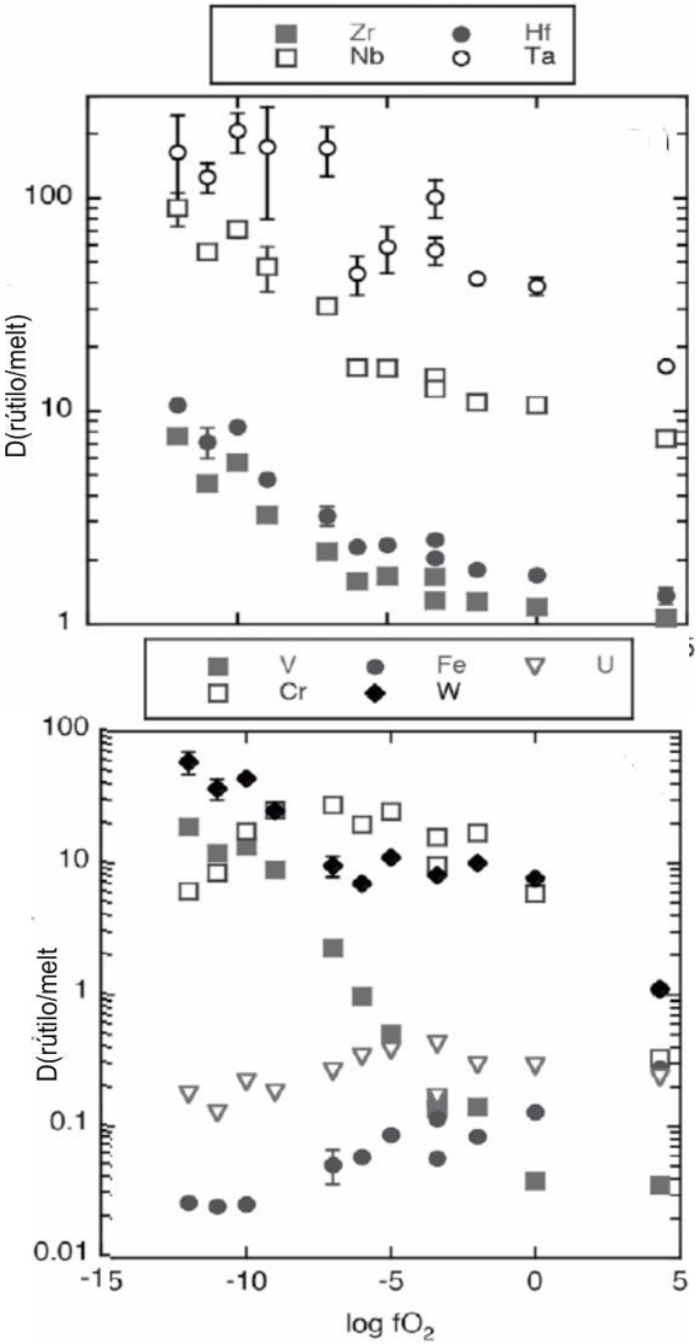
3 OSE



TiO_2 Polymorph Stability
Primary vs. Secondary



(Plavsa et al., 2017)



(Mallmann et al., 2014)

Alteration of Ti-rich phases

Ilmenite

$$FeTiO_3 + S_2 = FeS_2 + TiO_2$$

Ti-magnetite

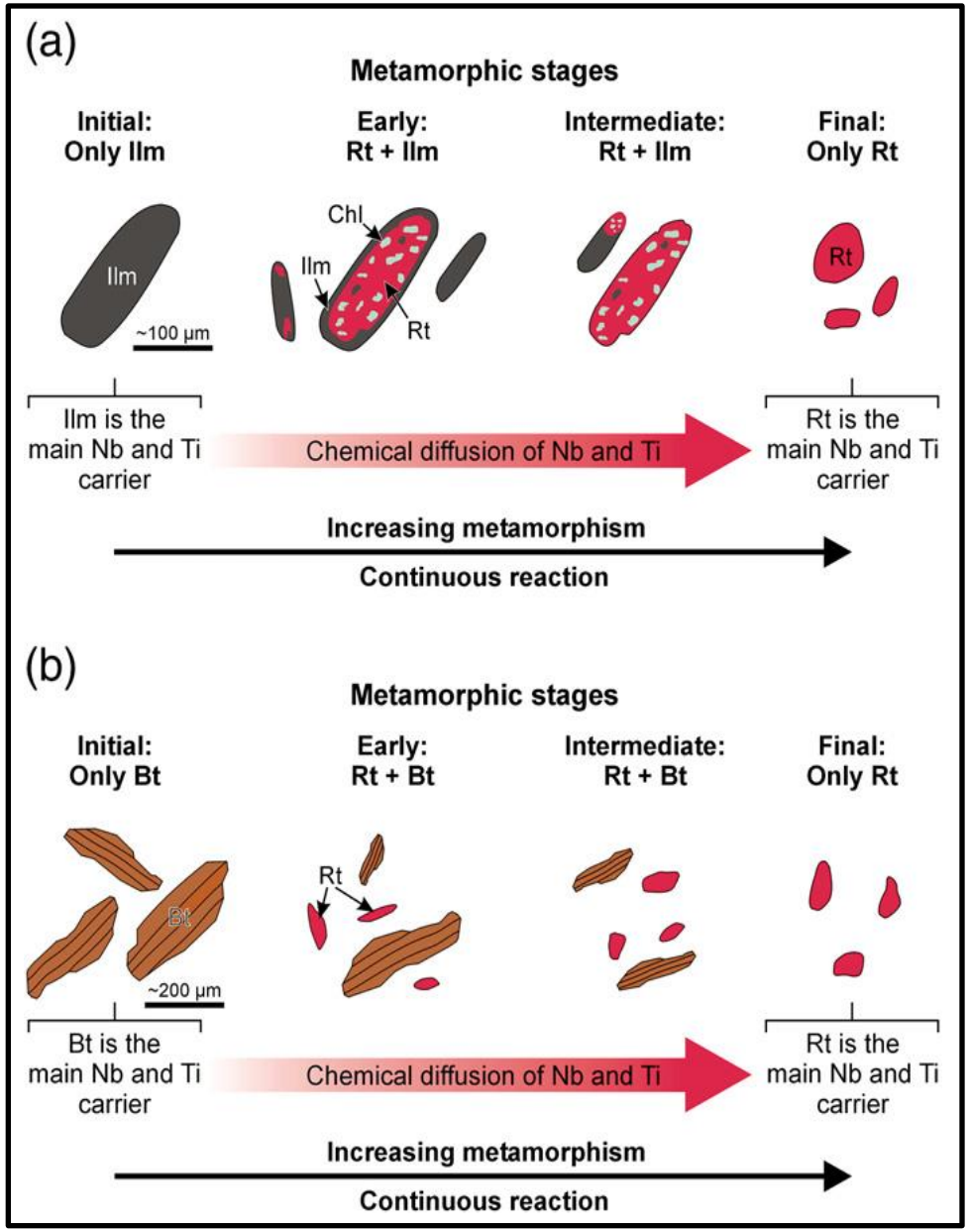
$$2(Fe,Ti)_3O_4 + S_2 = Fe_3O_4 + FeS_2 + TiO_2$$

Biotite

$$K(Fe,Mg,Ti)_3(Si_3Al)O_{10}(OH)_2 + S_2 = K(Mg,Fe)_3(Si_3Al)O_{10}(OH)_2 + FeS_2 + TiO_2$$

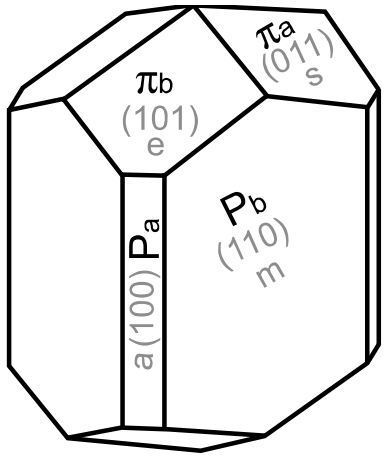
Titanite

$$CaTiSiO_5 + CO_2 = TiO_2 + CaCO_3 + SiO_2$$



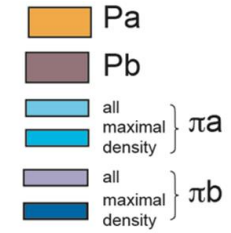
After Meinhold (2010)

Rutile Crystal Forms Controlling Trace Elements

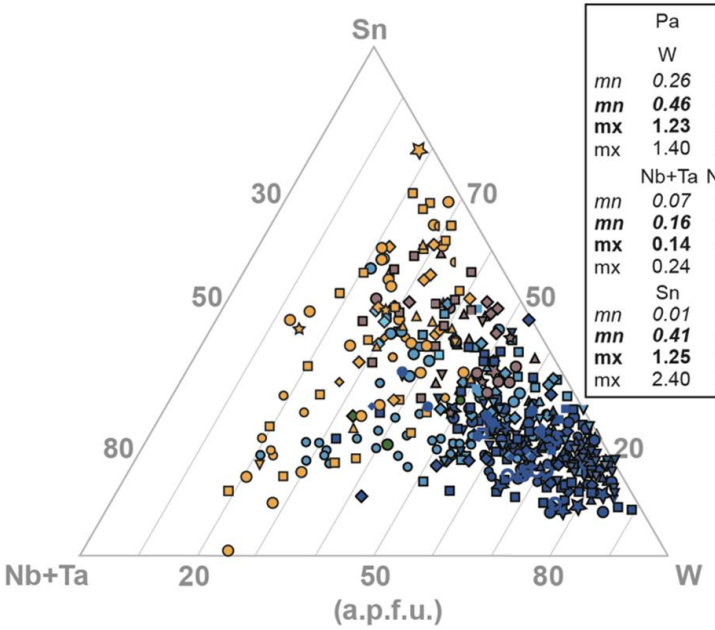


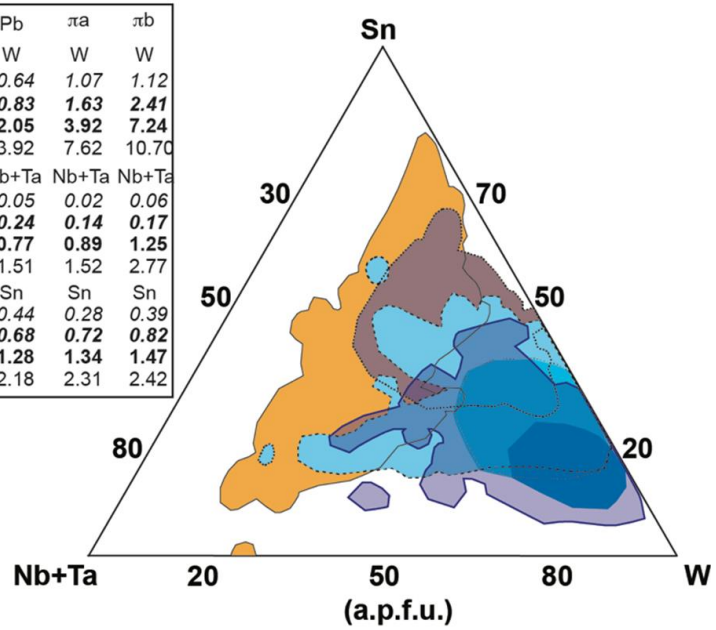
Carocci et al. (2019)

Rutile – Panasqueira deposit

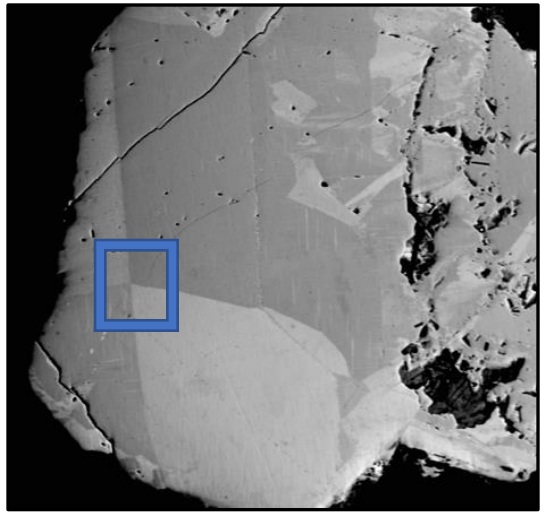


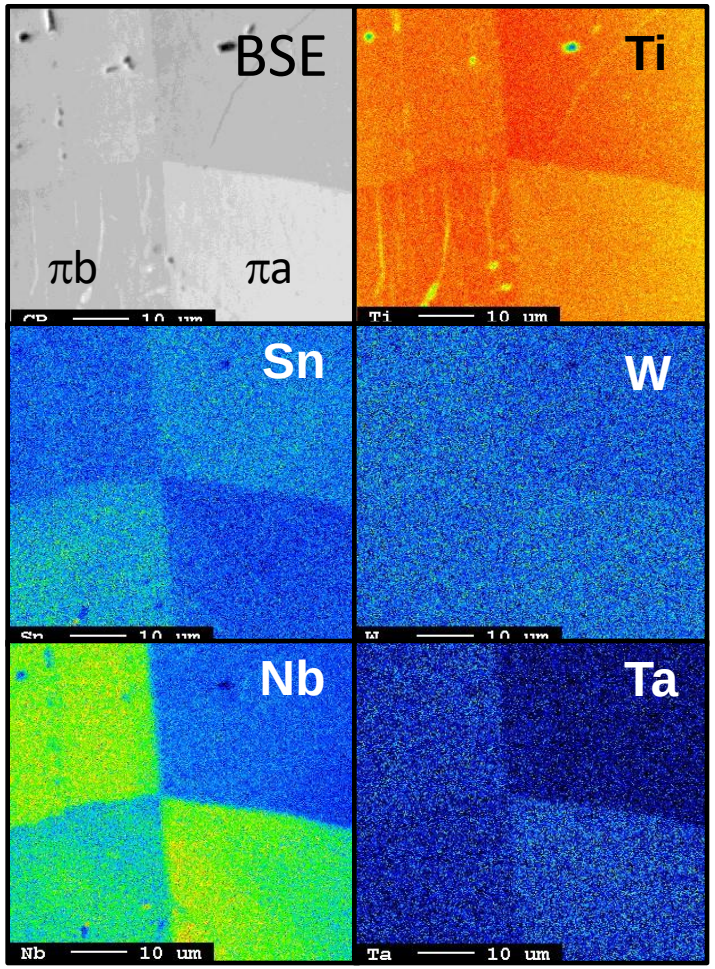
	Pa	Pb	πa	πb
	W	W	W	W
mn	*0.26*	*0.64*	*1.07*	*1.12*
mn	***0.46***	***0.83***	***1.63***	***2.41***
mx	**1.23**	**2.05**	**3.92**	**7.24**
mx	1.40	3.92	7.62	10.70
	Nb+Ta	Nb+Ta	Nb+Ta	Nb+Ta
mn	*0.07*	*0.05*	*0.02*	*0.06*
mn	***0.16***	***0.24***	***0.14***	***0.17***
mx	**0.14**	**0.77**	**0.89**	**1.25**
mx	0.24	1.51	1.52	2.77
	Sn	Sn	Sn	Sn
mn	*0.01*	*0.44*	*0.28*	*0.39*
mn	***0.41***	***0.68***	***0.72***	***0.82***
mx	**1.25**	**1.28**	**1.34**	**1.47**
mx	2.40	2.18	2.31	2.42

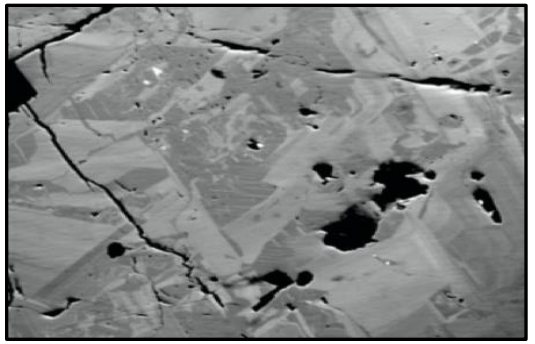




Grácio (2020)



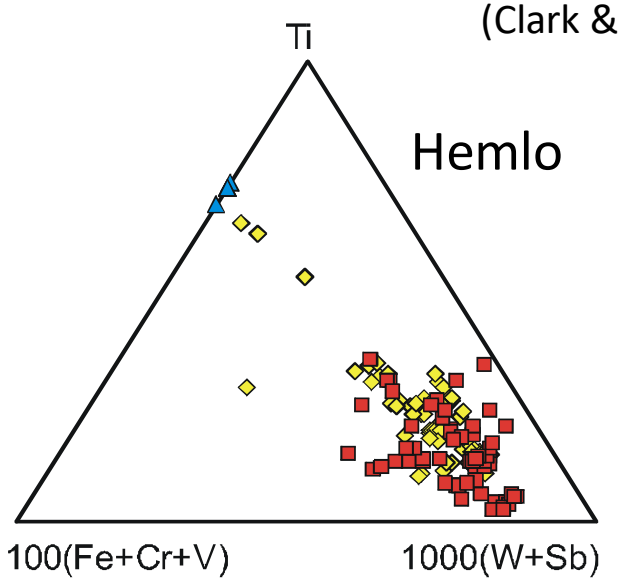


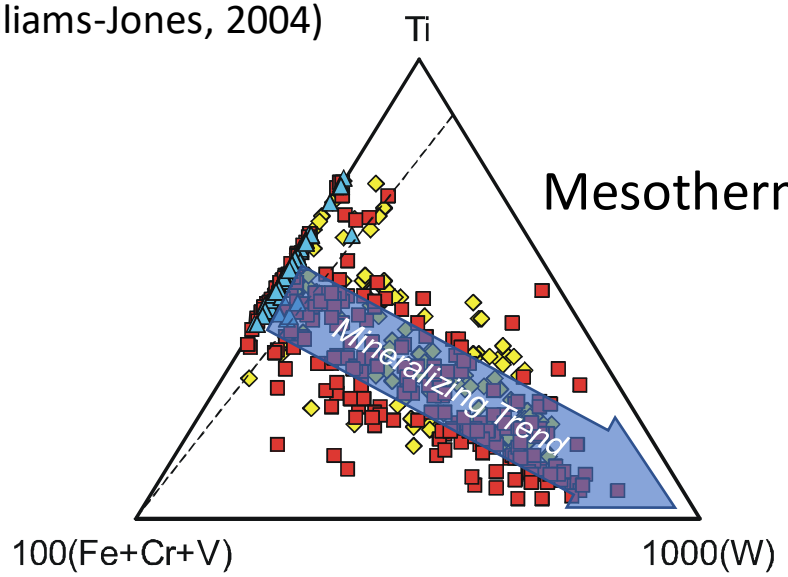


(Gracio, 2020)

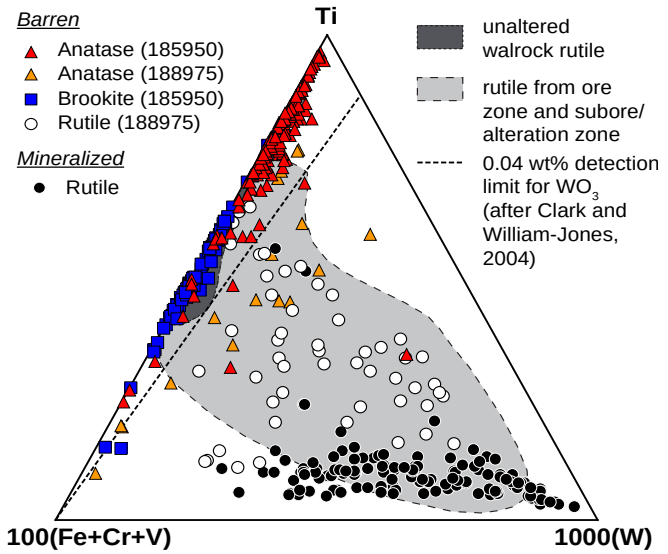
Exploration Tools – Trace Element Vectoring/Fingerprints

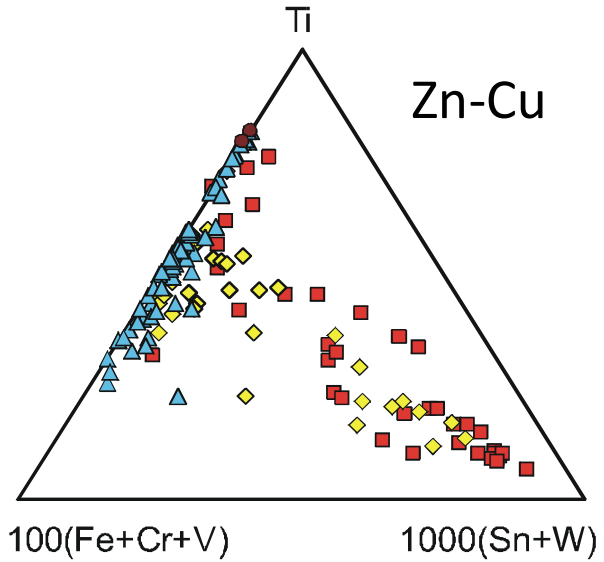
(Clark & Williams-Jones, 2004)

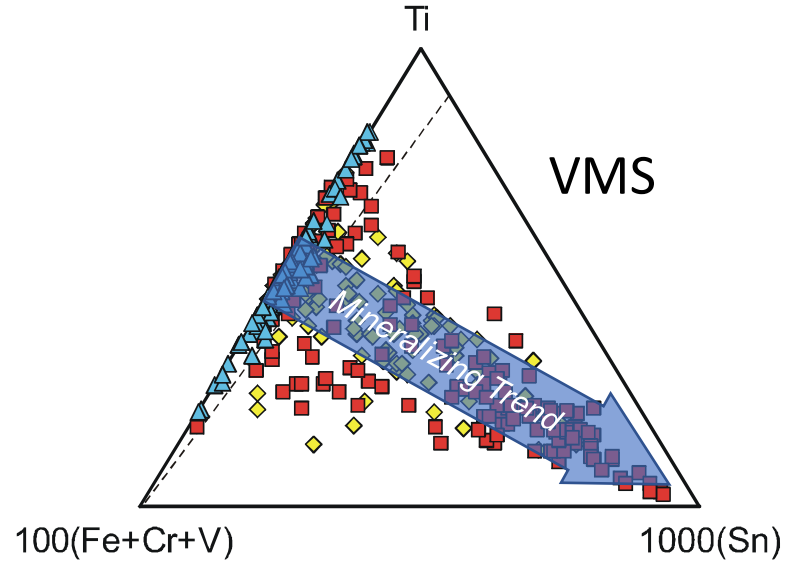




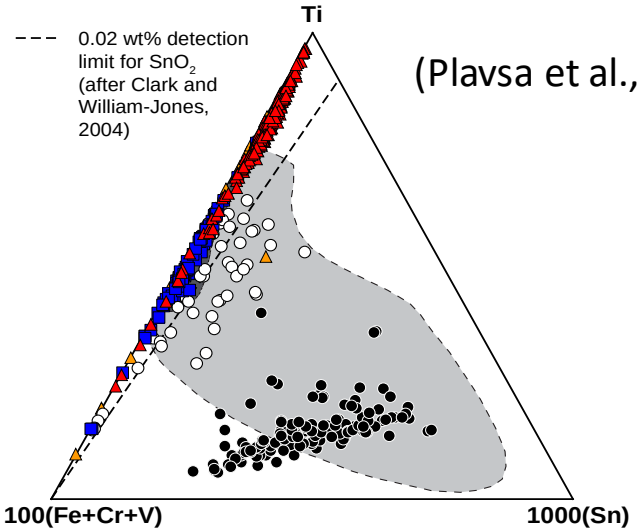
b) Mesothermal Au deposits







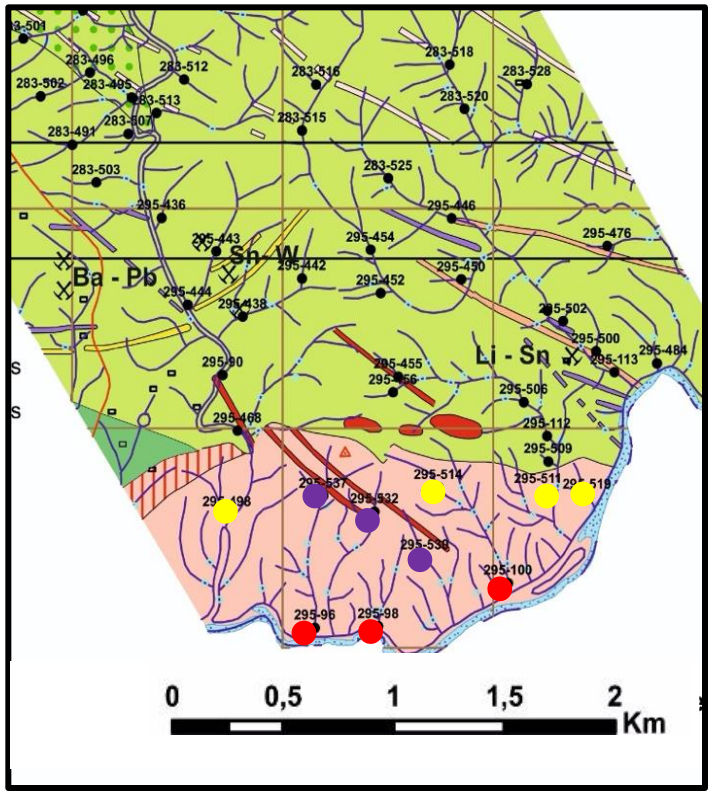
c) Base metal deposits



(Plavsa et al., 2017)

Exploration Tools – Trace Element Fingerprints

Granites

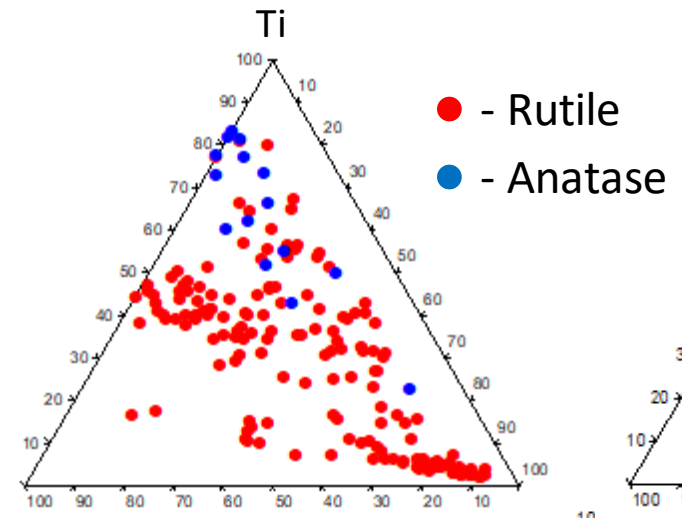


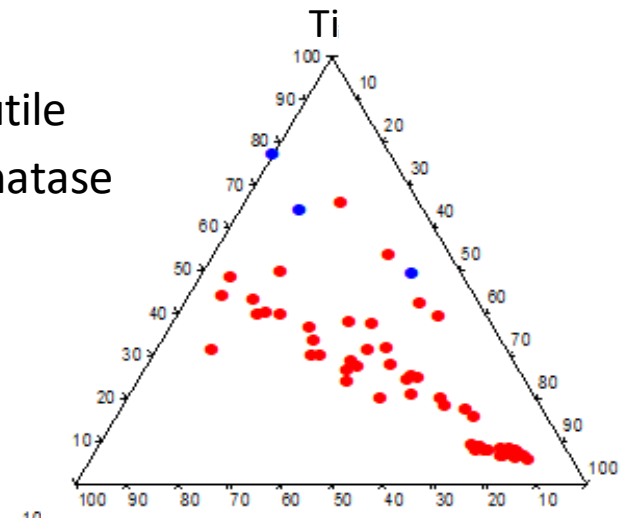
(Gracio, 2020)

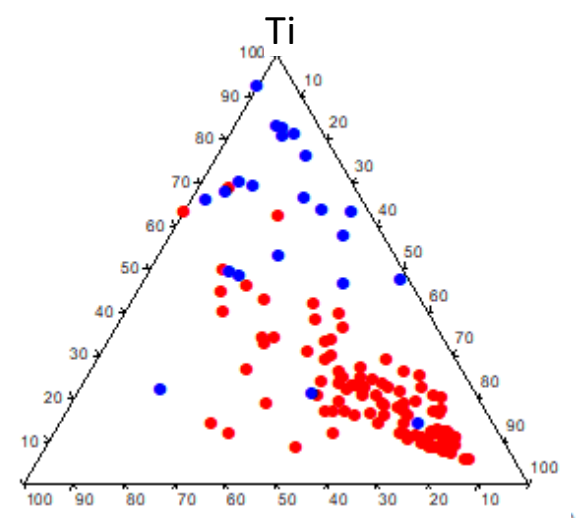
Internal Zone

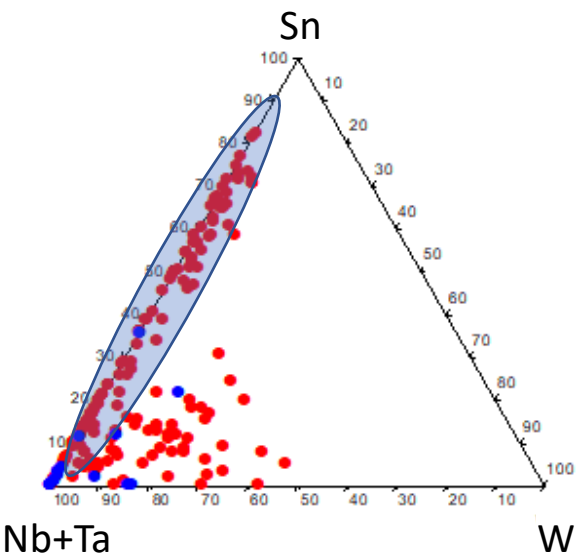
Border Zone

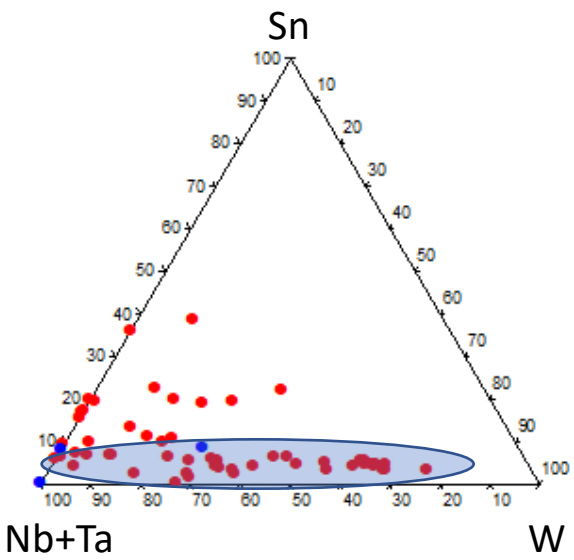
Aplitic-rich Zone

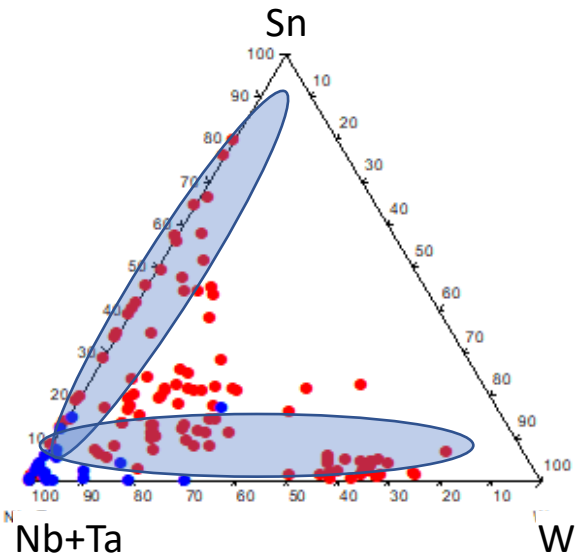






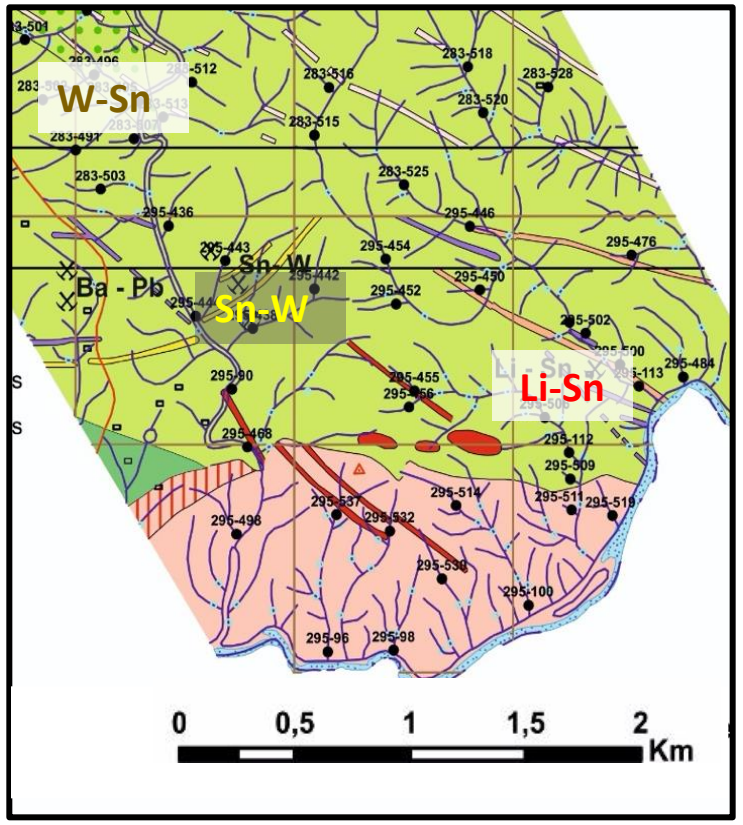






Exploration Tools – Trace Element Fingerprints

Sn-W Mineralized



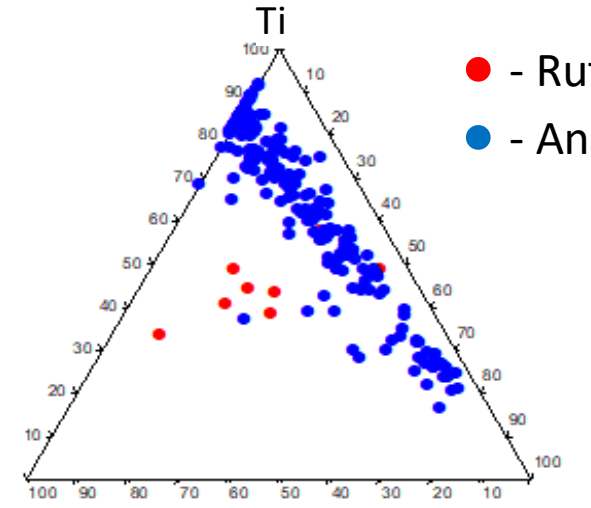
(Gracio, 2020)

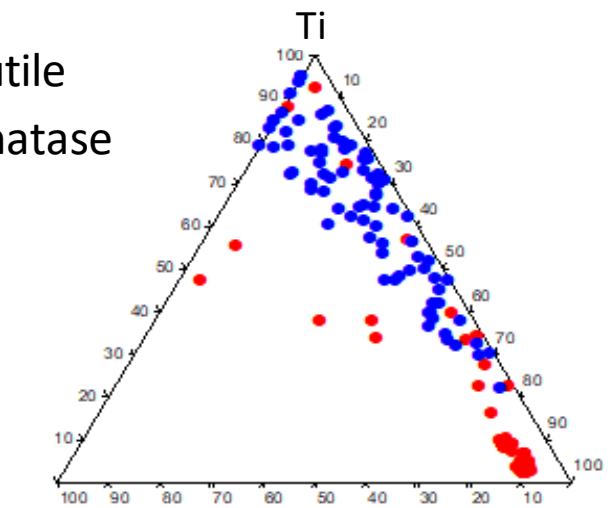
Sn ± W

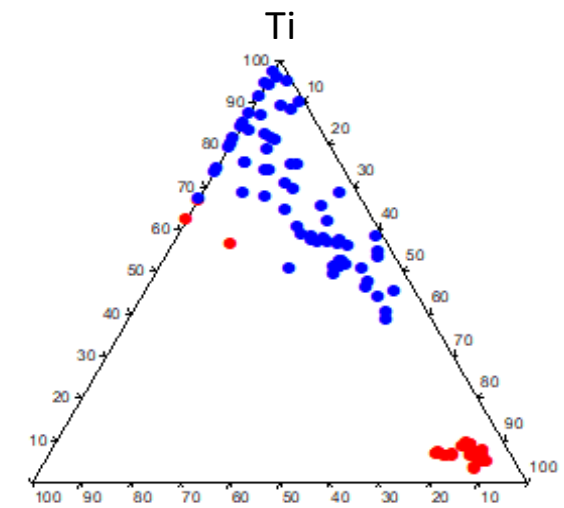
W ± Sn

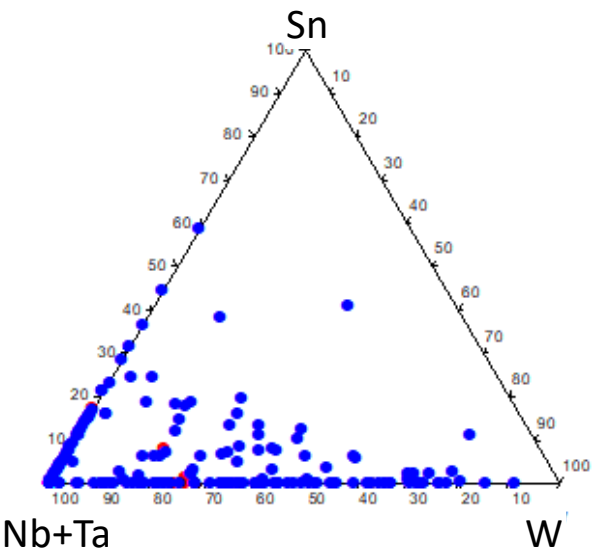
Li ± Sn

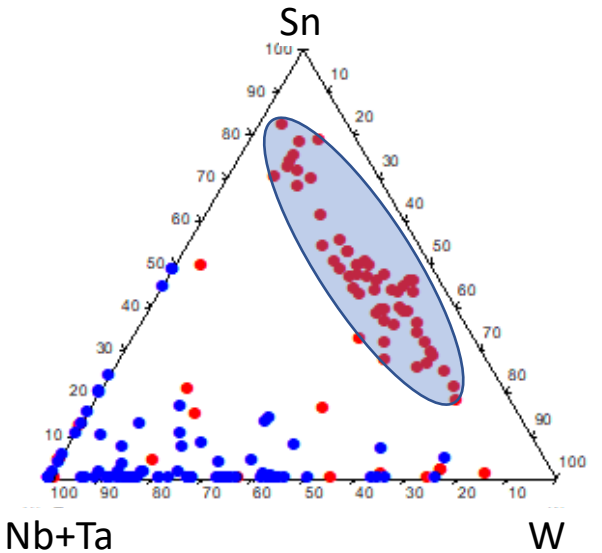
- Rutile
- Anatase

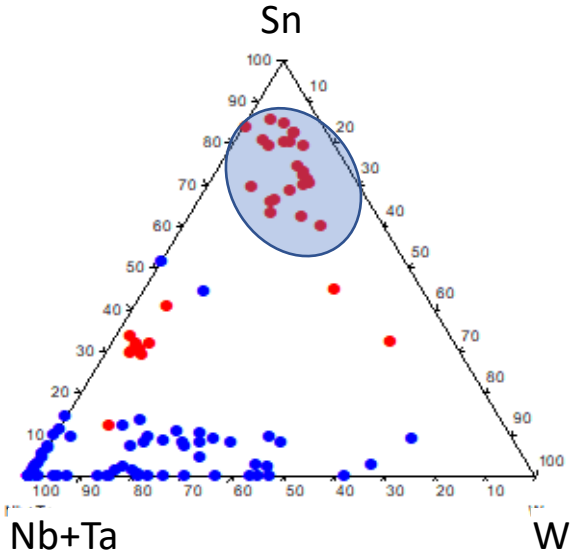






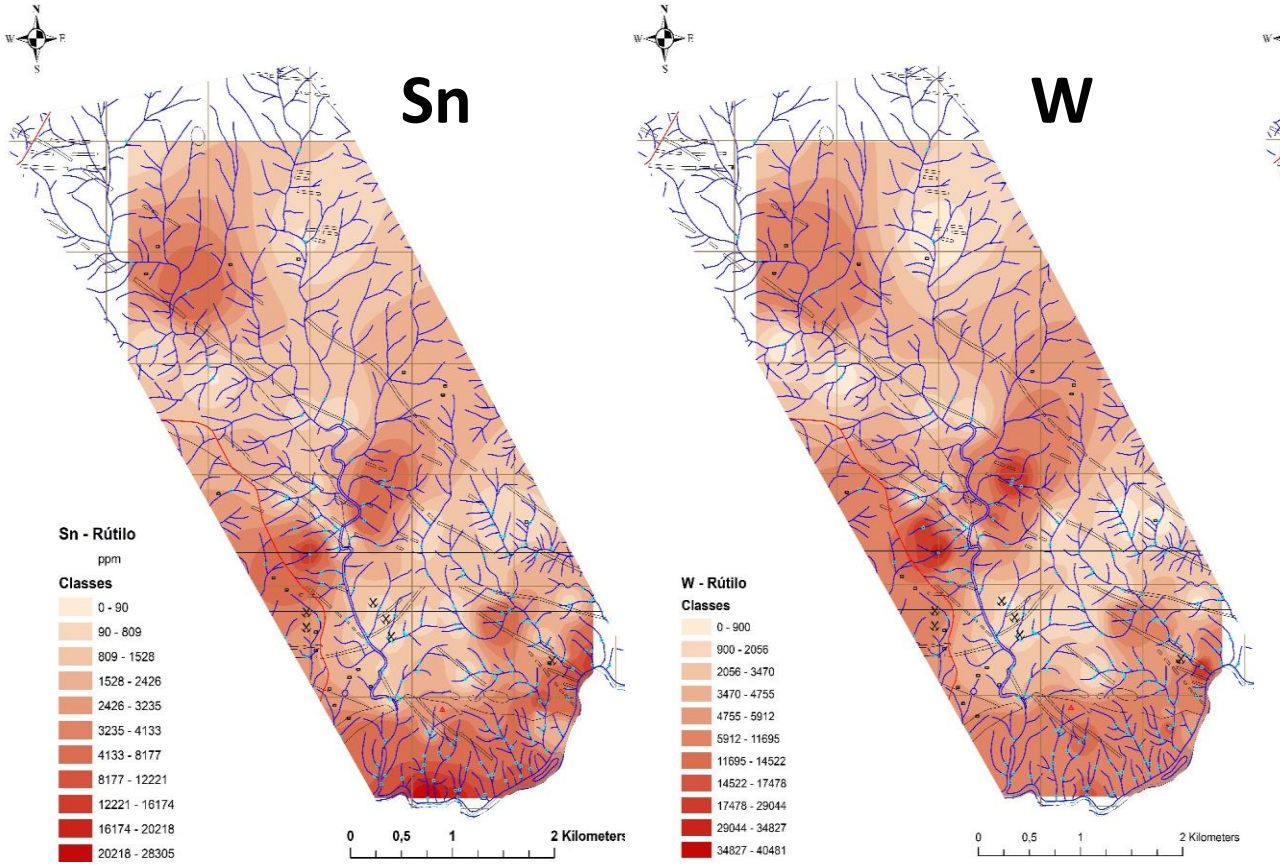




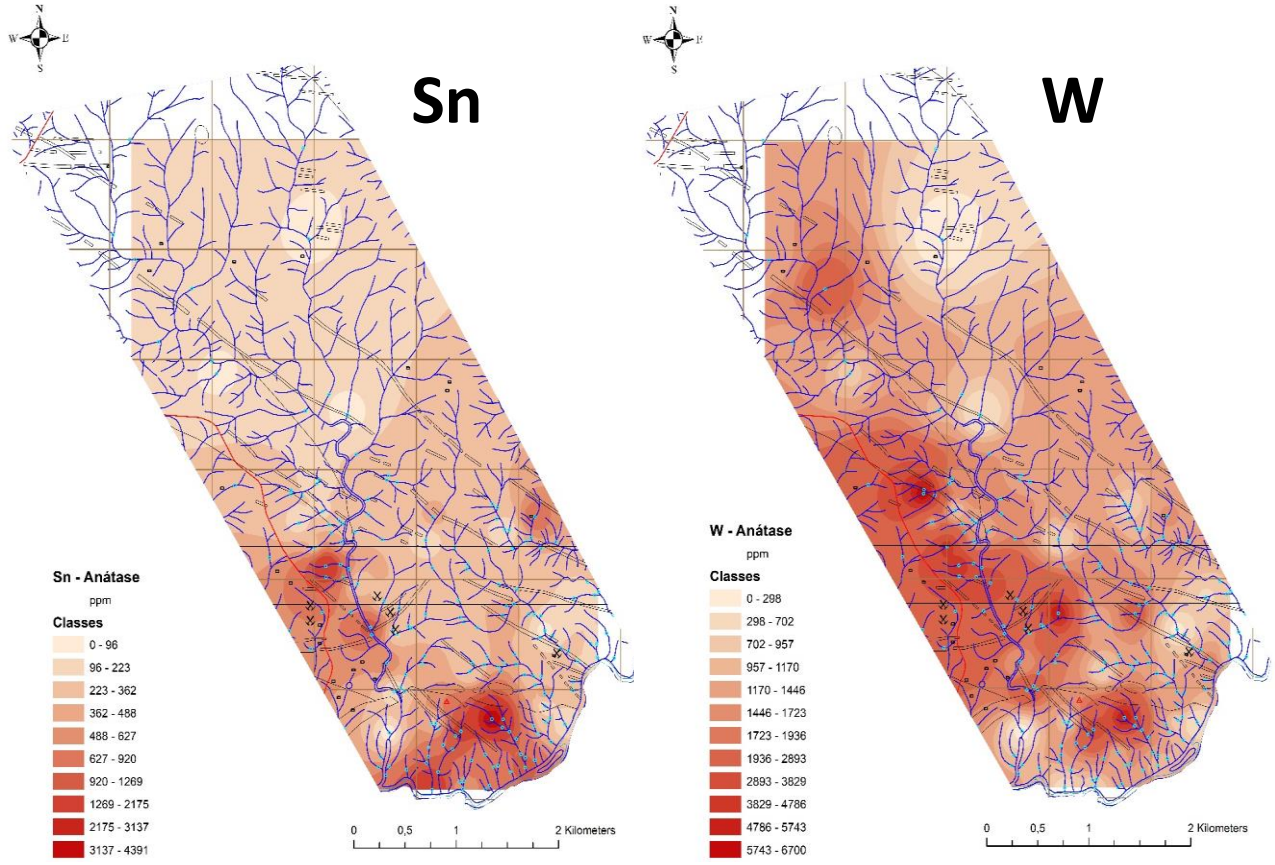


Exploration Tools – Trace Element Abundance Maps

Rutile



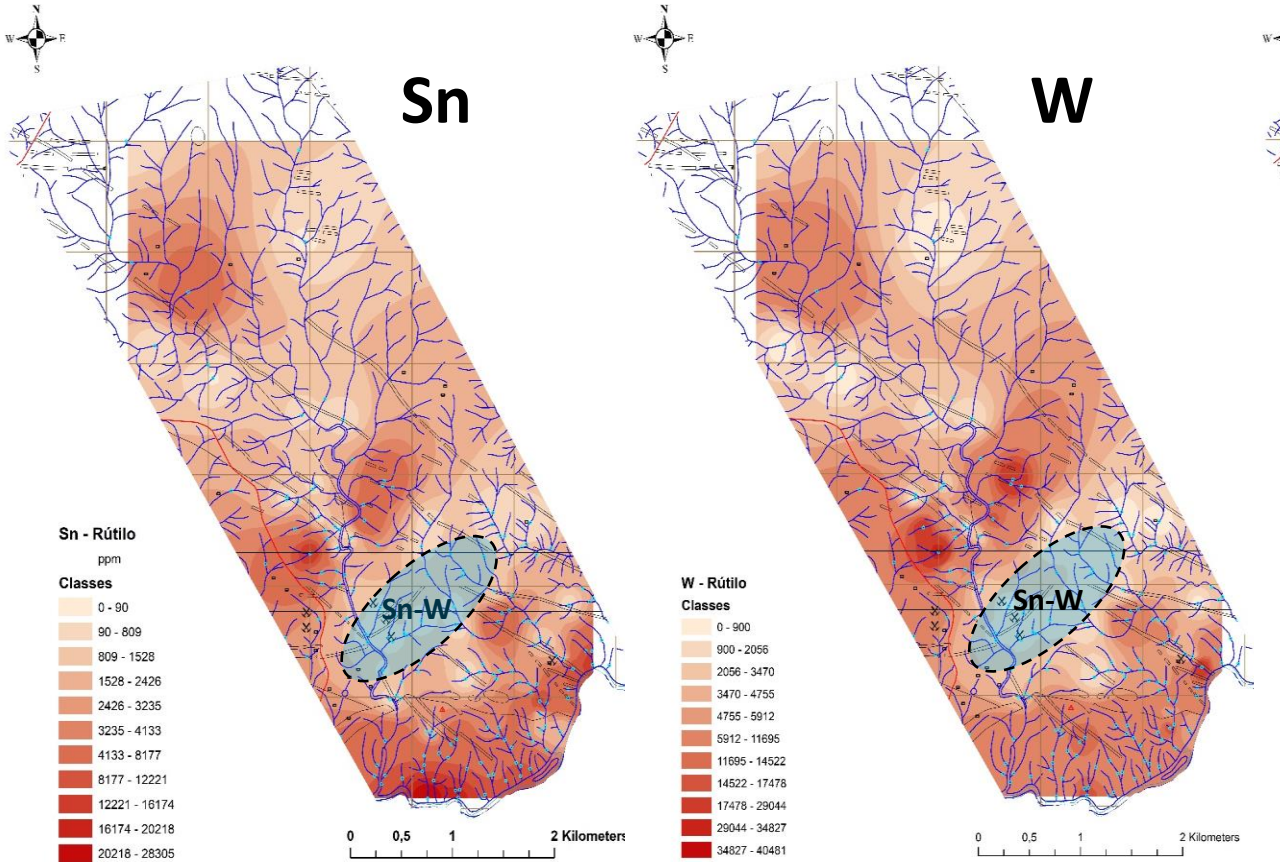
Anatase



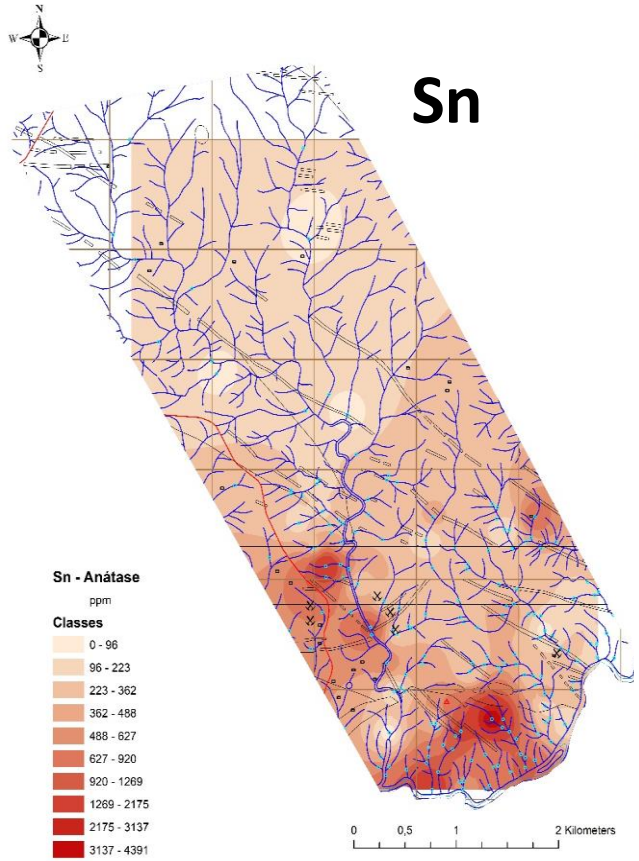
(Gracio, 2020)

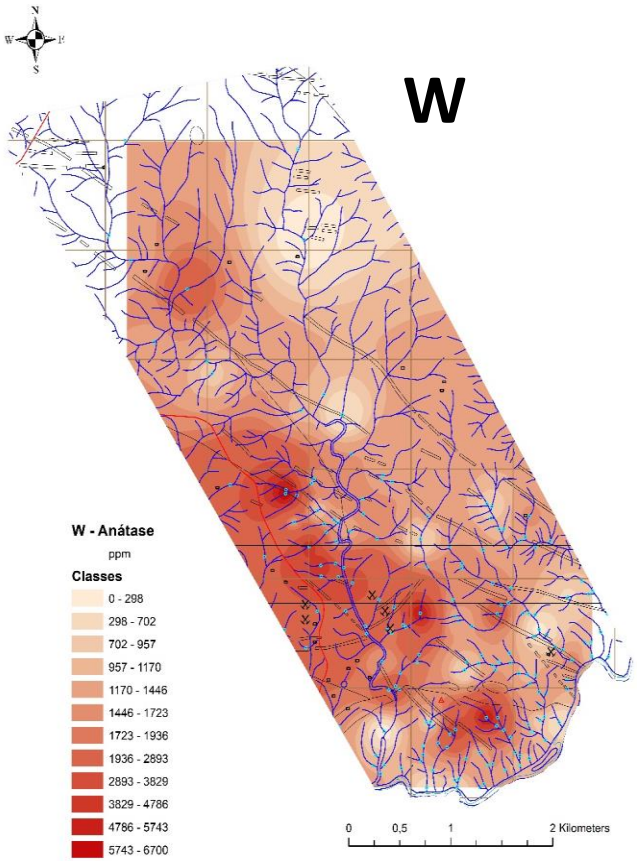
Exploration Tools – Trace Element Abundance Maps

Rutile



Anatase

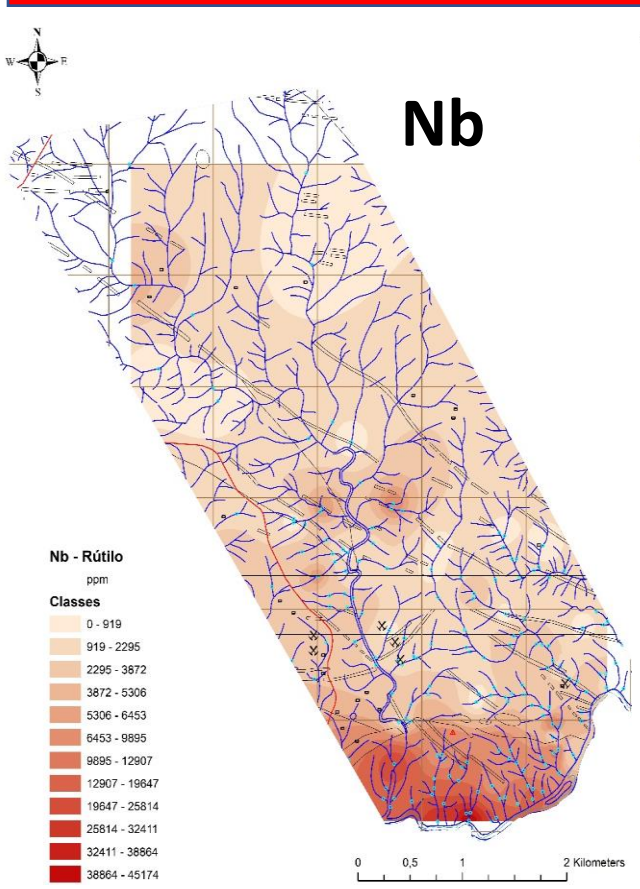


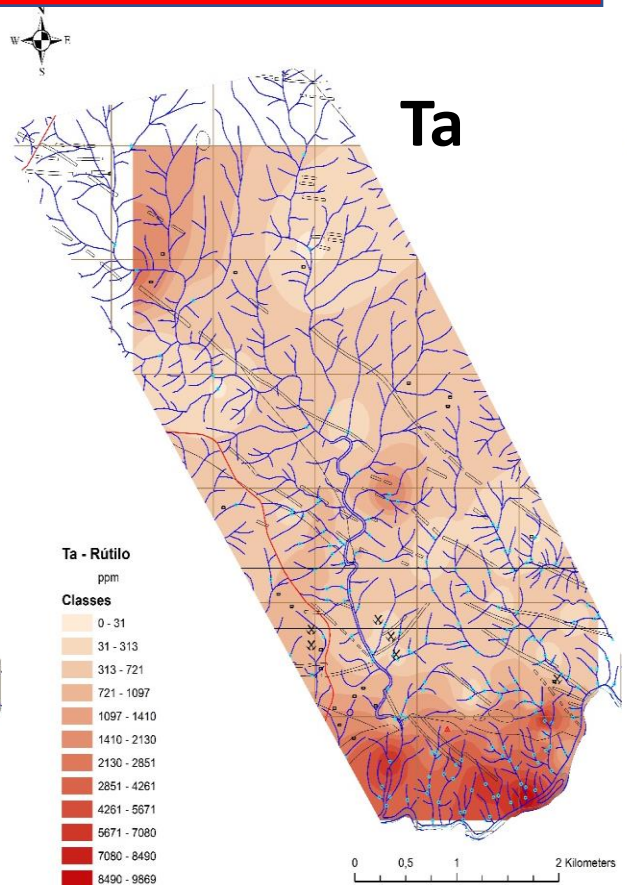


(Gracio, 2020)

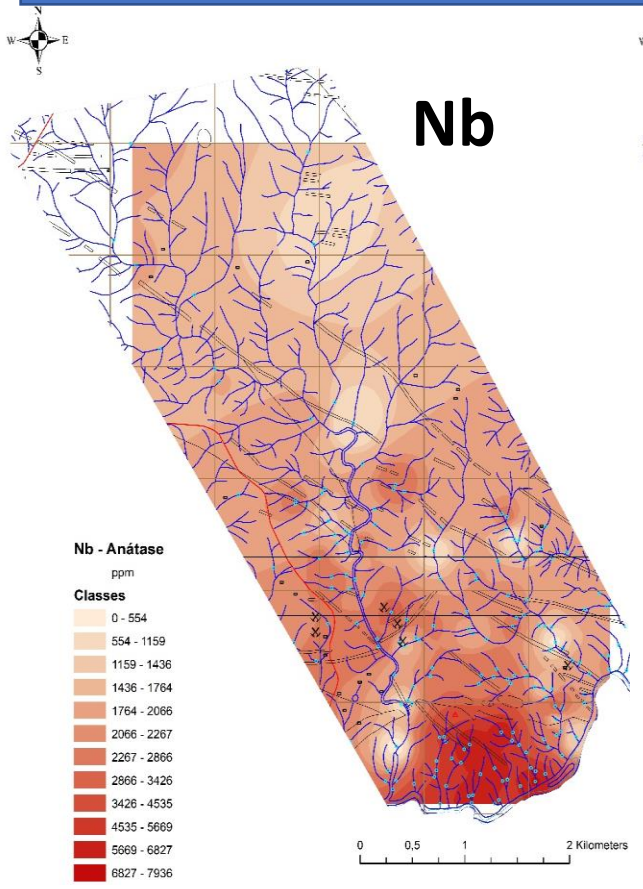
Exploration Tools – Trace Element Abundance Maps

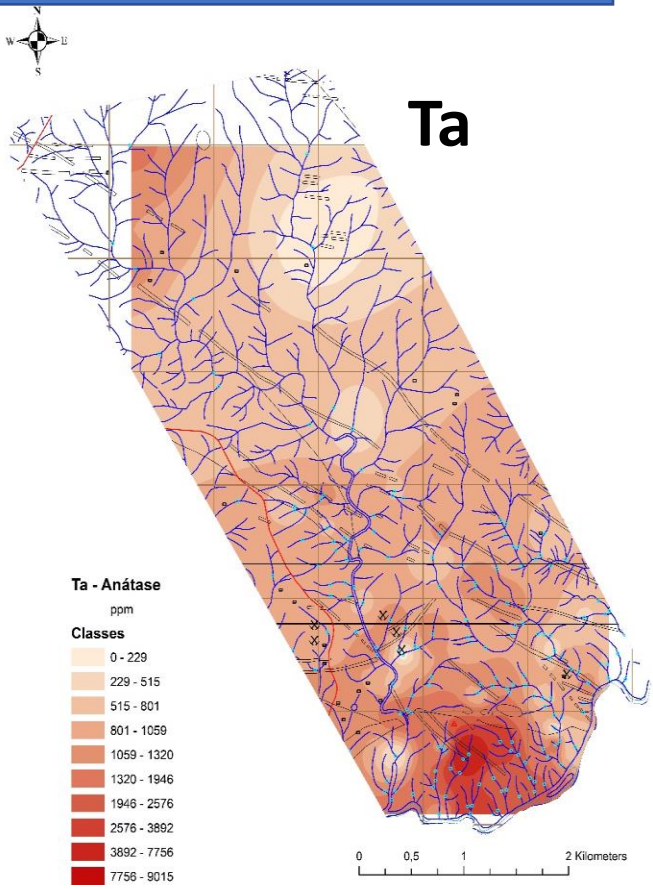
Rutile





Anatase



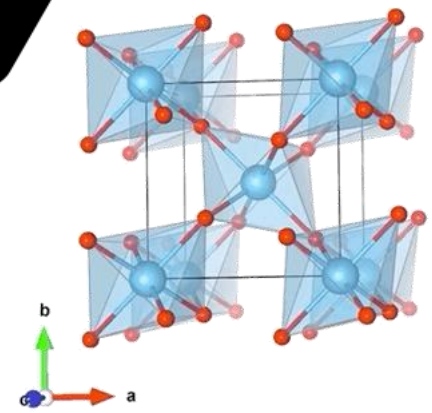


(Gracio, 2020)

Take Home Messages

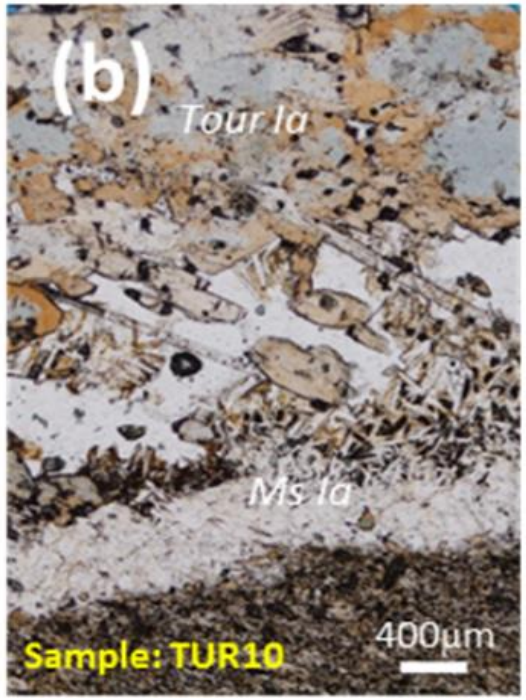
- Alluvial heavy mineral associations are a good proxy for local geology and mineralized areas.
- Alluvial heavy mineral abundance maps can pinpoint orebodies & unravel metamorphic and metasomatic processes related to the installation of productive intrusives.
- Alluvial rutile & anatase trace element geochemistry are an excellent exploration tool for Sn and W deposits:
  - Sn-rich and W-rich primary magmatic rutile can be used as a proxy for specialized and productive Sn & W granites;
  - Primary hydrothermal rutile & anatase, precipitated from mineralizing fluids, can be either enriched or depleted in HFSE depending on their relative position in the paragenetic sequence in respect to cassiterite (Sn), wolframite (W) and scheelite (W), or other HFSE forming minerals.

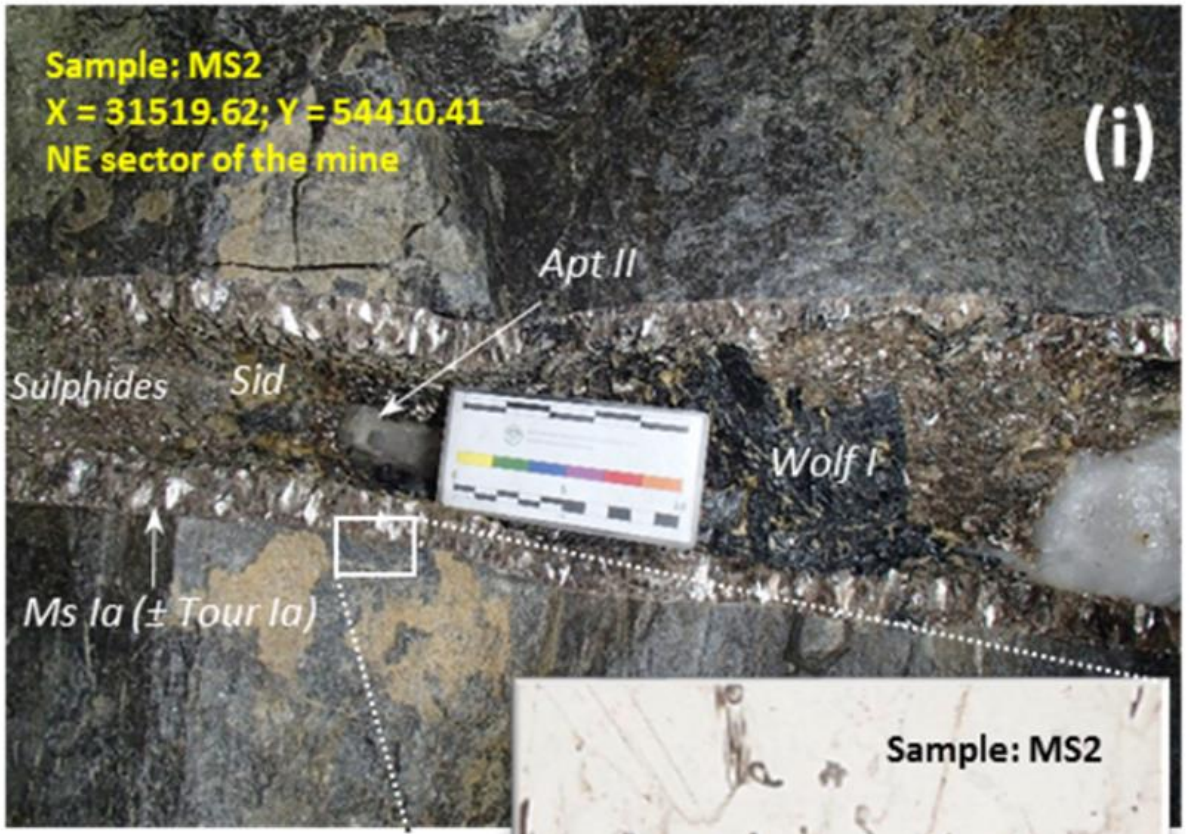
Thank You

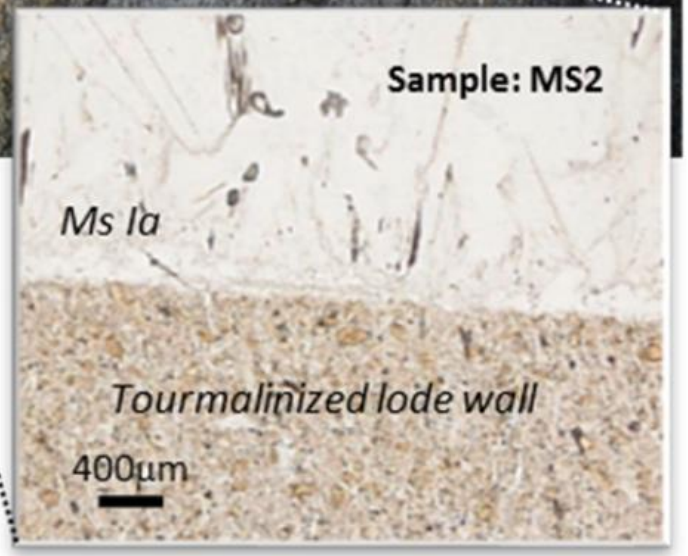


To be continued… Part III in about 5-10 min! Stay tunned! There will be coffee afterwads!

Panasqueira tourmaline



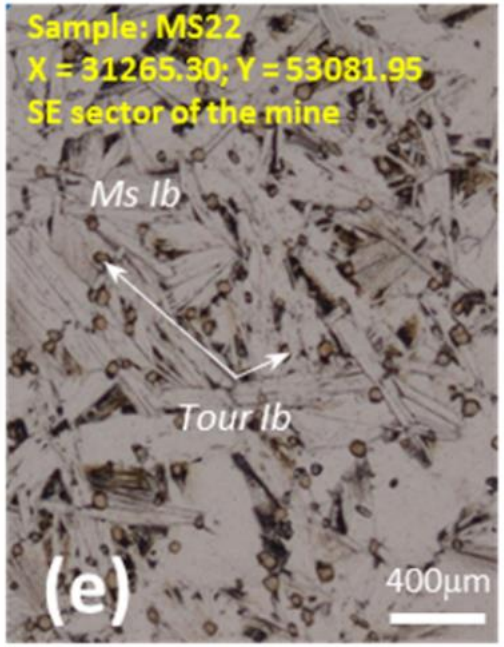


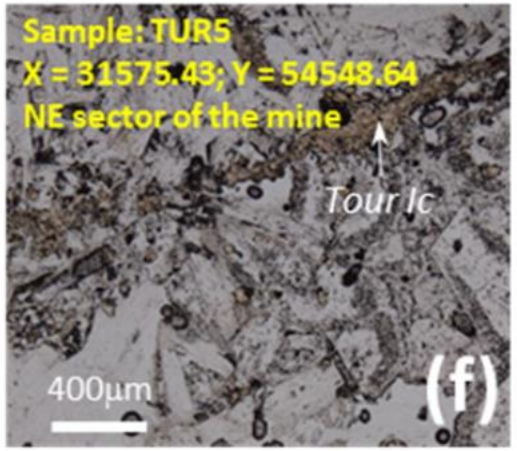


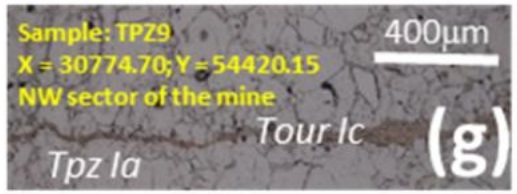
Tourmaline (Ia) selvages of quartz lodes intergrown with Ms(Ia) preciding Wfm(I) and Cass(I) metasomatic halos

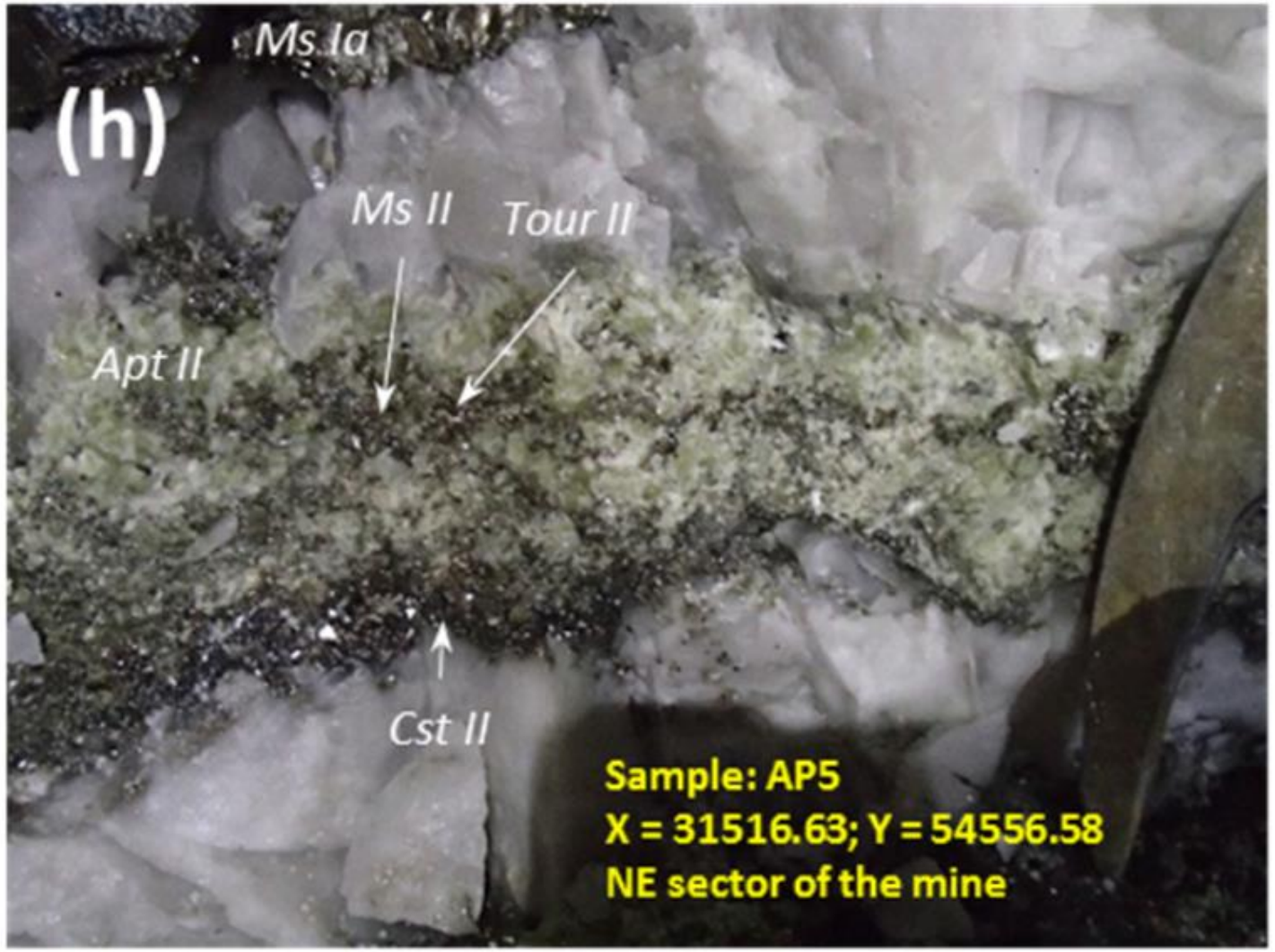
(Mateus et al. 2020)

Panasqueira tourmaline









Tourmaline Ib – Intergrown with MS(II)
Thin selvages with Tpz

Tourmaline Ic – veinlet structures

Tourmaline II – in selvages and reopening of Qz veins with Cst II and Ap II (OSS2)

(Mateus et al. 2020)