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## **Serpentinization of the Ronda Massif (Spain): structural control and fluid origin, a framework for metal mobility**

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## 1. Introduction

Serpentinization is a hydrothermal transformation of ultramafic rocks, such as the Sub-Continental Lithospheric Mantle (SCLM) which represents a reservoir of metals (e.g., Cu, Zn, Co, Ni, Cr, PGE, V, Ti, Au). During their exhumation, the mantle rocks are affected by various hydrothermal processes which can lead to economically viable metal deposits (e.g., seafloor massive sulfides; Patten *et al.*, 2022). Despite some works (Deschamps *et al.*, 2013; Lawley *et al.*, 2020), **the characteristics of metal mobilities during serpentinization still remain poorly constrained**, notably the related spatial scales. To address this issue, we have chosen a terrestrial example : the Ronda Massif (Spain). This massif is the largest remnant of SCLM in the world. It is partially serpentinized and is thus perfectly suitable to characterize metal mobilities at various scales (from the centimetre to the multi-kilometres scales). To date, **studies on the serpentinization of the Ronda peridotite remain scarce** (Pedrera *et al.*, 2016). Here we present the main serpentinization stages, then the structures along which serpentinization occurred and stable isotope data (*i.e.*, oxygen and hydrogen), as a pre-requisite to study metal mobilities.

## 2. Geological setting

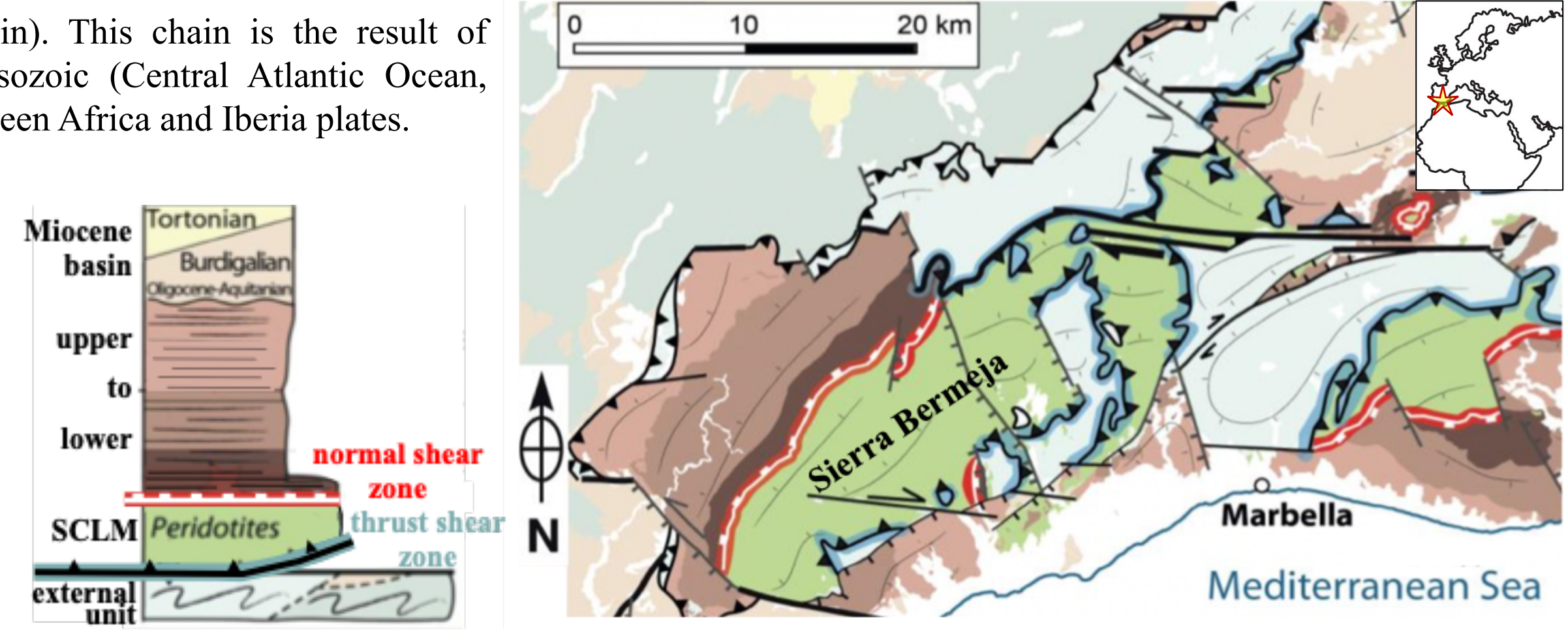
The Ronda Massif is located in the western Betic Cordilleras (Spain). This chain is the result of polyphase tectonics, starting from the oceanic openings during Mesozoic (Central Atlantic Ocean, Ligurian Tethys and Maghrebian Tethys), to Cenozoic convergence between Africa and Iberia plates.

The Ronda Massif is a paleolithosphere slice (*i.e.*, upper to lower crust with SCLM) exposed at the earth surface. However, the mechanisms and timing of this massif emplacement are still controversial.

To date, we retain 2 models :

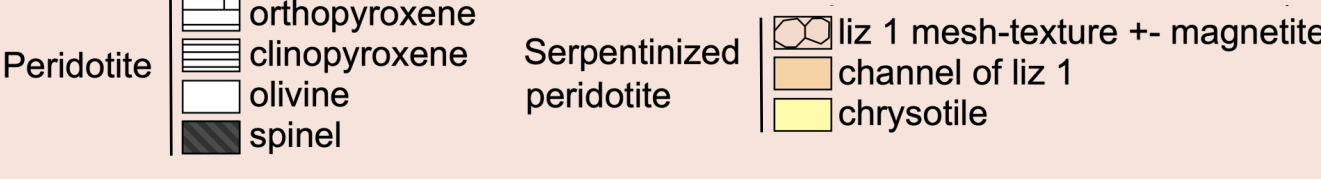
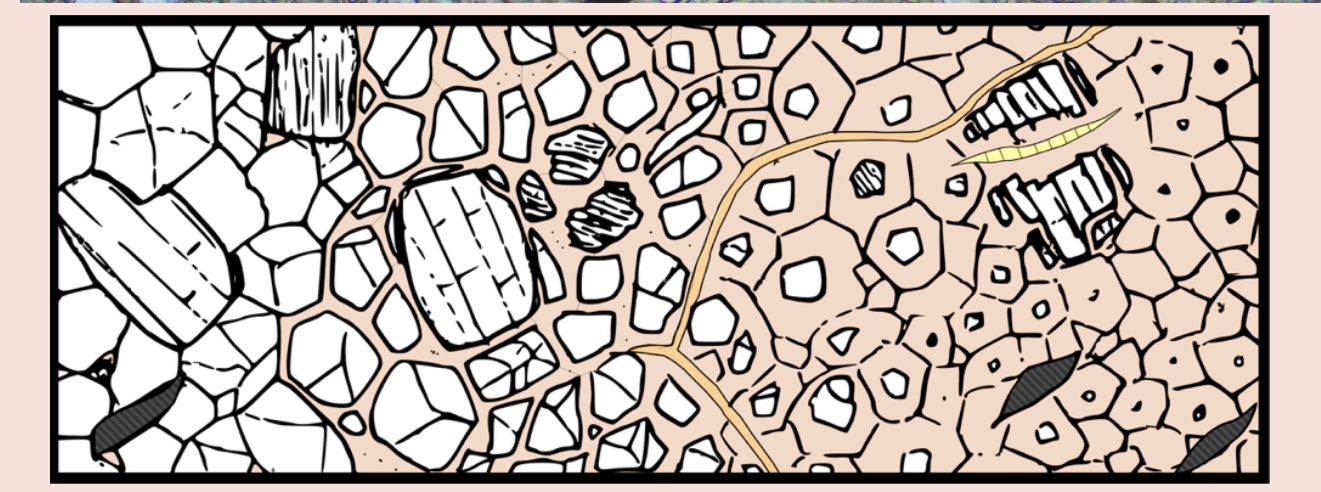
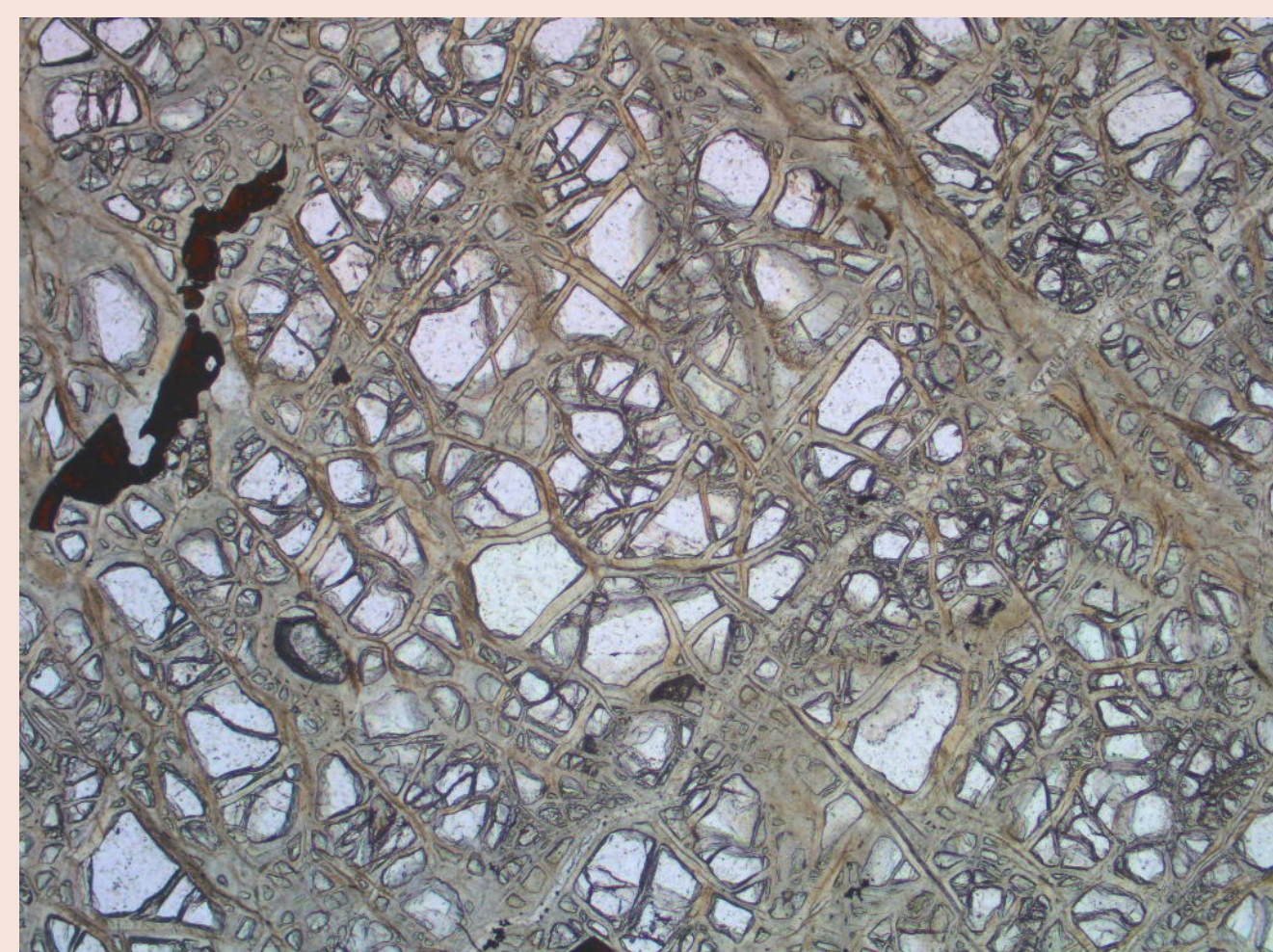
- i) transpressional emplacement (Mazzoli *et al.*, 2011),
- ii) back-arc rifting before thrusting (Frasca *et al.*, 2017).

The emplacement timing is approximated by dating differentiated felsic magmas that intruded the Ronda Massif between 19 and 22 Ma (U-Pb on zircon; Frasca *et al.*, 2017).

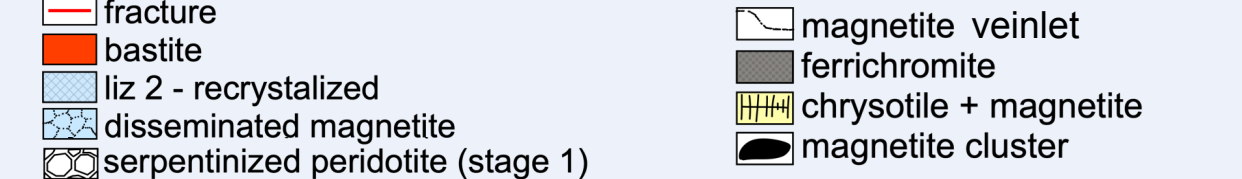
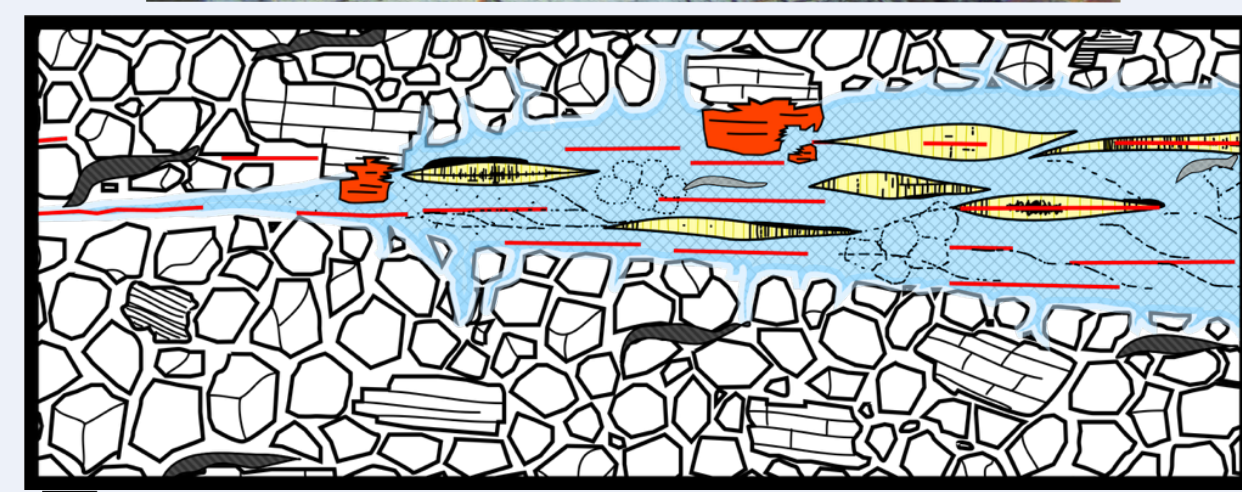
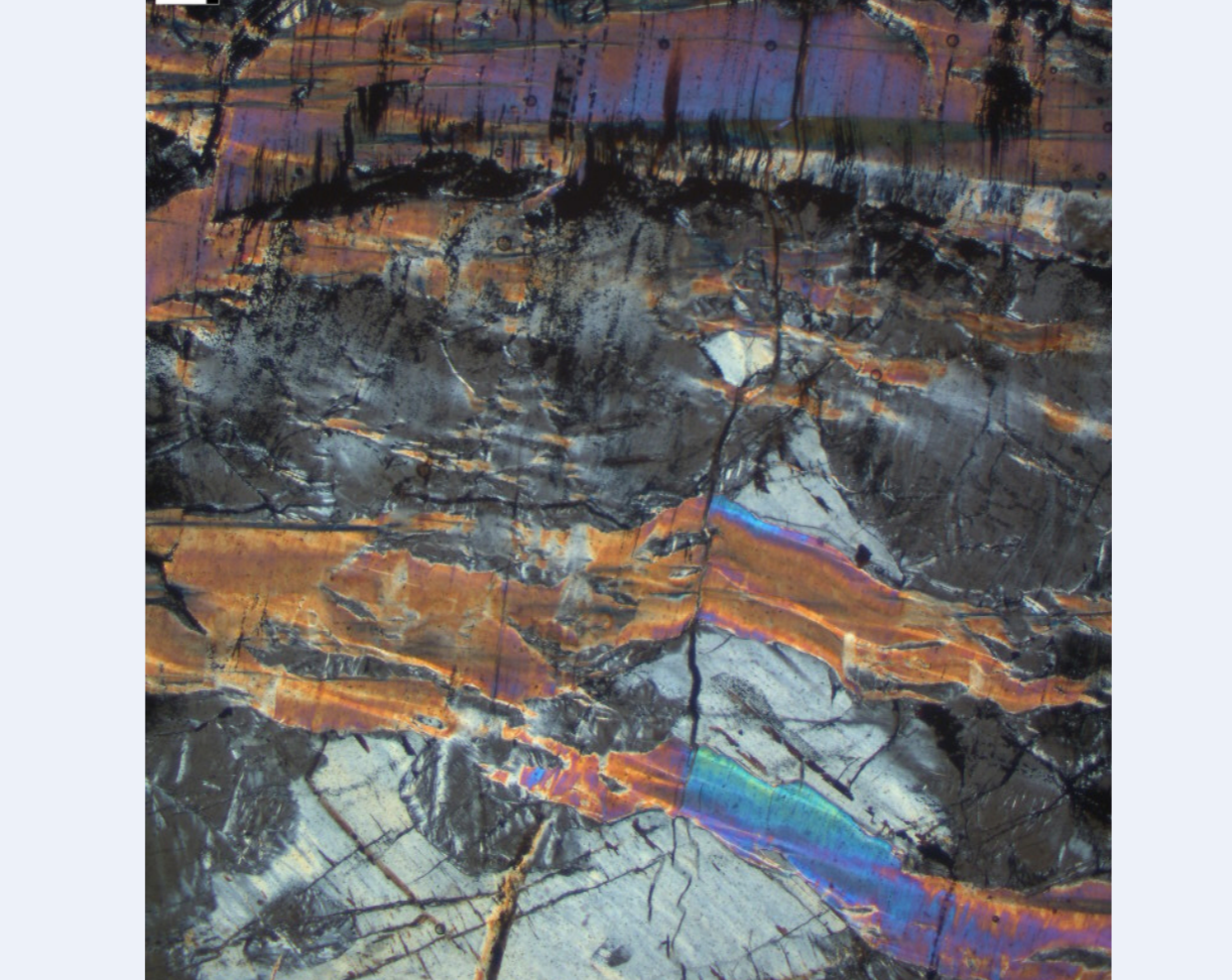
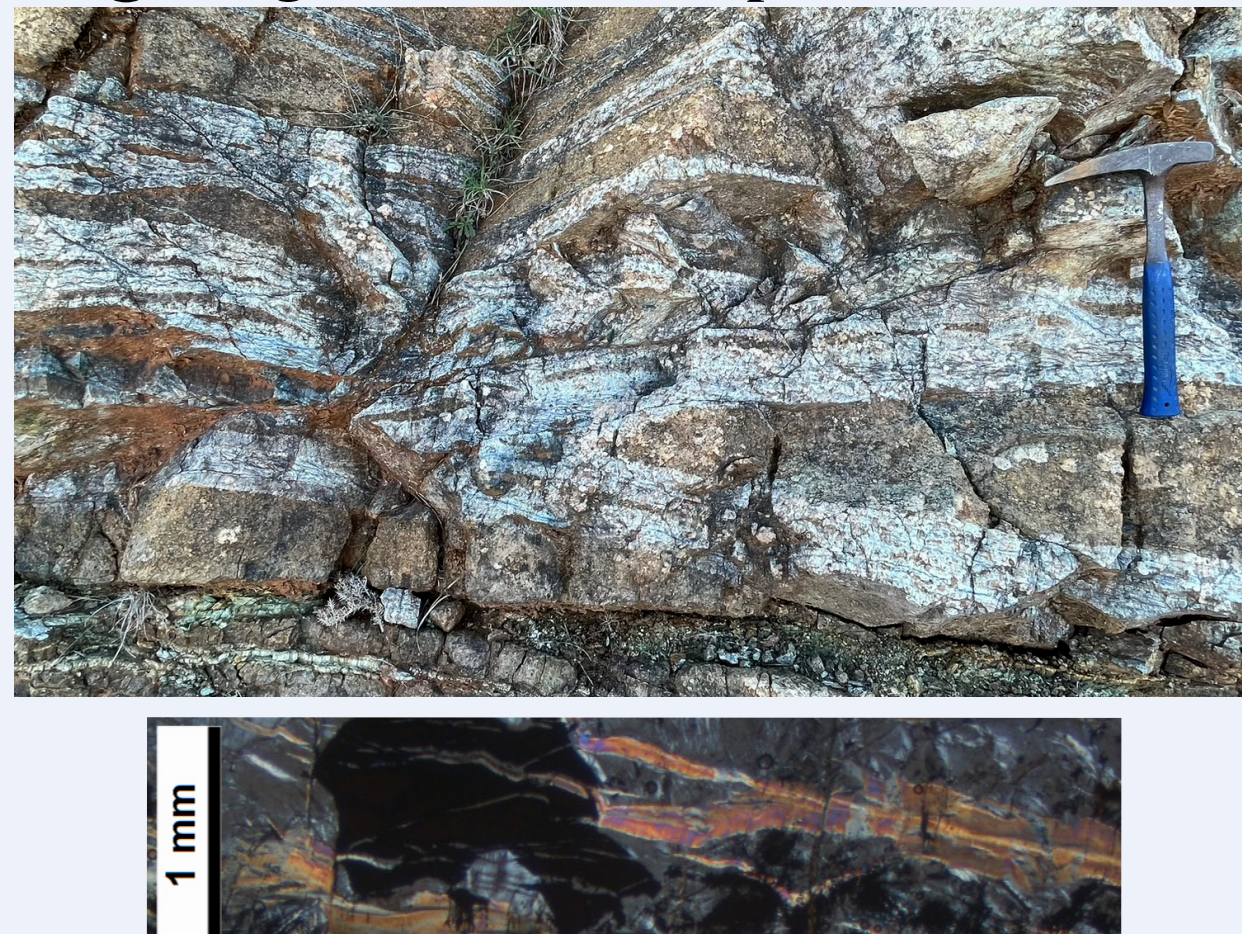


## 3. Three stages of serpentinization in the Ronda Massif

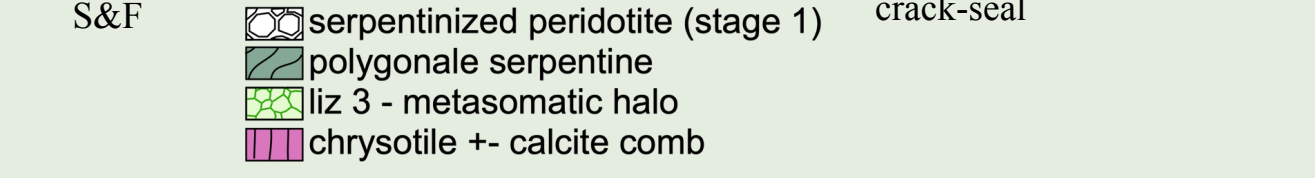
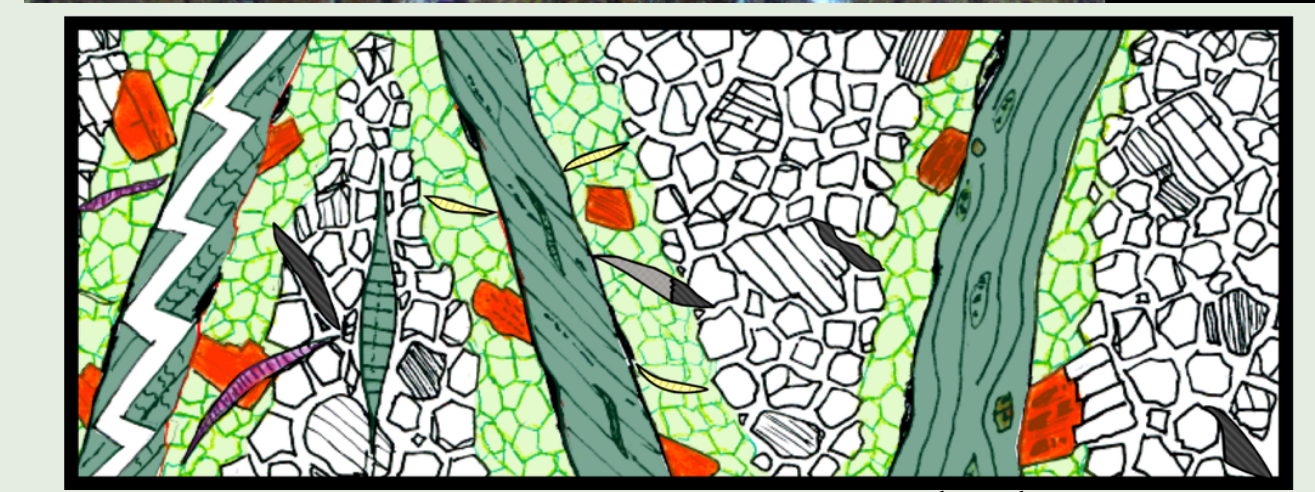
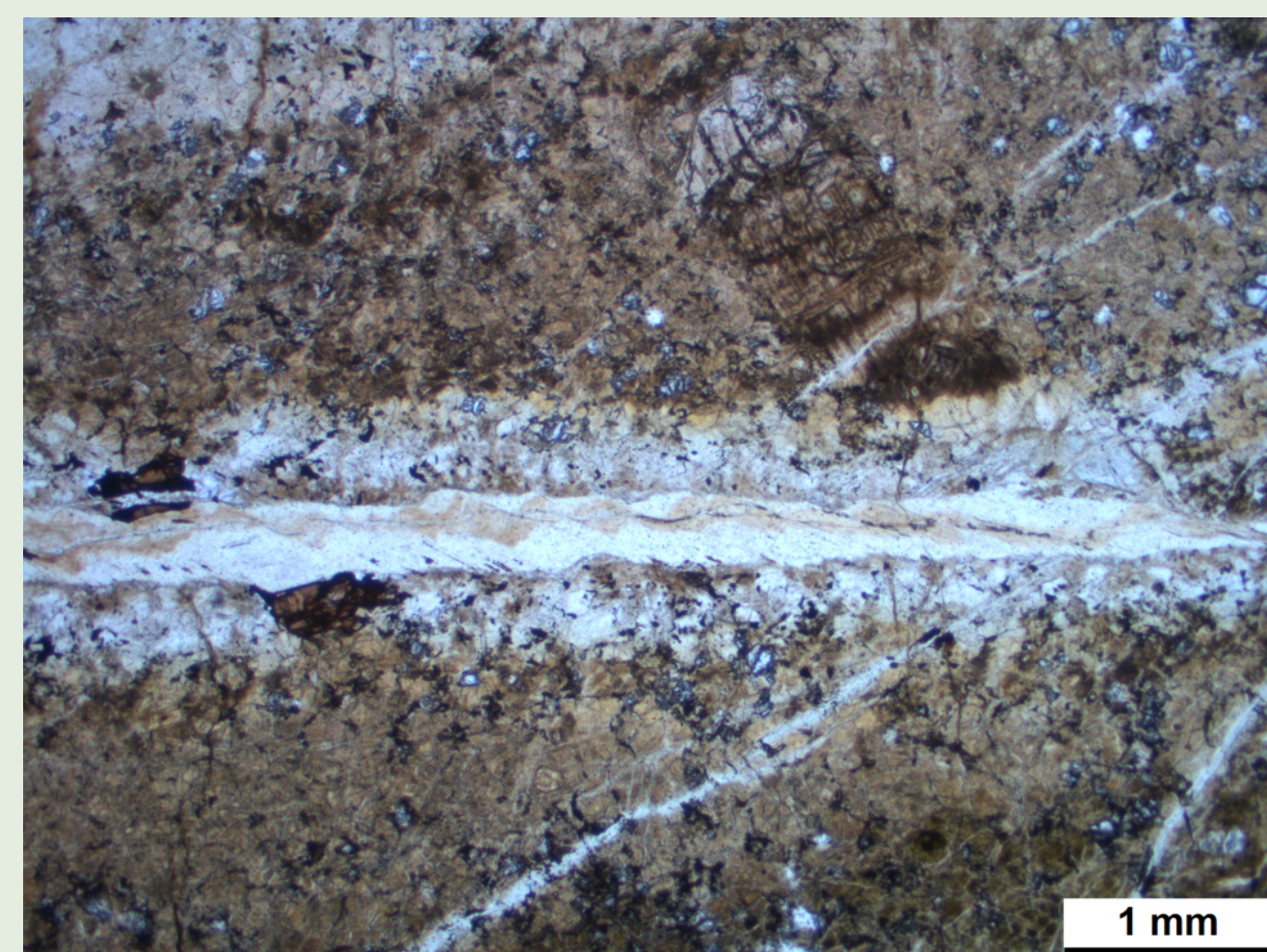
### Stage 1: pervasive mesh texture serpentinization



### Stage 2: corridor serpentinization



### Stage 3: syn-serpentinization cataclasis



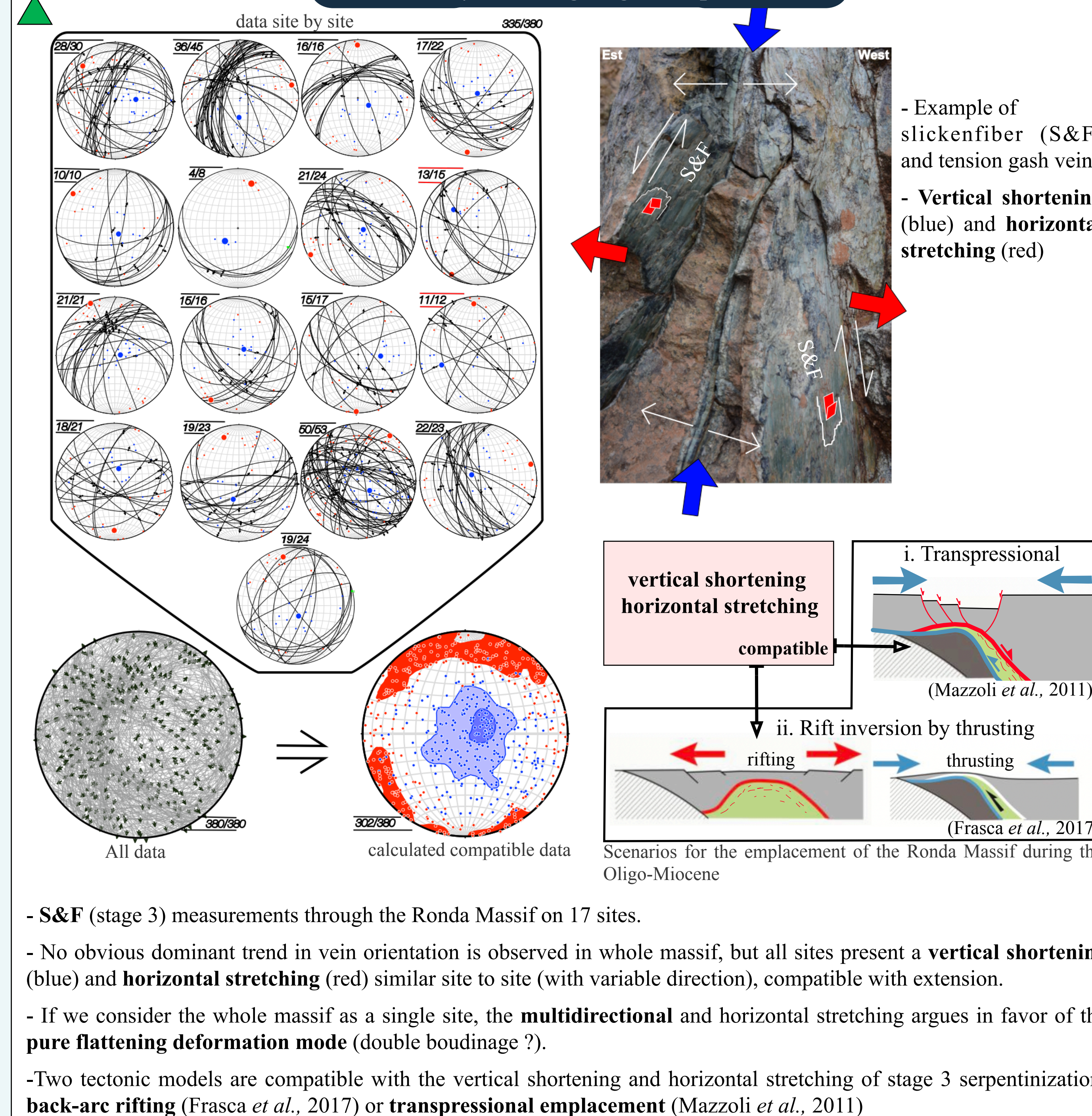
minerals	stages	stage 1	stage 2	stage 3	Other
Lizardite	serpentinized	liz 1 - mesh texture	liz 2 - vein - fibrous	liz 3	
Chrysotile	serpentinized		vein - fibrous or crack-seal		
Bastite	serpentinized				
Polygonal serp.	serpentinized				
Magnetite	serpentinized	mgt 1 - disseminated	mgt 2 - veinlet	mgt 3 - cluster	veinlet
Calcite	serpentinized				vein + comb
Others carbonates	serpentinized				
Syn-serpentinization deformation		?	?		
Intrusions		mafic 183-131 Ma		felsic 23 Ma	

- Stage 1 is represented by **pervasive serpentinization** with **variable rate** in peridotite. The serpentinized peridotite appears brown and massive in the outcrop, and contains **lizardite 1** in **mesh texture** with scarce magnetite.

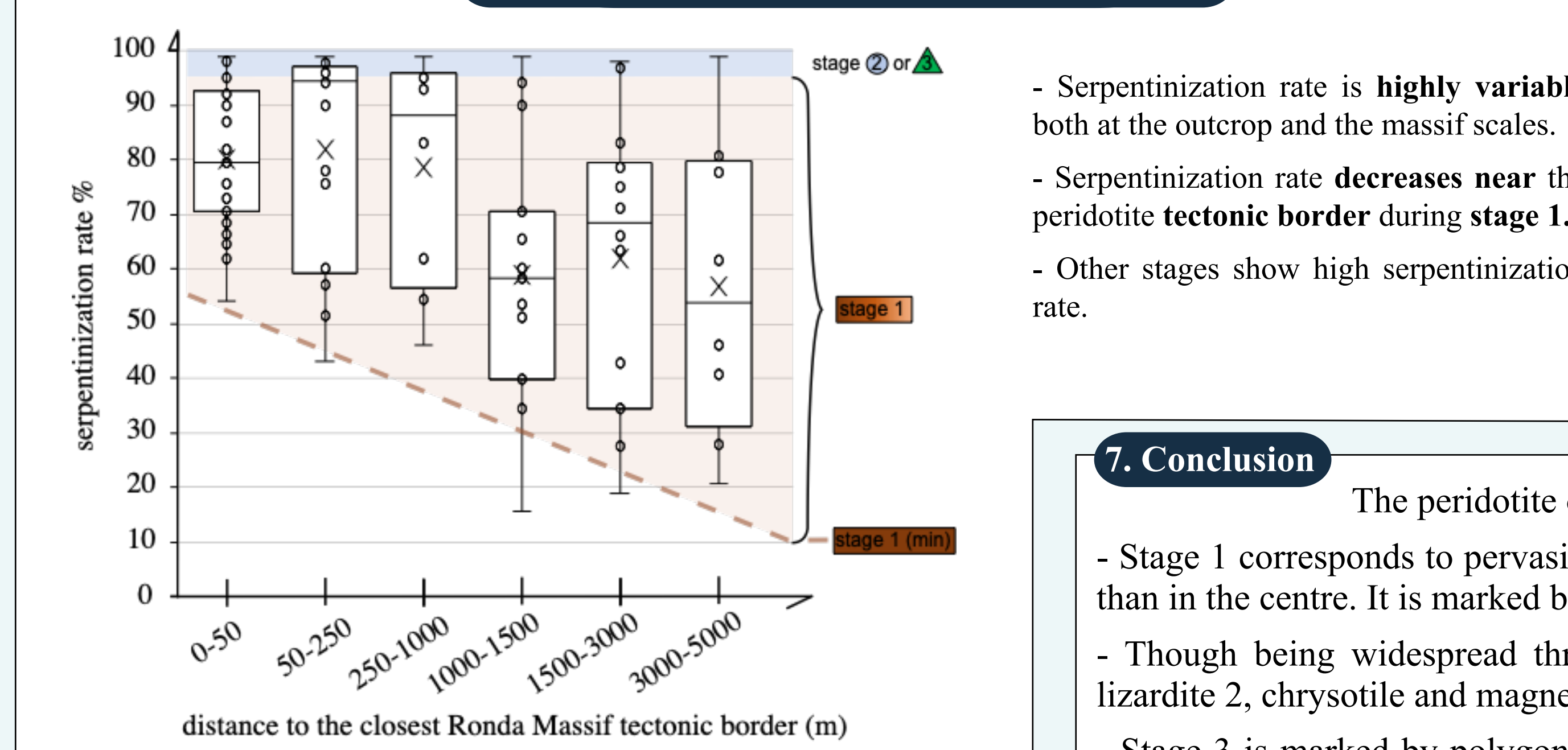
- Stage 2 corresponds to **localized serpentinization** in multi-centimetre white corridors, with development of **lizardite 2**, **bastite**, **chrysotile** and abundant **magnetite** (veinlet, disseminated and cluster).

- Stage 3 is associated to **cataclastic deformation**, with shear zones and multi-millimetre green syn-tectonic fibrous veins. The veins contain **polygonal serpentine** and/or **chrysotile**, with **lizardite 3**, **bastite** and **magnetite** cluster in metasomatic halo.

## 4. Strain analysis during stage 3 serpentinization



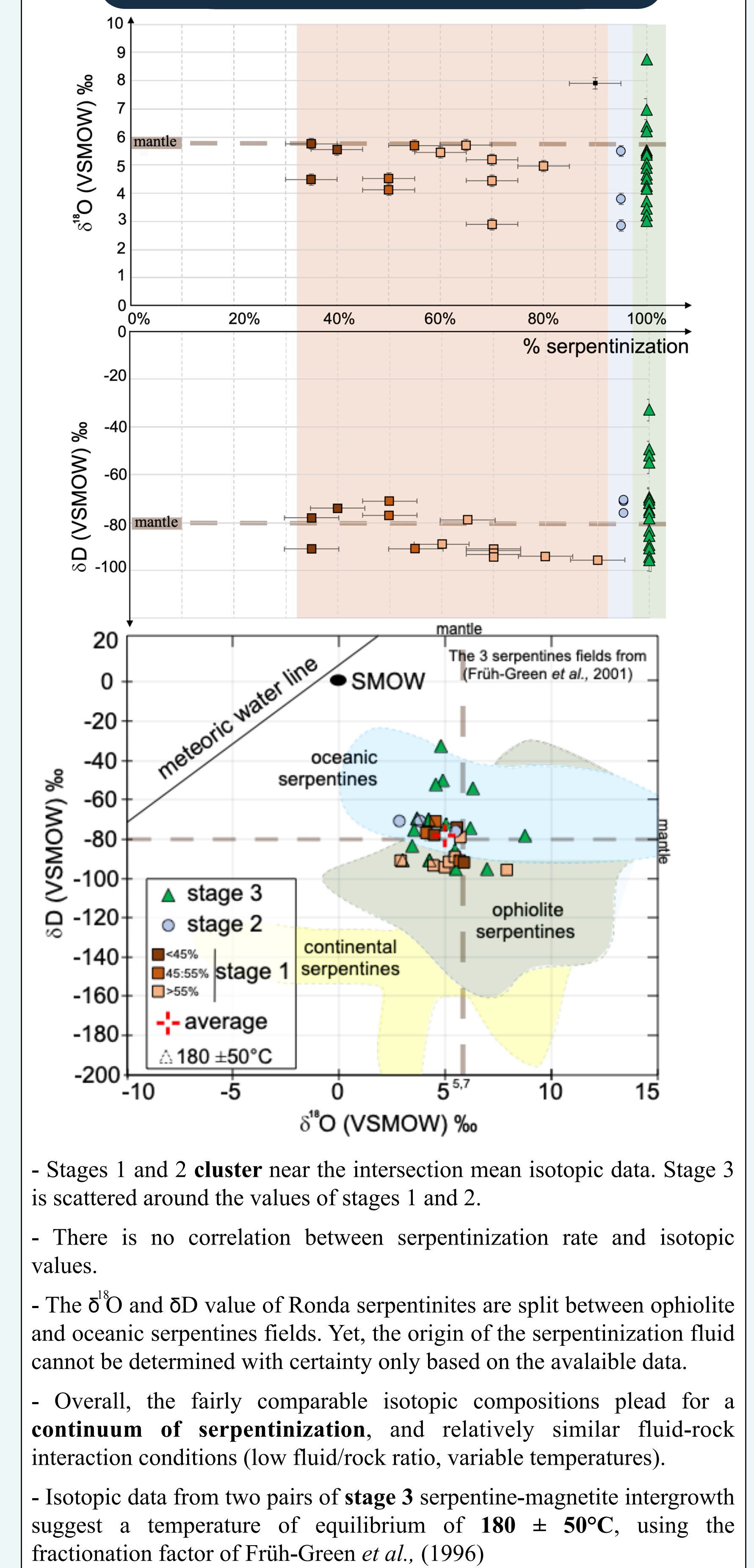
## 5. Serpentinization rate at the scale of the massif



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## 6. Oxygen and hydrogen isotope compositions



## 7. Conclusion

The peridotite of Ronda Massif has undergone three stages of serpentinization.

- Stage 1 corresponds to pervasive serpentinization more efficient near the outer contour of the massif than in the centre. It is marked by mesh texture lizardite 1.
- Though being widespread through the Massif, stage 2 consists of discrete cm-long corridors of lizardite 2, chrysotile and magnetite.
- Stage 3 is marked by polygonal serpentine veins which lie within cataclastic zones at temperatures around  $180 \pm 50^\circ\text{C}$  during the Oligo-Miocene. The cataclastic deformation is characterized by multi-directional horizontal stretching and vertical shortening, compatible with two tectonic scenarios.

The three serpentinization stages display comparable isotopic signatures with average  $\delta^{18}\text{O} \sim +5\%$  and  $\delta\text{D} \sim -79\%$ . Globally, both mineralogical and isotopic data suggest that stages 1 to 3 likely occurred during a unique, syn-tectonic, serpentinization event.