Plagioclase peridotite or olivine-plagioclase assemblage in orogenic peridotites: its implications on high-temperature decompression of the subcontinental lithosphere-asthenosphere boundary zone

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What we did in this study.

- We have examined four orogenic peridotite complexes, **Ronda, Pyrenees, Lanzo, and Horoman**, to clarify the extent of shallow thermal processing based on **olivine-plagioclase assemblage in plagioclase lherzolite**.
- The key approach of this study is to look at **textural relationships between olivine and plagioclase**, whose scale and mode of occurrence provide <u>extent and strength of thermal processing in the shallow upper mantle and thus asthenosphere activity related to the exhumation of lithospheric mantle</u>.

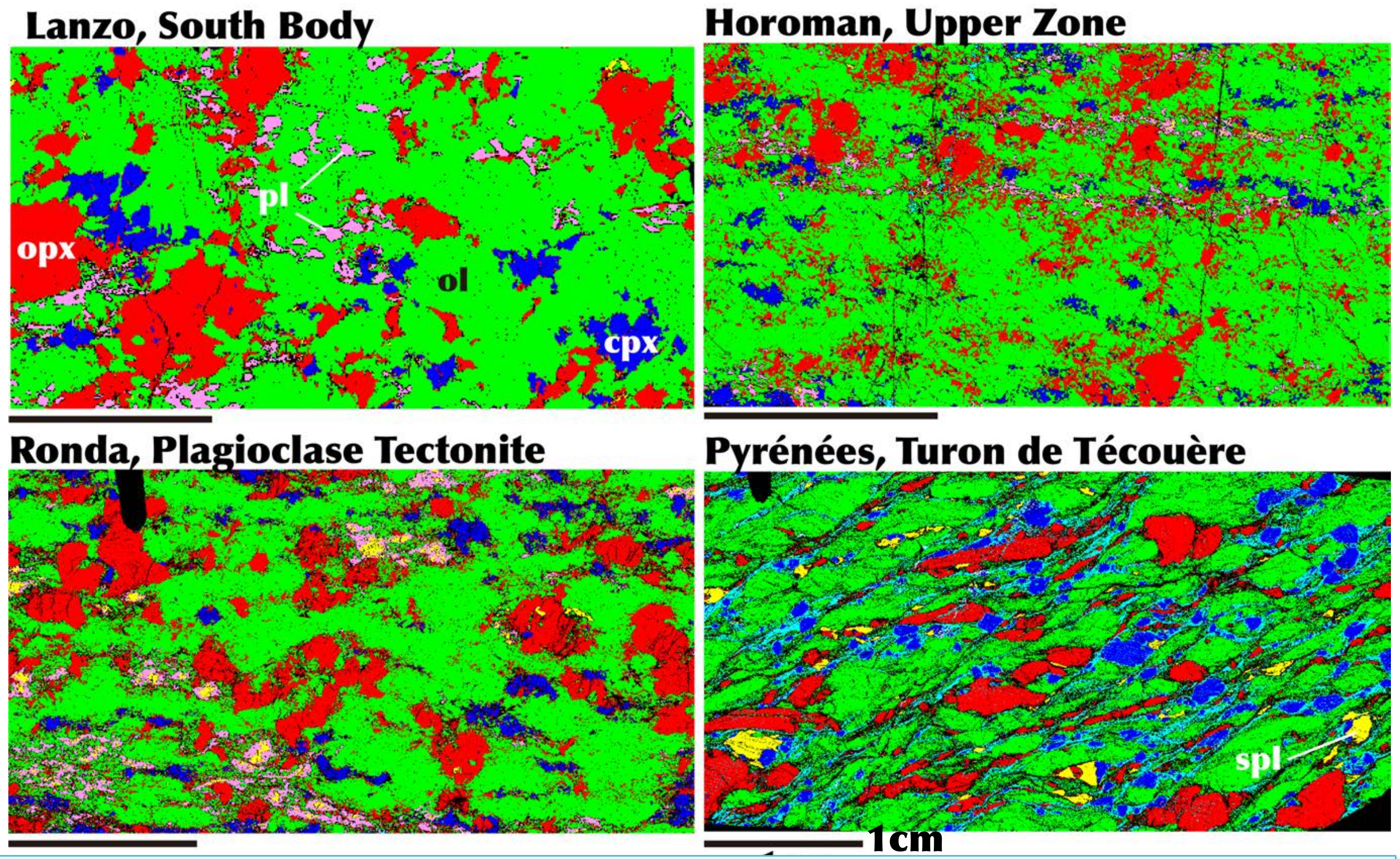
Plagioclase lherzolite proxy for dynamics of LAB

- Plagioclase (pl) -olivine (ol) assemblage in fertile system is not stable even at the depth of the upper most subcontinental lithospheric mantle (SCLM) because …..
  (1) The common crustal thickness in normal non-cratonic SCLM is ~35km.
  (2) The Moho temperature for the mean steady-state continental geotherm is much lower than 600°C.
  (3) The upper stability limit of plagioclase (plagioclase to spinel facies transition) becomes shallower with decrease in temperature.
  (4) Kinetic barrier for subsolidus reactions in the peridotite system becomes enormous at temperatures below 600°C.
- The occurrence of ol-pl assemblage in some orogenic peridotites thus implies transient and dynamic high-temperature (>800°C) processing at depth shallower than 20km
- High-T decompression of lithosphere-asthenosphere boundary (LAB) up to the depth closer to the Moho
  (1) Adiabatic decompression of high-T LAB → decompressional melting
  (2) Subsolidus heating to transform garnet or spinel peridotites to plagioclase peridotite but no transformation with efficient cooling

Examined Orogenic Peridotites

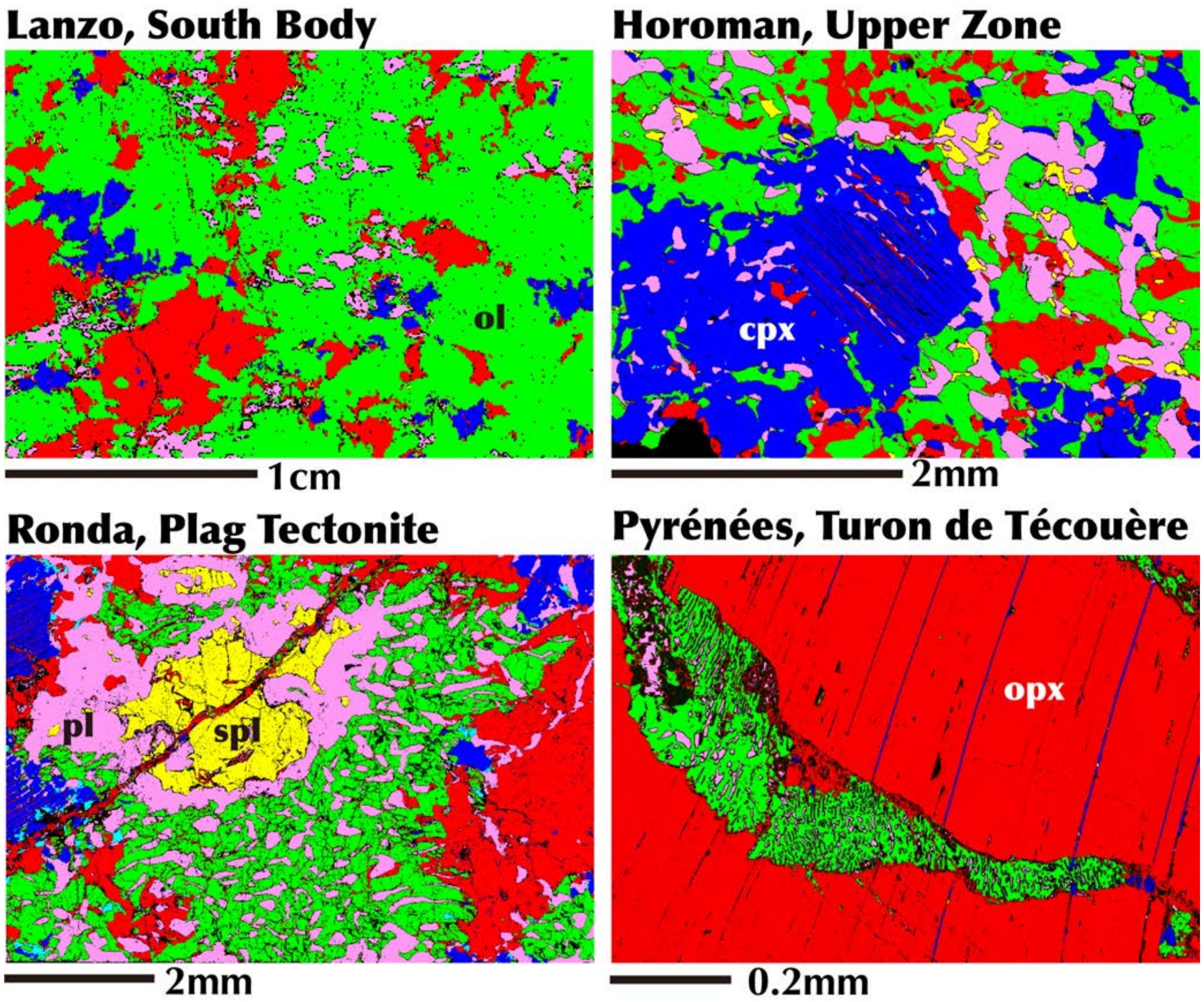
- Horoman, Hidaka Belt, Hokkaido, Japan
  - Takahashi and Ozawa (1995), Takazawa et al. (1996); Ozawa (1997, 2004); Takahashi (2001); Morishita and Arai (2001); Sawaguchi (2004); Odashima et al. (2008)
- French Pyrénées: Bestiac, Lherz, Moncou, etc.
  - Conquéré (1971, 1977); Fabriès and Conquéré (1983); Conquéré and Fabriès (1984); Sautter and Fabriès (1990); Fabriès et al. (1991, 1998); Ozawa et al. (2010) AGU; Ozawa et al. (2011) JpGU
- Ronda, Betic Cordilleras, Spain
  - Kornprobst (1969); Obata (1980); Van der Waal & Vissers (1993); Davies et al. (1993); Tubía (1994); Kornprobst et al. (1995); Morishita et al. (2001); Tubía (2004); Precigout et al. (2007); Lenoir et al. (2001); Garrido et al. (2011); Nagashima et al. (2008); Hidas et al. (2013a, b)
- Lanzo, Western Alps
  - Nicolas et al. (1972); Boudier and Nicolas {1972); Boudier, (1976, 1978); Nicolas (1984); Pognante et al. (1985); Bodinier, (1988); Bodinier et al. (1991); Müntener and Piccardo (2003); Piccardo et al. (2007); Kaczmarek & Müntener (2008, 2010); Guarnieri et al. (2012); Sanfilippo et al. (2014, 2017); Jollands and Müntener (2019)

Mode of occurrence of plagioclase



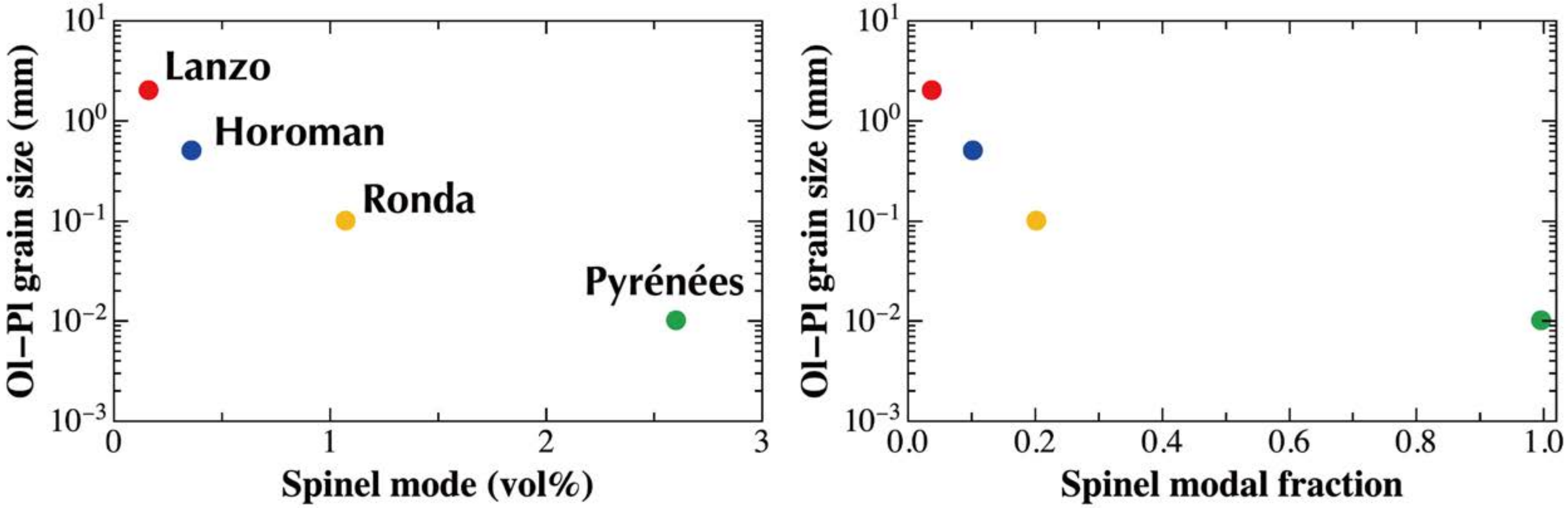
A variety of mode of occurrence of plagioclase in four examined orogenic peridotite bodies, indicating diverse thermal processing

Mode of occurrence pl-ol intergrowth



Lanzo: isolated pl in ol; Horoman: pl partially isolated and partially associated with spl; Ronda: pl in intimate association with spl surrounded by intergrowth with ol; Pyrénées: ditto but extremely fine-grained

Spinel mode vs. Olivine-plagioclase grain size

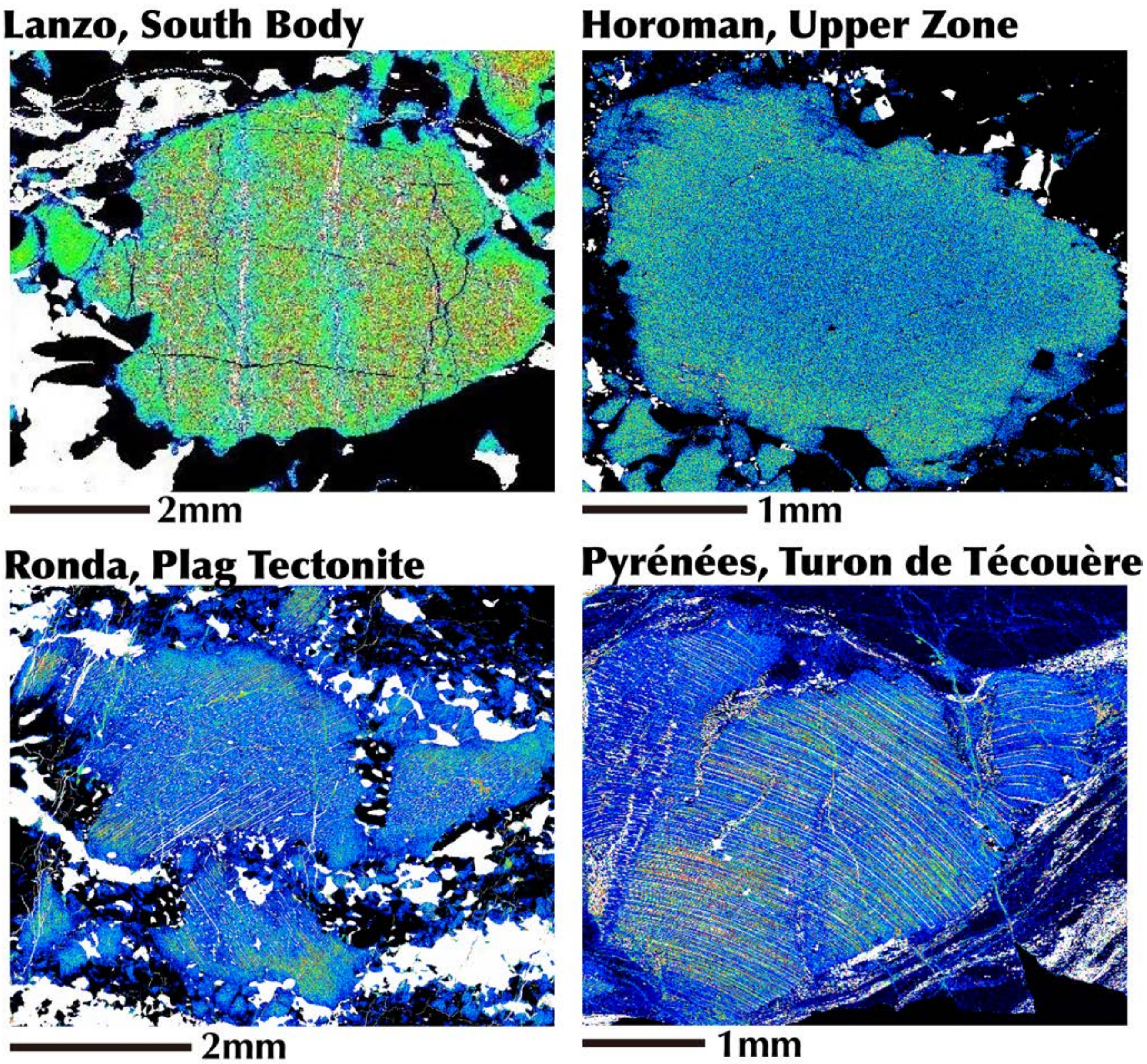


Lanzo	Horoman	Ronda	Pyrénées
(South)	(Upper Zone)	(Plag Tectonite)	(Turon de Técouère)

Increasing scale of plagioclase-olivine intergrowth
Increasing extent of reaction to form plagioclase+olivine

Increasing thermal processing during exhumation
Increasing extent of involvement of asthenosphere upwelling

Ca zoning in orthopyroxene



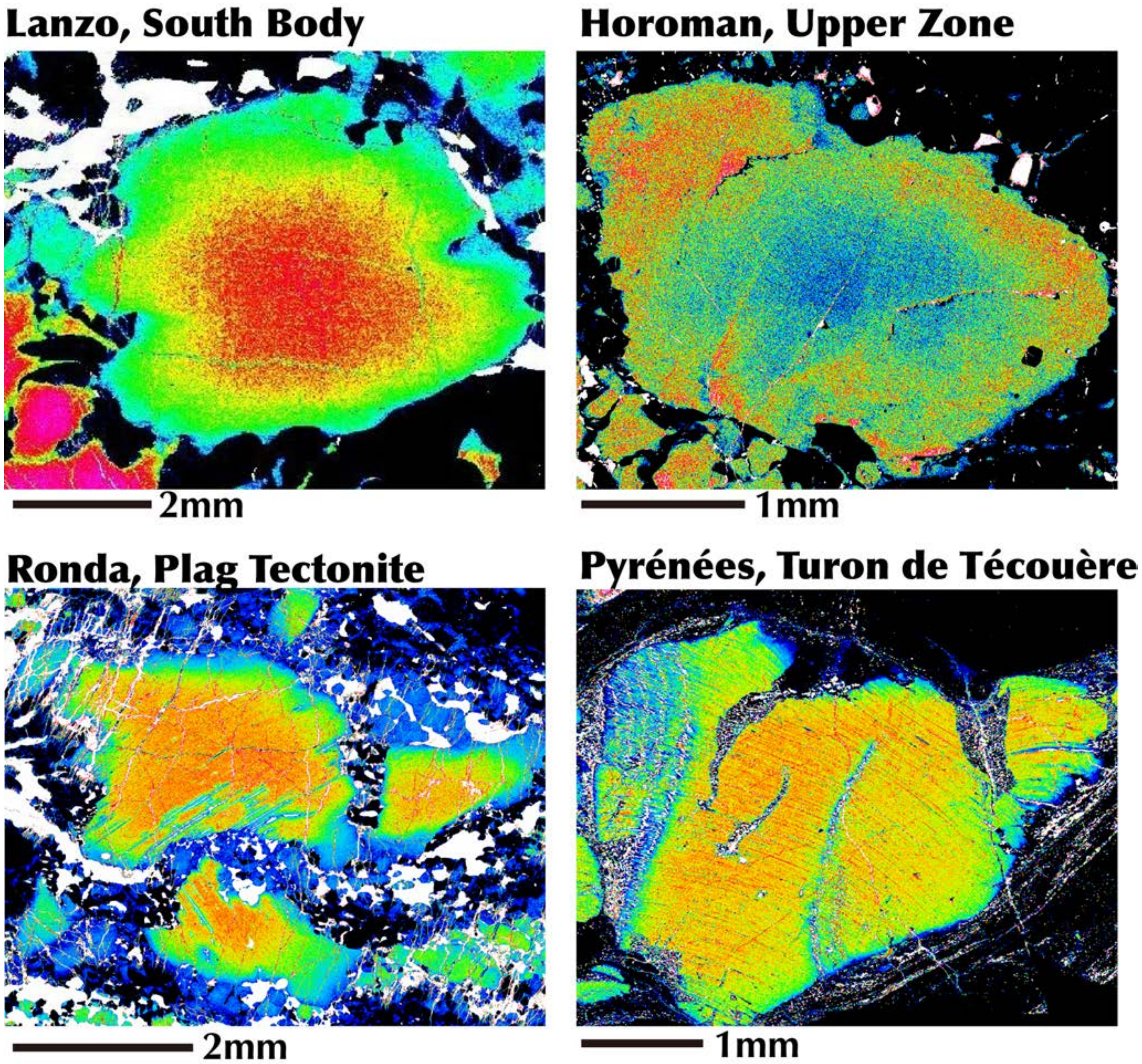
Lanzo:
trapezoidal pattern and sharp decrease in the margin, tilt boundary control

Horoman:
remarkable marginal high and central depression, no tilt boundary control

Ronda:
weak marginal high

Pyrénées:
gradual decrease, tilt boundary control

Al zoning in orthopyroxene



Lanzo:
remarkable gradual decrease, no tilt boundary control

Horoman:
remarkable marginal high and central depression, tilt boundary control

Ronda:
Gradual decrease

Pyrénées:
gradual decrease, tilt boundary control

Summary of our study

- The wide-spread occurrence of plagioclase peridotites and localized partial melting in Lanzo suggest exhumation along high temperature adiabatic paths from the thermally structured LABZ in the Seiland subfacies.
- The predominance of plagioclase peridotites and its localized partial melting in Horoman suggest exhumation along variously heated paths from the garnet stability field.
- The moderate development of plagioclase peridotites without partial melting in Ronda suggest exhumation along variously but weekly heated paths from the spinel-garnet stability field.
- The occurrence of minor plagioclase peridotites in Pyrénées suggest exhumation along cold path from the garnet-spinel facies boundaries.

See appendices for more details

Conclusions

- It is concluded that **the extent of shallower thermal processing decreases**, and thus **the extent of lithosphere thinning or asthenosphere upwelling becomes greater** in the order of **Pyrénées, Ronda (2nd stage), Horoman (Upper Zone), and Lanzo.**
- **Partial melting** was involved in the last two but not in the first two.
- This conclusion is **consistent with tectonic models** proposed for each orogenic peridotite bodies.

See appendix 2 for details

Appendix 1

Comparison of Petrologic Characteristics of Orogenic Peritotites

General information	Ronda	Pyrénées	Lanzo	Horoman
Length and width	30 x 10 km	<1.5 x 2km	20 x 10km	10 x 8km
Structure	Layered, Ga-Sp/Sp/Plag zoned	sedimentary/tectonic block	Foliated, North, Central, and South	Layered, Upper and Lower zones
Host rocks and geology	granulite (kinzigite)	flysch deposit/ metamorphosed limestone	Low T/high P metamorphic rocks	Hight T medium P metamorphic rocks
Melting age	1.2-1.4Ga	450-500Ma/138-177Ma/105Ma	400-700Ma / 158-163 Ma	833±78Ma
Emplacement age	22Ma/24Ma	92-104Ma/101-107Ma	>55 Ma	20.6±0.5Ma/23.0±1.2Ma
References (isochron ages)	Priem et al. 1979; Zindler et al. (1983); Reisberg et al. (1989)	Henry et al. (1998); Albarède & Michard-Vitrac (1978)	Bodinier et al. (1991); Kaczmarek et al. (2008); Rubatto et al. (2008)	Yoshikawa & Nakamura (2000); Yoshikawa et al. (1993); Kaneoka et al. (2001)

Key Primary Lithologies	Features	Ronda	Pyrénées	Lanzo	Horoman
Garnet lherzolite	spatial scalse	~1km local	< cm	not present	wide spread
	garnet	relict present	no relict	-	no garnet relict
	reaction	2px+sp kelyphite/symplectite	2px+sp symplectite (small-scale)	-	2px+sp symplectite
	ol + plag assemblage	(no examination)	(no examination)	-	common excepting refractory rocks
Garnet pyroxenite	spatial scalse	<2km local	common	not present	probably wide spread
	garnet	relict common	relict common	-	not present
	garnet breakdown	opx+sp+plag kelyphite	opx+sp+plag kelyphite	-	not clear (rare symplectite)
	ol + plag assemblage	intergrowth~granular	limited to late-stage vein	-	mostly granular wide spread
Spinel lherzolite	spatial sclale	~1-2km local	wide spread	refractory rocks/local in the south	occur as refractory layer
	spinel	Al-rich common	Al-rich common	Cr-rich	Cr-rich
	reaction	local rim of ol+plag intergrowth	non	non	non
	ol+plag assemblage	intergrowth present locally	(no examination)	(no examination)	(no examination)
Spinel pyroxenite	spatial sclale	~1-2km local	common	common	not common?
	spinel	relict common	Al-rich	relict	relict?
	reaction	rimmed with ol+plag	rimmed with garnet or plag depending on the distance from the host peridotite	rimmed with plag	rimmed with plag
	ol+plag assemblage	intergrowth on various scale	plag rim on spinel	common/as plag rim	common and wide spread
Plagioclase lherzolite	spatial scale	~1-2km local	ultramylonite/psuedotachylyte onlu	wide spread	common
	plagioclase	rimming spinel/in sp-plag intergrowth	very rare/ fine granular or intergrowth with olivine	isolated/rimmin spinel	isolated (Upper Zone) / in ol + sp + plag fine-grained aggregate (Lower Zone)
	reaction	all from 2px-sp, but rare plag vein in dunite	2px-sp or from melt?	plag rim on spinel common	2px+sp aggregate or symplectite to plag+ol
	ol+plag assemglabe	intergrowth on various scale	very rare in veins or from Touron de Técouèr	wide spread	wide spread

Appendix 2

Lithesphere-Asthenosphere Boundary Processes and Tectonics from Orogenic Peridotites

Interpretation/Tectonic models		Ronda	Pyrénées	Lanzo	Horoman
Heating and melting/melt migration/ ascent depth ranges	melting	extensive/non	local shear heating/psuedotachylyte	extensive	locallized partial melting
	melt migration	extensive/fracture	non	extensive	minor-extensive (spatial variability)
	lithosphere heating	non (sp)/weak (pl)	very weak	non	strong
	initial depth of litho.	garnet facies/spinel facies	ariegite subfacies	seiland subfacies	garnet facies
	final depth	sp facies/plag facies	seiland subfacies	plag facies	plag facies
Extent of lithosphere thinning or LAB shallowing		1st stage: moderate; 2nd stage: minor	strongly suppressed	extreme	moderate-extensive
lithosphere and asthenosphere boundary processes		Stwo-stages of asthenosophere upwelling. The first one was deep from the garnet to spinel stability fields induced by extensional passive upwelling. The second one was shallower close to the plagioclase stability field induced by forced convective upwelling.	Exhumation of continental lithosphere with effective cooling from above and suppressed thermal effects from the asthenospheric	Completely passive lithosphere and asthenosphere upwelling associated with melting/melt segregation and melt-rock interaction near the LAB	Exhumation of deep lithosphere with intensive heating leading to localized partial melting without significant melt segregation
Tectonic models		1st stage: Weak continental streching induced by slab rollback with keeping the crustal section maintained; 2nd stage: induced asthenospheric flow induced by subduction breakoff	Detachment tectonics leading to mantle exhumation and denudation inducing submarine gravity sliding (east) and later inversion tectonics (west)	Rapid continental rifting ending up a development of seafloor spreading and partial melting	Small-scale convection induced by subduction and possible slab breakoff
References (tectonic models)		Garrido et al. (2011)	Lagabrielle & Bodinier (2008); Lagabrielle et al. (2010)	Müntener & Piccardo (2003)	Tanoue (2020 MS)