

# Deciphering dynamics of thermal events at lithosphere-asthenosphere boundary from peridotite xenoliths of Ichinomegata maar, NE Japan

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Mantle xenoliths are fragments of mantle materials almost instantaneously transported to the surface by alkali basalt or kimberlite magmas (Nixon, 1987). They are unique in that they record temporal changes of mantle processes in chemical zonings and microstructures of constituent minerals. Thus, such information can potentially constrain time-dependent dynamic processes occurring in the lithosphere-asthenosphere boundary (LAB) zone, where mechanisms of heat and material transfer drastically change (Sleep, 2005, 2006). In this regard, Takahashi (1980) and Koyaguchi (1986) achieved key contributions. They examined chemical zonings of olivine and pyroxenes in spinel peridotite xenoliths from Ichinomegata, a latest Pleistocene andesitic-dacitic maar located in the back-arc side of NE Japan arc (Katsui et al., 1979). They clarified a variety of thermal history that the xenoliths underwent, but processes responsible for the diversity is not resolved yet because the derivation depth was not constrained. We have conducted very careful geothermobarometry of spinel peridotite xenoliths from Ichinomegata maar and successfully reconstructed the thermal, chemical, and rheological structures of the LAB zone beneath NE Japan arc at the time of Ichinomegata maar formation (80-60 ka) (Sato and Ozawa, 2017, 2018, JpGU meeting; Sato and Ozawa, 2016, 2017, AGU fall meeting; see our companion presentation in this meeting). We examined temporal changes of the structures through analyses of chemical zonings of pyroxenes in 9 plagioclase and spinel peridotite xenoliths from Ichinomegata.

In our previous study, the depths and temperatures of 8 of the 9 xenoliths just before the xenolith extraction are estimated to range 28-55 km and 828-1081 °C. The mantle beneath Ichinomegata consists of shallow (28-32 km), low temperature, granular (less strained), and amphibole-bearing zone and deep (41-55 km), high temperature, porphyroclastic (strained), and amphibole-free and melt-bearing zone. We identified the shallower zone as lithospheric mantle, the deeper zone as LAB zone, and that their boundary was controlled by wet solidus.

We obtained Ca, Al, Cr, and Ti zonings of large clinopyroxene and orthopyroxene using EPMA at the University of Tokyo and analyzed them with a diffusion model. The zoning patterns of Ca, Al, and Cr of pyroxenes allow us to identify 4 different thermal histories from 4 types of chemical zonings for orthopyroxene (O1-O4) and 3 types for clinopyroxene (C1-C3) as summarized in Table 1. They are (1) continuous cooling at a cooling rate of  $\sim 1 \times 10^{-4}$  °C/y over the time scale of  $\sim 1$ -10 million years from  $\sim 1000$  to  $\sim 830$  °C (constrained from O1 and C1), (2) cooling followed by weak heating at  $\sim 900$  °C over the time scale of  $\sim 10$ -100 thousand years (from O2 and C1), (3) cooling followed by strong heating at  $\sim 1050$  °C over the time scale of  $\sim 1$ -100 thousand years (from O3 and C2), and (4) prolonged cooling and heating at  $\sim 1000$  °C (from O4 and C3). There is a systematic depth variation of thermal histories as summarized in Table 2. It is notable that the shallow lithospheric mantle is characterized by simple cooling or cooling followed by weak heating and the deep LAB zone by cooling followed by strong heating. This systematic depth variation requires a thermal perturbation of asthenospheric mantle beneath the deeper LAB zone, most plausibly asthenospheric upwelling.

The age of the Japan Sea opening is comparable to the time scale of cooling estimated from O1 and C1, and the continuous cooling at the shallow lithospheric mantle is attributable to the cooling of the

back-arc basin lithosphere, The timescale of the heating event in the deep LAB zone is too short to be explained by LAB-fixed heat conduction model. Effective heat transportation mechanisms are necessary, either partial crystallization of melt generated in the asthenosphere that passed through the LAB zone as advocated by Takahashi (1980) or extensive lithosphere thinning.

Keywords: lithosphere-asthenosphere boundary zone, spinel peridotite xenolith, thermal history, chemical zoning

**Table 1.** Patterns of chemical zonings in orthopyroxene and clinopyroxene.

Zoning type	Patterns of zoning profiles from core to rim		
	Ca	Al	Cr
Orthopyroxene			
O1	simple decrease	simple decrease	
O2	decrease followed by weak increase	decrease followed by weak increase	
		decrease followed by weak increase	simple decrease
O3	decrease followed by intense increase	decrease followed by intense increase	
O4	faint increase	faint decrease	
Clinopyroxene			
C1	simple increase	simple decrease	
C2	simple decrease	simple increase or decrease followed by intense increase	
C3	flat	faint decrease	

**Table 2.** Depth variations of chemical zoning types of pyroxenes and thermal history.

Sample name	Pressure (GPa)	Depth (km)	Temperature (°C)	Chemical zoning of pyroxenes	
				Types	Decoded thermal history
HK64081206g	0.72 ± .52	28 ± 16	829 ± 23	O1 & C1	Simple cooling.
HK64081206c	0.80 ± .70	30 ± 21	828 ± 30	O1 & C1	Simple cooling.
HK64081206d	(0.82)	(31)	(875)	O2 & C1	Cooling followed by weak heating.
HK66031502	0.85 ± .42	32 ± 13	905 ± 19	O2 & C1	Cooling followed by weak heating.
IC81-5	1.16 ± .29	41 ± 9	1017 ± 15	O4 & C3	Cooling and long heating.
HK64081205a	1.29 ± .24	45 ± 7	1050 ± 12	O3 & C2	Cooling followed by strong heating.
IC81-8	1.46 ± .37	50 ± 11	1052 ± 19	O3 & C2	Cooling followed by strong heating.
HK66031501	1.51 ± .36	52 ± 11	1057 ± 18	O3 & C2	Cooling followed by strong heating.
HK64081205b	1.62 ± .44	55 ± 13	1081 ± 23	O3 & C2	Cooling followed by strong heating.