Mantle lherzolites from Troodos ophiolites: Mineralogy and ion probe geochemistry of clinopyroxenes

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Introduction. Peridotites of the Troodos ophiolite complex are represented by highly depleted harzburgite (e.g. Gass, 1990; Greenbaum, 1977). Recently we found spinel lherzolites between Amiandos mine and Pashi Livadia as a rock body at least 3 km in largest dimension, apparently the same rock type previously described as high-Al harzburgite (Duncan & Green, 1987). The spinel lherzolites are characterized by slightly depleted mineral composition similar to Mid Oceanic Ridge peridotites (MORP).

Petrography and mineral composition of peridotites. Troodos peridotites are tectonites with protogranular or porphyroclastic textures typical of residual mantle peridotites (Mercier & Nicolas, 1975).

Spinel Lherzolite. 70–75% olivine (Ol) (Fo 90.5–91), 15–20% orthopyroxene (Opx) (Mg# 90–91), 5–7% clinopyroxene (Cpx) (Table 1) and 1–2% Cr-Al spinel (Sp) (Cr/(Cr+Al)=0.28–0.45). Cpx occurs as deformed irregular grains (1.5–2.5 mm) with Opx exsolution lamella. Cpx-bearing harzburgites (2–3% Cpx) are closely associated with spinel lherzolite and have transitional mineralogy.

Harzburgite. (Ol:Opx:Sp:Cpx= 70–85:15–25:1–2:0.5–1), Ol (Fo 90.6–92), Opx (Mg#=91–92), more refractory Sp (Cr/(Cr+Al)=0.5–0.7). Small Cpx (0.5 0.7 mm) grains rim large Opx grains.

Methods and results. Cpx from spinel lherzolite and harzburgite were analysed for *REE*, Ti, Sr, Y, Zr and Hf on the Cameca IMS-4f ion probe in Mekhanobr Institute, St. Petersburg, (Russia). The analytical method was recently calibrated with the kind help of N. Shimizu using basic ideas from Shimizu and Hart (1982). The accuracy of analyses is better than 20% rel. for most data and better than 40% rel. for the lowest concentrations on the 0.01 ppm level, judging from repeated standard analyses. Cpx from both types of peridotites show strong depletion in the middle *REE*s and enrichment in light *REE*s (Fig. 1). Cpx from spinel lherzolite have relatively high *HREE*s abundance corresponding to the Cpx from the most depleted MORP (Johnson *et al.*, 1990). Cpx from harzburgite show lower concentration of heavy *REE*s and are more depleted than Cpx from MORP. *HREE* abundance in Cpx are correlated with the extent of the depletion of basaltic

TABLE 1. Compositions of Cpx, associated Ol and Sp from Troodos peridotites

Sample	TV-2	TV-5	TV-28	TV-25	TV-34	Trd-117	Trd-116
Al_2O_3	4.30	4.80	4.19	2.82	2.33	2.91	2.36
Mg#	92.8	92.3	93.0	93.6	94.5	94.0	93.6
Ti	744	896	574	268	261	163	101
Sr	3.1	1.5	3.9	1.5	1.6	0.5	3.4
Y	6.3	9.3	5.1	3.5	2.9	0.7	0.3
Zr	1.2	0.7	1.6	0.4	0.4	0.4	0.3
La	0.03	0.04	0.05	0.02	0.08	0.01	0.04
Ce	0.06	0.05	0.06	0.04	0.10	0.02	0.12
Nd	0.07	0.05	0.04	0.04	0.04	0.02	0.01
Sm	0.14	0.14	0.09	0.07	0.03	n.d.	n.d.
Eu	0.08	0.09	0.04	0.06	0.03	0.01	0.01
Dy	0.85	1.21	0.68	0.53	0.36	0.08	0.06
Er	0.60	0.93	0.47	0.35	0.32	0.13	0.08
Yb	0.61	0.92	0.55	0.35	0.37	0.22	0.16
Hf	n.d	0.30	n.d.	0.11	0.08	-	-
Fo, Ol	90.7	90.5	91.1	-	-	90.6	91.2
Cr#,Sp	0.28	0.31	0.37	0.41	0.48	0.52	0.62

Sample: TV-2; TV-5; TV-28 are Sp lherzolites, TV-25, TV-34 Cpx-bearing harzburgite, TRD-116, TRD-117 harzburgites, n.d.- not detected component in the peridotites, represented by Al contents in Cpx and Sp (Fig. 2). In these diagrams, Cpx show the continuous compositional range from spinel lherzolite to harzburgite with significant overlap with compositions of MORP.

Discussion

Origin of CPX. Using Opx–Cpx solvus (e.g. Lindsley and Andersen, 1983), up to 1–2% of modal Cpx could be expected to exsolve from Opx in studied harzburgite by cooling from magmatic temperatures (1400–1500°C). This and the observed positive Ti and Zr anomalies suggests an exsolution origin of Cpx from Troodos harzburgite. Lherzolite Cpx is too abundant, shows no geochemical and structural evidence for exsolution origin and probably represents a residual phase.

Origin of lherzolites. The lherzolite Cpx show very steep *LREE* depleted pattern similar to most depleted MORP (e.g. Johnson and Dick, 1992), suggesting very efficient melt extraction and open system or critical melting models. We estimate using models of Johnson and Dick (1992) and Sobolev and Shimizu (1992), that the amount of the melt which could be extracted from the residual mantle source for Troodos (mantle porosity) was as low as 0.5 wt.%. This corresponds well with data of Sobolev *et al.* (1993) on the compositions of ultra-depleted melt inclusions from Troodos lavas. Strong enrichment of La, Ce and Sr (Table 1) of Cpx suggests the involvement of a subduction related component.

Origin of harzburgites. The harzburgites and lherzolites show a continuous compositional range and strong positive correlation between Yb and Al (Fig. 2), which could be expected as a result of extended melting. But the lack of correlation between these parameters and Fo-content of Ol (Table 1) argues against a simple model of advanced melting. Instead, reactions between melt and host rocks could produce observed features at nearly constant Fo content of Ol (e.g. Kelemen *et al.*, 1992). This model is not applicable to high magnesium harzburgite, also known from Troodos.

References

Dick H.J.B. (1989) In *Magmatism in the ocean basins*, (A.D. Saunders and M.J. Norry, eds.), Geol. Soc. Lond. Spec. Pub. 42, 71–105.

Duncan R.A. and Green D.H. (1987) *Contrib. Mineral. Petrol.*, **96**, 326–42.

Gass I.G. (1990) In *Ophiolites. Oceanic crustal analogues*, (J. Malpas, E.M. Moores, A. Panayiotou, C. Xenophontas, eds.), The Geological Survey Department, Nicosia, Cyprus, 1–10.

Greenbaum D. (1977) *Econ. Geol.*, **72**, 1175–94.

Johnson K.T.M., Dick H.J.B. and Shimizu N. (1990) *J. Geoph. Res.*, **95**, NO. B3, 2661–78.

Johnson K.T.M. and Dick H.J.B. (1992) *J. Geoph. Res.*, **97**, NO. B6, 9219–41.

Kelemen P.B., Dick H.J.B. and Quick J.E. (1992) *Nature*, **358**, 635–41.

Lindsley D.H. and Andersen D.J. (1983) *Proc. Lunar Planet. Sci. Conf., 13th, part 2, J. Geoph. Res.*, **88**, suppl., A887–A986.

Mercier J-C.C. and Nicolas A. (1975) *J. Petrol.*, **16**, 454–87.

Shimizu N. and Hart S.R. (1982) *Ann. Rev. Earth Planet. Sci.*, **10**, 483–526.

Sobolev A.V. *et al.* (1993) *Petrology*, **1**, 331–61.

Sobolev, A.V. and Shimizu N. (1992) *Dokladi Akad. Nauk*, **326**, 354–60.

Sun S-S. and McDonough W.F. (1989) In *Magmatism in the Ocean basins*, (A.D. Saunders and M.J. Norry, eds.), Geol. Soc. Lond. Spec. Pub., No. 42, 313–45.

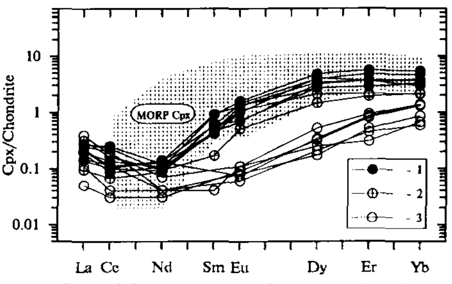

FIG. 1. Chondrite normalized *REEs* abundances for Cpx from Troodos peridotites (data are the average for each sample from at least 3 grains). Chondrite values are from Sun and McDonough (1989). Cpx from: 1 - spinel lherzolite, 2 - Cpx-bearing harzburgite, 3 - harzburgite, field of MORP Cpx after (Johnson *et al.*, 1990, 1992).

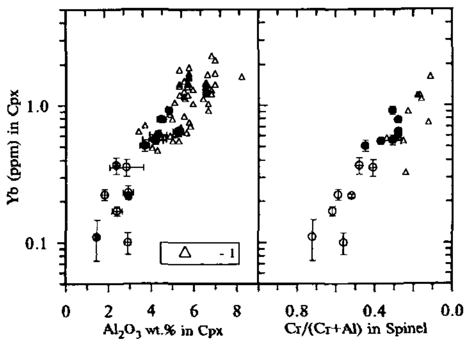

FIG. 2. Yb versus Al_2O_3 in Cpx and Cr/(Cr + Al) ratio in Cr-spinel. Error bar corresponds to 1σ. 1-MORP data from (Johnson *et al.*, 1990, 1992, Dick, 1989), other symbols as in Fig. 1.