THERMOBAROMETRY AND RECONSTRUCTED CHEMICAL COMPOSITIONS OF PYROXENE-SPINEL SYMPLECTITES: EVIDENCE FOR PRE-EXISTING GARNET IN LHERZOLITE XENOLITHS FROM CZECH NEOGENE LAVAS.

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Silicate-spinel symplectites are relatively common features in upper mantle xenoliths in alkali basalt and kimberlite. Such intergrowths include a range of textures, mineral modes, mineral compositions, and reconstructed compositions of precursor phases, reflecting different conditions and mechanisms of formation (Smith, 1977; Field & Haggerty, 1994). Peridotite xenoliths in Czech Neogene lavas contain pyroxene-spinel symplectites, whose mineral modes and compositions are consistent with their formation by reaction of pre-existing garnet with olivine. Thermobarometry demonstrates equilibration of the symplectites in the spinel peridotite field at 980-1090°C, 12.0-15.1 kbars.

Upper mantle xenoliths are abundant in Neogene lavas in the Bohemian Massif. The investigated xenoliths occur in nepheline basanite lava flows of Kozákov volcano (4-6 Ma; Šibrava and Havlíček, 1980), which is located in the north-central part of the Bohemian Massif about 7 km east of Turnov. Kozákov volcano occurs in the Labe tectonovolcanic zone and is situated on the WNW-trending Lusatian (Lužice) fault, which marks the northeastern termination of the Eger (Ohře) Graben. Basanite lavas typically contain 2-3% peridotite xenoliths, and when olivine xenocrysts and peridotite xenoliths are taken together, the lavas contain approximately 10% of upper mantle mateial.

Peridotite xenoliths are spheroidal to ellipsoidal in shape, are commonly 6-10 cm in diameter (rarely up to 70 cm), and consist predominantly of spinel lherzolite, with subordinate harzburgite and dunite. Two textural varieties of lherzolite occur: very coarse-grained protogranular lherzolite (grain diameters on the order of 1 cm), and medium-grained equigranular mosaic lherzolite. In mosaic lherzolite, spinel occurs as discrete, intergranular grains, but in protogranular lherzolite, spinel occurs only in symplectic intergrowth with pyroxene. The pyroxene-spinel symplectites are ellipsoidal in shape, have dimensions on the order of 1 cm, and consist of vermicular spinel intergrown with subequant grains of orthopyroxene and clinopyroxene, which are 0.5-2.0 mm in diameter.

Mineral compositions in three protogranular xenoliths were determined by EMP analysis, with the following results: olivine, Fo 90.2-91.0; orthopyroxene, En 90.5-91.4, Al_2O_3 3.78-5.23%, Cr_2O_3 0.46-0.53%; clinopyroxene, Wo 44.4-46.7, Di 48.5-50.4, Hd 4.4-5.4, Al_2O_3 4.33-6.11%, Cr_2O_3 0.75-0.85%; spinel, X_{Mg} 0.771-0.798, X_{Cr} 0.142-0.220, $Fe^{3+}/(Fe^{3+}+Al+Cr)$ 0.027-0.044. Each mineral species is homogeneous within a given xenolith, and the compositions of ortho- and clinopyroxene in symplectite are closely similar to those in the surrounding matrix.

The chemical compositions of pyroxene-spinel symplectite domains (Table 1) have been calculated from compositions, densities, and modal proportions of their constituent phases; modes were determined by computer processing of digital x-ray and back-scattered electron maps of symplectite by means of imaging software (National Institute of Health, "Image"). The bulk symplectite compositions are too rich in Al_2O_3 for symplectite to have formed by exsolution of spinel from aluminous pyroxene; in addition, the bulk compositions preclude symplectite from having formed by simple decomposition of garnet, in which $XO:Y_2O_3:SiO_2$ is 43:14:43 on a mol basis. However, the bulk compositions are consistent with symplectite having formed by the reaction, garnet + olivine = pyroxene + spinel, for which $XO:Y_2O_3:SiO_2$ is ~50:10:40, depending on the alumina content (t) of pyroxene. Symplectite from two Czech samples and one from Green Knobs, Colorado Plateau (Smith, 1977) have values of $XO:Y_2O_3:SiO_2$ that are very close to those for the theoretical reactants, and values for the third Czech sample are reasonably close.

Table 1

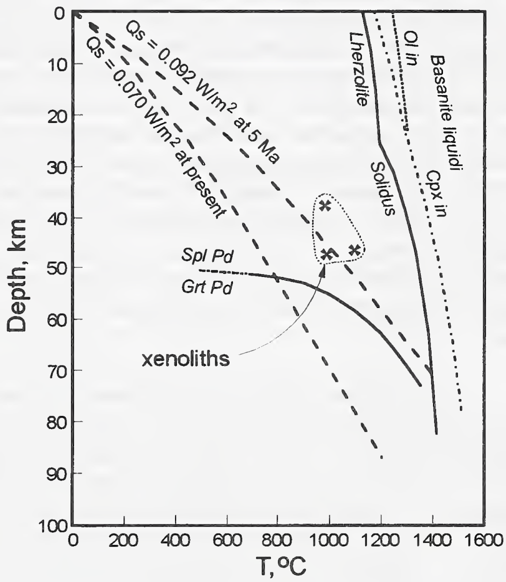
	Reconstructed Compositions of Pyroxene-Spinel Symplectite				*Theoretical Compositions of Pyroxene-Spinel Reactants*
	----- Czech Republic -----			Colorado	
Sample	KZC2	KZC3	KZC6	Plateau	
wt %:				Smith (1977)	
SiO_2	36.40	40.15	40.81	41.26	
TiO_2	0.03	0.05	0.11	0.00	$aX_3Y_2Si_3O_{12} + X_2SiO_4 =$
Al_2O_3	19.47	15.42	17.36	11.13	garnet olivine
Cr_2O_3	6.02	5.59	3.74	9.25	
FeO	8.39	7.16	6.75	7.81	$2aX_{(2-t)}Y_{(2t)}Si_{(2-t)}O_6 + XY_2O_4$
MnO	0.12	0.11	0.11	0.18	pyroxene spinel
NiO	0.13	0.11	0.10	0.00	
MgO	26.70	26.66	25.88	26.77	where: X = Fe, Mn, Ni, Mg, Ca
CaO	2.72	4.43	4.99	4.77	Y = Al, Cr
Na_2O	0.12	0.17	0.32	0.05	a = 1/(1-2t)
Sum	100.09	99.83	100.17	101.22	

mols:	pyroxene-spinel symplectite				*theoretical reactants*		
XO	49.9	49.7	48.8	50.1	50.0	49.2	48.9
Y_2O_3	13.8	11.0	11.4	9.9	10.0	10.5	10.6
SiO_2	36.3	39.3	39.8	40.0	40.0	40.3	40.4
	t = 0.084	0.081	0.105	0.056	0.000	0.080	0.100

Temperature-pressure conditions have been calculated for the three Kozákov symplectite-bearing lherzolite xenoliths by the two-pyroxene thermometer (Brey & Köhler, 1990), the Ca-in-olivine barometer (Köhler & Brey, 1990), and the olivine-spinel thermometer and oxygen barometer (Ballhaus, Berry & Green, 1991). Special attention was paid to the analysis of Ca in olivine; for the analytical conditions and Ca standard in the University of Wisconsin EMP laboratory (Cameca SX51), a counting time of 300 seconds yields a minimum detection limit of 0.036 wt% CaO and a precision, based on counting statistics, of 3%.

Because the compositions of enstatite and diopside in symplectite are very similar to those of surrounding matrix grains, the results of TP calculations are also similar, using either pyroxene population; the results for matrix grains are reported here. TP values obtained from the two-pyroxene thermometer and Ca-in-olivine barometer are 977°C, 12.0 kb; 982°C, 15.1 kb; and 1090°C, 14.7 kb. Interestingly, Fe-Mg exchange between spinel and olivine appears to have re-equilbrated at lower temperatures of 784°C, 844°C, and 849°C; corresponding oxygen fugacities are within one log unit of FMQ (+0.67, +0.45, and -0.34, respectively).

TP conditions for the Kozákov lherzolite xenoliths are in the spinel peridotite field, between the present day geothermal gradient and a dry lherzolite solidus and calculated liquidi for Kozákov nepheline basanite (corrected for 10% xenocrystic olivine). However, the xenolith TP conditions are consistent with a high heat flow regime, such as that in the present-day Basin and Range Province in the U.S., which may have existed 5 million years ago in the northern Bohemian Massif, when the Kozákov volcano was active. We suggest that the three analyzed xenoliths were initially garnet lherzolite, perhaps residing metastably in the upper mantle at depths of 35-45 kms as a result of Variscan tectonic imbrication, that garnet reacted with olivine to form pyroxene-spinel symplectite in response to heating associated with a high regional heat flux during Neogene volcanism, and that the re-equilibrated lherzolites were rapidly excavated and brought to the surface by the Kozákov basanite, which originated at greater depths.



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