clinopyroxene + garnet pairs can be estimated (Ellis and Green, 1979) : the primary association would have crystallized at about 1325 °C (at 20 Kbar) or 1370 °C (at 30 Kbar).

The crystallization of sapphirine from cor + sp + gt assemblages has been studied in a Fe- and Ca-free system involving water (Ackermand et al., 1975). At temperatures mentionned above the primary association would have crystallized out of the stability field of sapphirine, under pressures as high as 30 Kbar, i.e. in the garnet-lherzolite field (O'Hara et al.,1971): it is time to recall that pressures between 27 and 30 Kbar have been advocated to account for the possible partial melting event in the ultramafic body (Kornprobst, 1970).

Even if the pressure of equilibration of the primary association cannot be accurately determined, it is possible to consider that reaction (1) could play an important role in the mineral facies of the mafic rocks at mantle depth : as clinopyroxene, garnet and spinel are costable on the low pressure side of the equilibrium, this reaction may occur at pressure greater than required for the crystallization of the ariegite association from the reaction :

OPX + PL + SP ⟶ CPX + GT.   (2)

Then, as already suggested by Sobolev et al. (1966), a grospydite subfacies must be emphasized (fig. 3), characterized by the breakdown of plagioclase in Ca- and Al-rich compositions. Because of the lack of reliable experimental data it is not yet possible to define accurately the limits of this subfacies.

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H10   SULFIDE MINERALOGY AND CHEMISTRY IN SOME FRENCH SPINEL-LHERZOLITE XENOLITHS

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Sulfides are the only opaque phases present as traces (0,01 to 0,06 %) in the unaltered spinel-lherzolite xenoliths trapped by the alkali-basalts from the Massif Central and Languedoc volcanic suites (120 samples from 23 localities). The sulfides occur mainly as inclusions (10 to 100µ) in the silicates, less frequently as relatively abundant interstitial grains.

Independant of locality, texture (coarse-grained poïkilitic, equant or tabular, porphyroclastic and granuloblastic) and equilibrium temperatures of the parent silicates (900° to 1200°C), the inclusions are composed of the same primary phases : Ni-rich pyrrhotites, pentlandite (Ni/Fe at. rat.~ 1,3) with small amounts of chalcopyrite. Pyrrhotites crystallize in two optically distinct phases, both with the same range of sulphur/metal atomic ratio (M_9S_{10} to M_7S_8) :

- "grey pyrrhotite" ($Po_{ss}1$), as mono - or polyphase inclusions, showing the highest nickel contents ever found in natural pyrrhotites (20 to 27 weight %), with an average composition (18 inclusions) of $Fe_{36,4} Ni_{23,7} Co_{0,3} Cu_{0,1} S_{39,1}$ wt. % ;

- "pink pyrrhotite" ($Po_{ss}2$), which shows more variable Ni-contents (7 to 19 wt. %) but is always Ni-poorer than the coexisting $Po_{ss}1$. The "pink pyrrhotite" is always directly associated to the "grey" type, most frequently intimately intergrown, leading to bulk compositions (defocused beam microprobe analyses) which spread in the range (23 inclusions) : Fe : 37-47 ; Ni : 13-24 ; Co : 0,1-0,5 ; S : 38-40 wt. %.

The modal proportions (200 inclusions) show an unimodal distribution between : $Po_{ss}(1+2)$: 70-100 % ; Pn : 0-30 % ; Cp : 0-20 %, giving an average mode : Po_{ss} : 82 % ; Pn : 12 % ; Cp : 6 %.

Phase analysis were done for 45 inclusions, giving bulk compositions with a range : Fe : 33-47 ; Ni : 13-29 ; Co : 0,1-0,5 ; Cu : tr.-7 ; S : 36-39,5 wt. % and resulting in an average bulk pyrrhotite composition (M_9S_{10}) : $Fe_{37,7} Ni_{21,0} Co_{0,3} Cu_{1,6} S_{38,3}$ wt. %.

Experimental phase diagrams in the Fe-Ni-Cu-S system, indicate that such an average composition, as well as the compositions of most individual inclusions, totally crystallized as monosulfide solid solutions (Mss) at 1000°C. The bulk chemical differences observed among the inclusions could be explained by some local differentiations, during deformations, at temperatures between 1000° and 1100°C, where the Mss coexist with more or less Ni and Cu enriched liquids. Present parageneses result from a suite of reactions in the solid state continuing down temperatures between 250° and 300°C, well below those which control the last equili-

Where sulfides are predominant as interstitial grains, their mineralogy and chemistry differ markedly from those of the inclusions, even if both coexist in the same rock sample. In the type suite selected here (Montferrier, Herault), interstitial grains are composed of pentlandite (Ni/Fe ~ 1) associated to a Ni-poor (≤ 0,5 %) pyrrhotite (Fe_7S_8) and minor amounts of chalcopyrite.

Although broadly different from one grain to the other, the mean modal proportions measured in each individual sample (17 inclusions) remain in a relatively restricted unimodal field. Thus, the average mode can be determined to : Po : 47 % ; Pn : 48 % ; Cp : 5 %, with a corresponding bulk chemical composition : $Fe_{45,3} Ni_{16,1} Co_{0,4} Cu_{1,7} S_{36,0}$. These characteristics are believed to result essentially from an early desulphurization of a primary liquid akin to the average composition of the inclusions. This event could have occured during the main episode of deformation and recrystallization of the host rocks, at temperatures between at least 1200° and 1000°C.

The relative sulphur decrease of the pristine interstitial sulfide phase and its differenciation in an open system, may explain both the great modal variation on a small scale and the final crystallization of Po+Pn+(Cp) instead of Po_{ss}+(Pn)+(Cp) at the same low temperature (250°-300°C). It should be noted that both the interstitial and enclosed assemblages are quite different from the sulfide paragenesis due to secondary thermal mobilizations directly related to the basalt eruption.

Most generally, it is concluded that, at least in the area studied, the whole sulfide associations observed in the spinel-lherzolite xenoliths, crystallized directly or were differentiated from a primary homogenous liquid which individualized at high temperatures

I > 1200°C and is characterized by a relatively high Ni content. Preliminary results show that the same hypothesis can be applied to explain the origin of the sulfide phases in the spinel-lherzolites of the ultramafic bodies from Ariege (French Pyrenees).

H11

SUBSOLIDUS PHASE RELATIONS BETWEEN COEXISTING GARNET AND PYROXENES AT 50 TO 100 kbar IN THE SYSTEM CaO-MgO-AL2O3-SiO2

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Extensive experimental studies simulating chemical compositions of coexisting garnet, orthopyroxene and clinopyroxene of kimberlite xenoliths have been made in the system CaO-MgO-Al2O3-SiO2 (e.g. Boyd,1970; Akella,1976; Parkins & Newton,1980). Most of these studies, however, are in the pressure range below 40 kbar, because of the limitation with the piston-cylinder apparatus. Akaogi & Akimoto (1977, 1979) carried out a series of high pressure experiments with a multi anvil type high-pressure apparatus and found that the composition of garnet coexisting with pyroxenes becomes nonstoichiometric (pyroxene-garnet solid solution) above about 50 kbar, and the amount of pyroxene components dissolved in the garnet increases drastically at higher pressures. In order to clarify the thermodynamic nature of the garnet solid solution in equilibrium with two pyroxenes in the pressure range 50 to 100 kbar and formulate geothermometer and geobarometer for kimberlite xenoliths, we have started a series of high pressure experiments. A preliminary result of the experiments is given in this report.

All the experiments were made with a uniaxial split-sphere type multi-anvil apparatus of the Institute for Thermal Spring Research (Ito & Yamada,1982), using graphite heater and pyrophyllite pressure media. In order to improve the thermal gradient across the experimental charge, a graphite heater with 5° taper (2.2 mm average I.D., 3 mm O.D., and 11 mm length) was designed (Takahashi et al, 1982). Experimental run temperatures are believed to be within 20°C to the measurements by the Pt/Pt-Rh thermocouples with the aid of the tapered heater. Two types of starting materials were employed; 1) EWC, which is a glass of enstatite 72.5 mol %, wollastonite 20.0%, corundum 7.5%; and 2) EDP, which is a mixture of synthetic enstatite, diopside and pyrope crystals equivalent to EWC in bulk chemical composition. Both the charges were encased in a Pt-tube (0.9 mm O.D., 2 to 3 mm length) and 0.1 to 3.0 wt % of H2O was added prior to welding the Pt. Experimental run products were sectioned prallel to the length of the furnace assembly and the thin sections were examined with an electron microprobe X-ray analyzer.

Reversal experiments have been made at 1400°C and 75 kbar (Fig.1) and it was found that pyroxenes crystallized from both the starting materials give identical chemical compositions. Garnets started from the crystalline mixture (EDP) are chemically zoned but the rim compositions are very close to those from the hydrous glass (EWC). The compositions of coexisting garnet, orthopyroxene and clinopyroxene crystallized from EWC at other P/T conditions are shown in Fig.2.
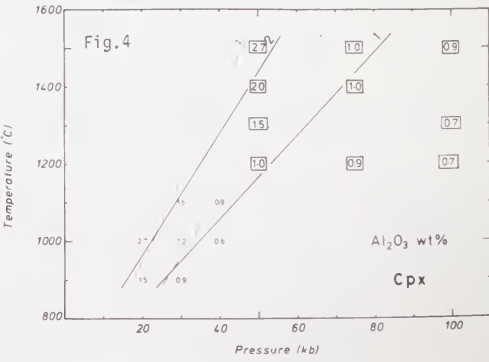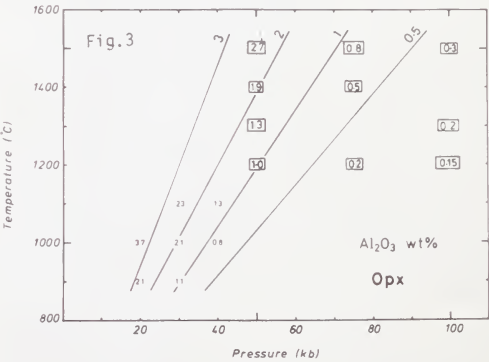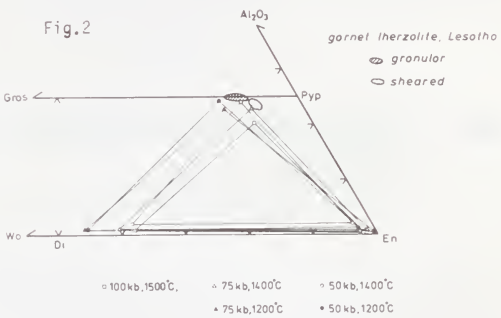
Fig.2

gornet lherzolite, Lesotho
- granular
- sheared

○ 100kb,1500°C. △ 75kb,1400°C ◦ 50kb,1400°C
▲ 75kb,1200°C ● 50kb,1200°C

Fig.3

Al2O3 wt%

Opx

Fig.1

HY811219

75 kb, 1400°C, 3.3hr

starting materials, ○ EWC, ● EDP

Fig.4

Al2O3 wt%

Cpx