

THE POLYBARIC HISTORY OF FAMOUS BASALT 527-1-1: EVIDENCE FROM TRACE ELEMENTS IN OLIVINE

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Olivine plays a major role in the petrogenesis of oceanic basalts erupted at active spreading centers. It is the major mineralogical constituent of the source and of the residuum after partial melting and is a liquidus or near-liquidus phase over a very wide range of pressures (0 to as high as ~15 kb). Thus it controls the liquid line of descent of ascending basaltic liquids over a considerable depth range. It is thus not surprising that olivine phenocrysts and microphenocrysts are ubiquitous in fresh basalt glass collected along mid-ocean ridges.

The composition of the olivine is determined by the bulk composition of the liquid from which it crystallized and the intensive thermodynamic (T, P, fO_2 , PH_2O , etc.) and kinetic parameters operating at the time of crystallization.

The transition metals Cr, Mn, Co, and Ni that occur in trace concentrations in mid-ocean ridge basalts are, to varying degrees, preferentially incorporated into the olivine, and thus can be sensitive recorders of olivine crystallization. The abundances of the transition metals in ocean floor basalts have been used to constrain models for their petrogenesis.¹⁻⁹ Experimental studies of the partitioning behavior of the transition metals between olivine and basaltic liquids¹⁰⁻¹² constrain the temperature-composition dependence of the partition coefficients and permit numerical modeling of olivine fractionation.^{3,11,13-15}

The application of the partitioning behavior of trace transition metals to the modeling of the petrogenesis of natural basalt systems has been hampered by the difficulty of obtaining precise analyses with high spatial resolution. The electron microprobe provides the needed spatial resolution (2-3 μm^3) but trace element analysis is a painstaking procedure that can be applied to only a few of the elements of interest. Bence et al.¹⁶ discuss some of the problems encountered in the determination of trace element concentrations by electron microprobe and describe a procedure by which these measurements can be made for selected trace elements in specific systems with high degrees of precision. Nabelek¹⁷ used this procedure to measure the partitioning of nickel between olivine and basaltic liquid in reversal experiments conducted on FAMOUS basalt, 527-1-1. Preliminary measurements on selected olivines in that basalt indicated that the partitioning was not simple, prompting the present study to investigate, in some detail, the characteristics of the Ni distribution in olivines from 527-1-1. We have used the technique described by Bence et al.¹⁶ to determine the distributions of Ca, Mn, Cr, and Ni in selected olivines and observe zoning trends that are inconsistent with normal fractional crystallization at low pressure but that may be explained by a polybaric crystallization history.

Analytical Procedures

Major and trace-element analyses of the coexisting olivines and glass of basalt 527-1-1 (~96% glass, ~3% olivine, <1% spinel, and trace plagioclase) were obtained on an automated 4-spectrometer ARL-EMX-SM electron microprobe. Major element oxide compositions were calculated by the technique of Bence and Albee¹⁸ and an a-matrix modified from that given by Albee and Ray.¹⁹ Trace-element concentrations, detectability limits, and precision were determined by the procedures described by Bence et al.¹⁶ The run conditions for the trace-element determinations were: accelerating potential, 30 kV; specimen current (on brass), 0.015 μA (standards) and 0.15 μA (unknowns). Ten 30s replications were obtained for each point analyzed. Background intensities were obtained on both sides of the peak and were redetermined for each point. Errors and detectability limits are cal-

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culated for the 99% confidence level.

Preliminary major element and Ni concentrations were obtained for the cores and rims of approximately 40 olivines and the adjacent glass in four separate thin sections of 527-1-1. From these data eight olivines chosen to represent the total variability in the sample were selected for detailed analysis.

Results and Discussion

The microprobe analyses of the eight olivine crystals reveal rather complex zoning profiles for Ni, Mn, Ca, and Cr in relation to the major element zoning. Markedly different trace-element distributions occur in immediately adjacent olivines. Examples of the two extremes observed are shown in Figs. 1 and 2. "Normal" zoned olivines have generally uniform Mg/(Mg + Fe), but have cores with higher Cr and Ni and lower Mn and Ca than the rims (Fig. 1). "Inverse" zoned olivines have high Mg/(Mg + Fe) and Mn cores but Ni, Cr, and Ca are lower relative to the rim (Fig. 2). The latter type is frequently rimmed with olivine having "normal" zoning. Zoning in the glass at the glass/olivine

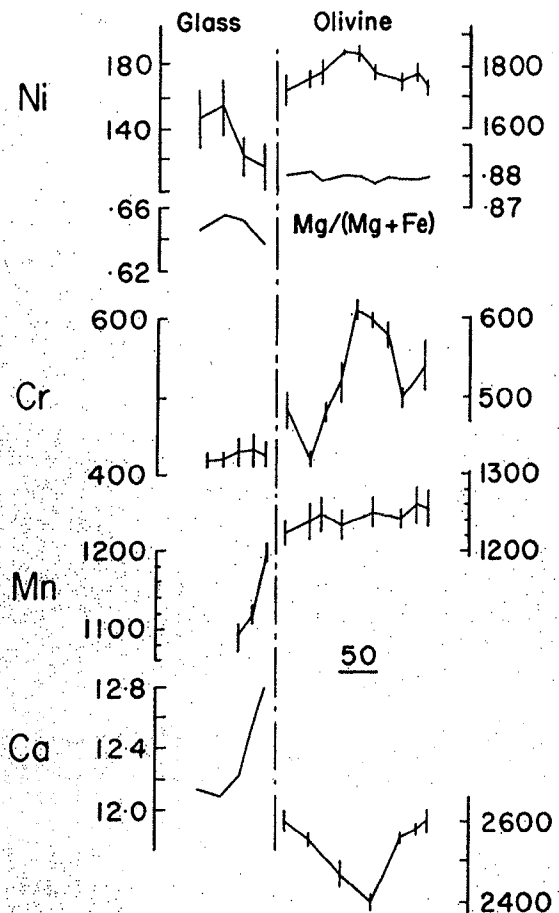


FIG. 1.--Electron microprobe traverse across "normal" zoned olivine microphenocryst into adjacent glass. Error bars are calculated from the counting statistics for 99% confidence level. All concentrations in wt.ppm except Ca in glass which is wt.% CaO. Mg/(Mg + Fe) is atomic ratio. Scale bar in micrometers.

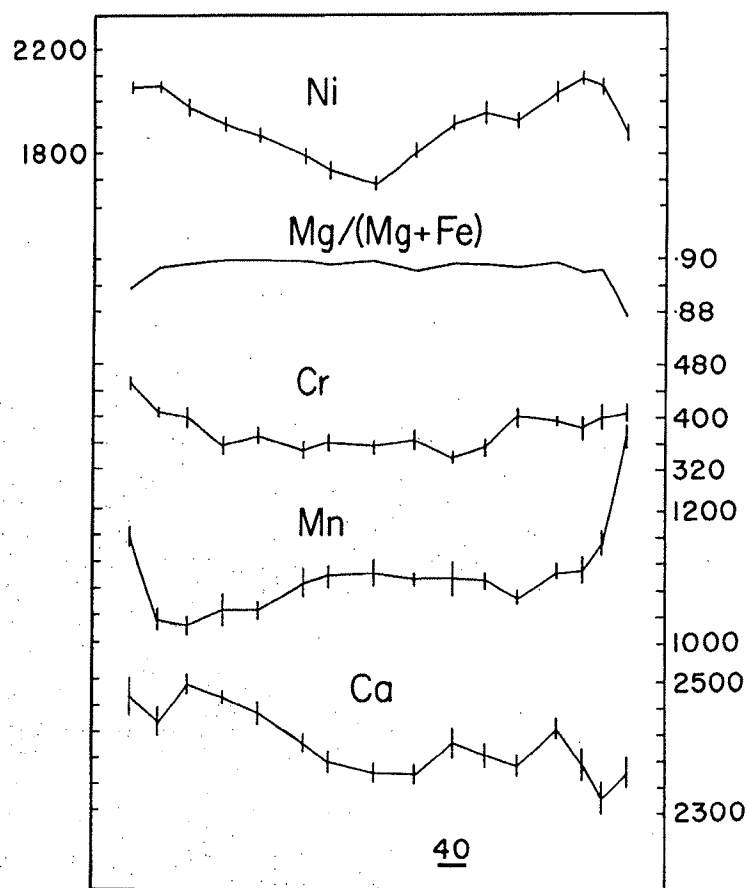


FIG. 2.--Electron microprobe traverse across "inverse" zoned olivine phenocryst. Error bars as for Fig. 1.

interface (Fig. 1) is the result of the quench growth of olivine on an olivine nucleus when the basalt came in contact with seawater. Controlled cooling experiments conducted on a Project FAMOUS basalt glass²⁰ that used the depletion and enrichment zones around phenocrysts as a means of calibration indicate that the melts were quenched at rates in excess of 150°C/hr. In these zones Ni is depleted because it is strongly partitioned into the olivine and Ca and Mn are enriched at the growing face because they are preferentially excluded from the olivine.

A plot of Ni concentration vs Mg/(Mg + Fe) (Fig. 3) reveals that the "normal" zoned olivines follow a calculated one atmosphere fractionation path. This path was calculated from the equations of Leeman¹⁰ and Hart and Davis¹¹ by the type of calculation employed by Hanson and Langmuir.²¹ Rayleigh fractionation is assumed. "Inverse" zoned olivines follow a different path and have core Ni concentrations that are lower than those predicted by low pressure fractionation. However, their compositions approach those defined by the 1-at. fractionation paths. We suggest that the "normal" zoned olivines record a low-pressure crystallization history at the time of eruption. The "inverse" zoned olivines record a high-temperature--high-pressure crystallization history followed by low-pressure crystallization.

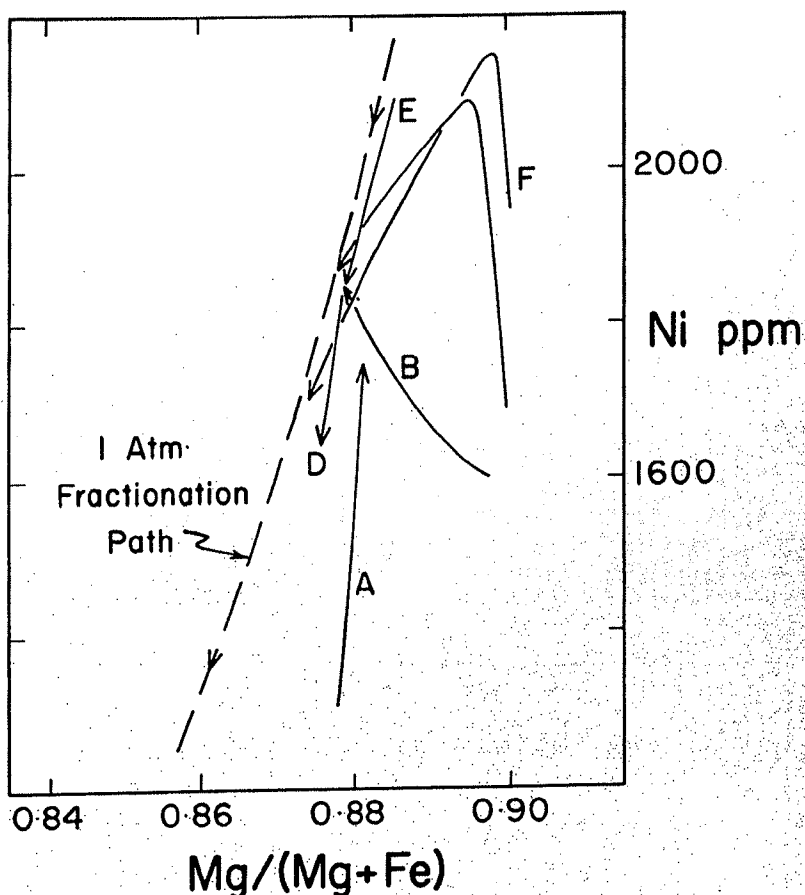


FIG. 3.--Ni vs Mg/(Mg + Fe²⁺) for "normal" (D, E) and "Inverse" (A, B, C, F) zoned olivines. Olivines C and F have "normal" zoned rims.

At 10 kb the liquidus temperature for 527-1-1 is 1310°C. At 1310°C, $k_d^{Ni} (O1/L) = 9.07$ and at 1268°C (low pressure liquidus), $k_d^{Ni} = 11.22$. Thus if a magma forms at depth and crystallizes olivine on its way to the surface, the nickel content of the olivine should change to reflect the changing bulk composition and changing (increasing) K_d . These effects should tend to cancel each other. Therefore, the fact that the olivine Ni content increases from core to rim in the "inverse" zoned crystals is convincing evidence that changing K_d is the dominant process.

The experiments of Leeman,¹⁰ Hart and Davis,¹¹ and Bickle et al.²³ indicate that $k_d^{Ni} (O1/L)$ is largely temperature- rather than pressure-dependent. Thus we conclude that we are seeing the pressure effect indirectly through the changing liquidus temperature as a

melt is brought up from depth. This conclusion is substantiated by the Cr data, which correlate with Ni. The increase of Cr from core to rim is consistent with a K_d^{Cr} (O1/L) increase as temperature decreases.

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