FRACTIONATION, PARTIAL MELTING, AND MIXING IN NORMAL BASALTS FROM 22-25° N, MID-ATLANTIC RIDGE

by
W. B. BRYAN
Department of Geology and Geophysics
Woods Hole Oceanographic Institution

INTRODUCTION

Much of the recent work on ocean ridge basalts has been directed toward supposedly «abnormal» sections of spreading ridges associated with inferred «mantle plumes». Such samples are especially well represented in the successful deep drilling accomplished by DSDP leg 37 (Aumento, Melson, et al., 1977) and in the data set from FAMOUS (White and Bryan, 1977; Langmuir et al., 1977; Bryan, 1979). The Mid-Atlantic Ridge near 22° N has been the source of many of the basalt samples on which our concepts of «normal» sea floor are based. As a result of a series of cruises associated with study of a «normal» oceanic crustal section in and near the Kane Fracture Zone at 24° N, about 150 new glass and whole rock major element analyses and trace element analyses of selected samples have been completed, representing dredge stations betwen 22° and

25° N. The data are discussed in detail by Bryan et al., 1981. These dredge data are supplemented by extensive published data for DSDP sites 395 and 396 located nearby (Melson, Rabinowitz et al., 1978 ; Dmitriev, Heirtzler et al., 1978).

In both quantity and compositional diversity, these samples approach those from leg 37 and FAMOUS. However, some important differences do exist, both in absolute element abundances and in the nature of inter-element co-variances of both major and trace element data.

MAJOR ELEMENT VARIATION

Using glass data from the Woods Hole collections near the Kane Fracture Zone and from other locations along the Mid-Atlantic Ridge from 0-37° N, Melson and O'Hearn (1979) showed that important major element differences exist between modern ocean ridge basalts located north or south of about 29° N. The northern group of samples include those from leg 37 and FAMOUS and are relatively enriched in Al_2O_3, MgO and CaO. The southern group, of which those near Kane and 22° N are typical, are relatively enriched in FeO, TiO_2, and Na_2O. Bryan and Dick (1981) have shown that these data sets define distinct liquidus trends which may be represented as regression lines in the normative plagioclase-pyroxene-olivine ternary (Fig. 1). Because existing experimental data indicate that both the FAMOUS and 22° N liquidus trends are consistent with low-pressure phase equilibria, Bryan and Dick (1981) argue that these trends must reflect differences in mantle source major element compositions rather than different depths of origin or different melting histories.

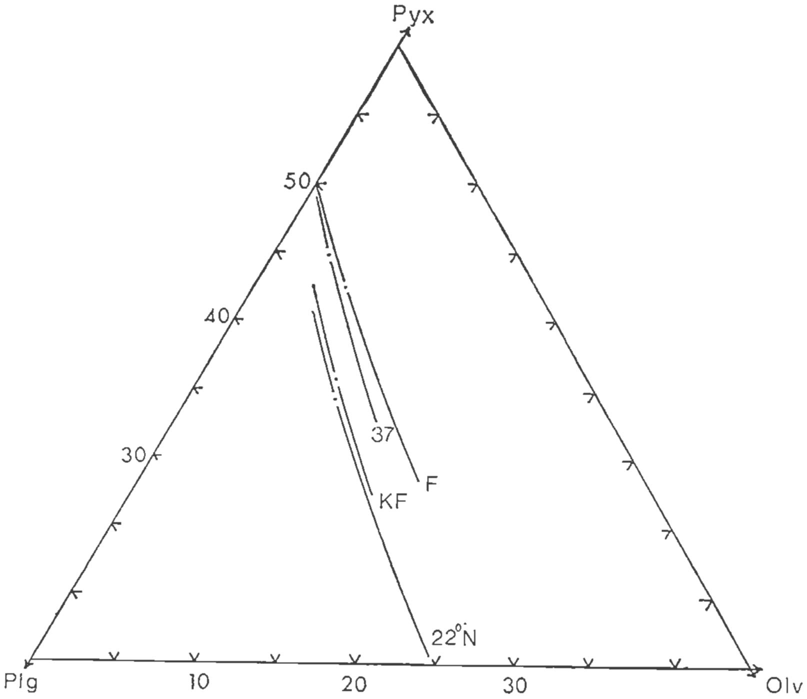

Fig. 1 — Comparison of basalt glass variation trends in the normative ternary plagioclase-pyroxene-olivine. F = FAMOUS, 37 = leg 37, KF = Kane Fracture Zone ; 22°N = other samples south of Kane Fracture Zone. After Bryan and Dick, 1981.

TRACE ELEMENT VARIATION

Basalts near 22° N all show the depletion in large-ion lithophile elements that is considered typical of «normal» ocean ridge basalt. Chondrite-normalized rare-earth patterns show characteristic depletion in La and Ce relative to Sm and heavy rare earths, and all patterns are sub-parallel. In contrast to

FAMOUS and leg 37 (Langmuir et al., 1977 ; Bryan and Thompson, 1977) there is little variation in relative incompatible element enrichments and crossing rare earth patterns have not been observed. Trace element data, as well as major element data, are very similar in overall abundances and ranges to data for DSDP sites 395 and 396, although the modern ridge basalts extend both to somewhat more «primitive» and somwhat more «evolved» compositions than have been reported from those drill sites. It is of particular interest that no special basalt compositions are associated with the Kane Fracture Zone, and there are no significant major or trace element differences between the basalts erupted north and south of the fracture zone.

PETROGENESIS

In detail, the basalts near 22° N show many of the same genetic problems as do those from the FAMOUS area. However, unlike FAMOUS, the consistency in incompatible element depletion levels makes it unnecessary to appeal to complex melting models. Probably all the basalts were ultimately derived by similar degrees of melting from a relatively homogeneous source. That source must differ in both major and trace element compositions from the source of the FAMOUS and leg 37 basalts, and possibly also in mineralogy, to account for specific differences between FAMOUS and 22° N basalts.

Various subsets of the basalt data document the importance of low-pressure crystal-melt equilibria in accounting for much of the compositional variation. Significant variation exists within individual samples of phyric basalts. The quenched glass rims of these basalts represent some of the most fractionated composition in the data set, while their bulk compositions (glass plus phenocrysts) are very similar in composition to some of the least fractionated glasses (Fig. 2). Modal analyses and materials balance calculations (Table 1) confirm that differences between glass rim and bulk rock compositions are accounted for by the phenocryst assemblages, and that this difference mimics the variation trend in the glass data set as a whole, reflecting up to about 30 % crystalization. This within sample variation is interpreted to represent varying degrees of crystalization within vents and/or temporary storage chambers as these individual magma batches ascended to the surface. Apparently, both magma ascent and the rate of crystallization were sufficiently rapid that there was no opportunity for selective separation of crystals from liquid.

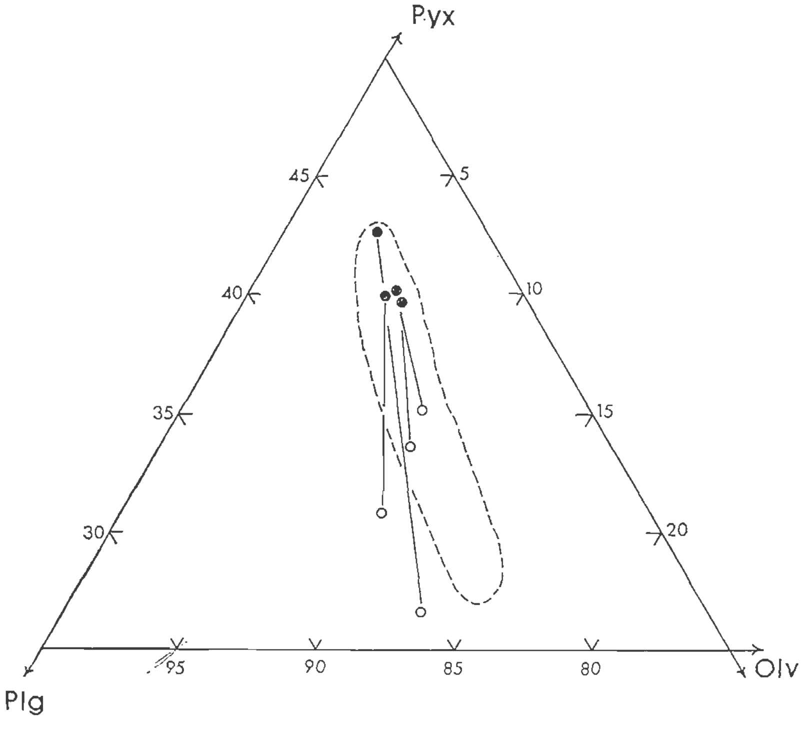

Fig. 2 — Normative plagioclase-pyroxene-olivine ternary, showing relation between quenched glasses (solid circle) and their corresponding whole rock compositions (open circles) ; tie lines connect compositions from individual samples.

Similar fractionation schemes can be shown to account for compositional differences among different aphyric basalt samples, both within single dredge collections, or selected from more widely separated sites (Bryan et al., 1981). In these cases, it is inferred that more prolonged fractionation took place in shallow chambers where crystal settling was effective; such a process is also supported by the layered gabbros collected from deeper crustal exposures in or near the Kane Fracture Zone (Dick et al., 1980). In several data subsets, the residual liquid is enriched in incompatible elements in excess of what can be acounted for by simple fractionation; such relations evidently are not limited to «abnormal» basalts. In all of these fractionation schemes, pyroxene plays a significant role, a role also supported by its presence as microphenocrysts in the more fractionated basalts.

Certain data subsets are best explained by low-pressure fractionation followed by simple mixing of new parental liquid and the fractionated liquid remaining in an evolving magma chamber. The resulting «intermediate» liquids are characterized by relatively high concentrations of both compatible and incompatible elements. These relations are illustrated graphically in figure 3, and are further supported by materials balance calculations (Bryan et al., 1981). However, as is also shown in the figure, other «intermediate» basalts appear to be the normal products of simple low-pressure fractionation, while others appear to require mixing of more extreme «residual» or «parental» liquids than have so far been recognized in the collection.

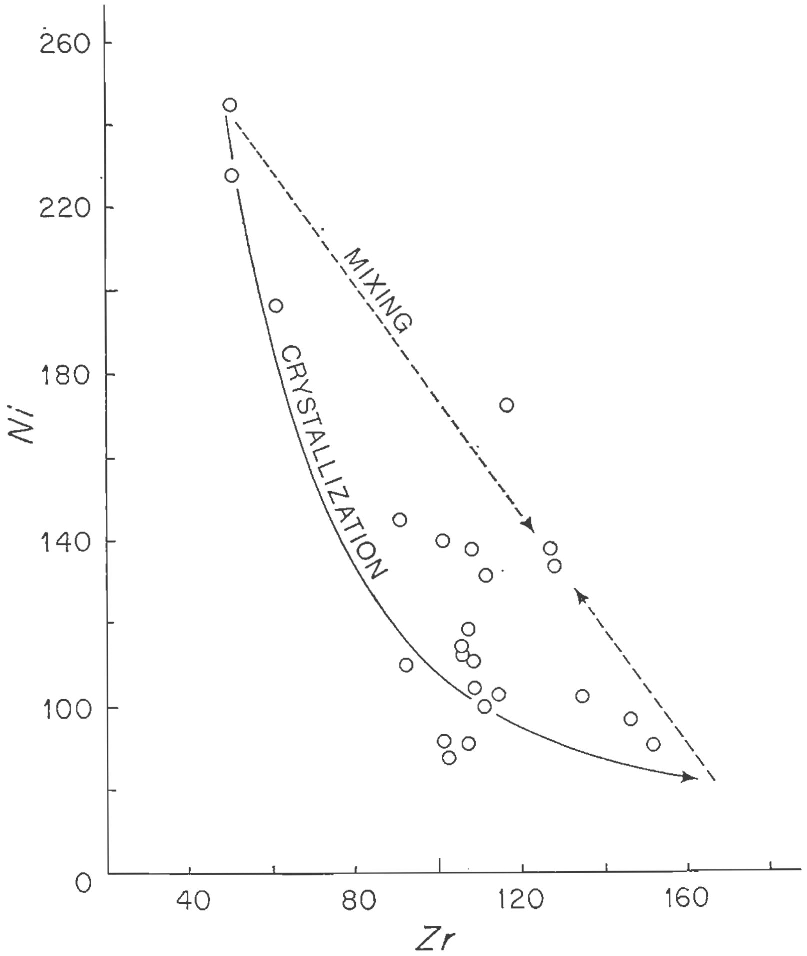

Fig. 3 — Variation in Ni vs Zr, showing theoretical crystallization trend (solid line) and mixing trend (dashed line). Crystallization curve computed assuming equilibrium crystallization and distribution coefficients of 3.5 for Ni, 0.1 for Zr.

SUMMARY

Basalts near 22° N all show the incompatible element depletion considered to be «typical» of ocean ridge basalts remote from sites of mantle plumes or other «abnormal» mantle sources. Basalts in or near the Kane Fracture Zone show no special compositional features; all seem to have originated in the median valley north or south of the Kane by similar degrees of melting of a homogeneous source. Both major and trace element data suggest, however, that this mantle source differs in composition from that in the FAMOUS area. A large part of the compositional variation in the data can be accounted for by low pressure fractionation in combination with simple mixing. Small differences in initial degree of partial melting seem adequate to explain remaining discrepancies between trace and major element variation.

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TABLE 1

COMPARISON OF GLASS RIM, CALCULATED, AND OBSERVED BULK ROCK COMPOSITIONS OF BASALT

AII 96-6-44, and a natural glass from basalt AII 96-8-21

	A	B	C	D
SiO_2	51.34	50,45	50.51	50.47
TiO_2	1.86	1.52	1.51	1.52
Al_2O_3	14.79	16.23	16.17	16.02
FeO_2 *	10.65	9.40	9.28	9.38
MgO	6.54	7.37	7.37	7.69
CaO	11.36	11.71	11.63	11.32
Na_2O	3.07	2.76	2.90	2.92
K_2O	.15	.15	.12	.15
P_2O_5	.17	.13	.13	.14
Total	99.93	99.72	99.62	99.61

A Glass rim, phyric basal sample AII96-6-44.
B Bulk rock, phyric basalt sample AII96-6-44.
C Bulk rock composition calculated as a linear combination of glass plus phenocrysts.
D Glass rim, basalt sample AII96-8-21. Data from Bryan et al., 1981.