# 68. MINERAL ANALYSES FROM THE PERIDOTITE-GABBRO-BASALT COMPLEX AT SITE 334, DSDP LEG 37

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## ABSTRACT

Fifty-one analyses of silicates, oxides, and sulfides from a suite of ultrabasic and basic rocks at Site 334 are presented. The intrusive rocks show rhythmic, cryptic, and phase layering and are closely analogous to the Rhum-layered intrusion. The extrusive rocks are mineralogically similar to the intrusives, but are unlikely to be genetically related to them.

## INTRODUCTION

Drilling at Site 334 penetrated ~50 meters of basalts which overlie at least 68 meters of gabbros and peridotites. The basalts are generally aphyric, or sparsely porphyritic containing phenocrysts of olivine, clinopyroxene, and plagioclase. The presence of very coarse grained rocks at shallow depth under the basalts is in itself surprising and significant. The peridotites show well-developed cumulus textures in which olivine and spinel are always cumulus phases, whereas two pyroxenes and plagioclase are cumulus phases only in the gabbros. The present mineral analyses were undertaken to determine if the gabbros and peridotites are the complements of the overlying basalts, i.e., if there is a genetic relationship between the intrusive rocks below and the extrusive rocks above.

All analyses were done by electron microprobe (Cambridge Microscan MK-5) using natural minerals as standards. The raw data were processed using the EMPADR VII correction procceedure of Rucklidge and Gasparrini (1969).

## MINERAL ANALYSES

Analyses of silicate minerals appear in Tables 1-3 and are graphically represented in Figure 1. In addition, Table 4 contains analyses of chrome spinels from the three peridotite specimens investigated. Also a qualitative petrographical investigation is summarized in Table 5. Finally, some of thee rocks were briefly studied for their sulfide mineralogy and the following two analyses were made in gabbro 334-21-1, 47-49 cm:

| | Pyrite | Chalcopyrite |
|---|---|---|
| Fe | 47.83 | 30.63 |
| Cu | - | 34.54 |
| Ni | 0.07 | 0.03 |
| S | 53.27 | 34.26 |
| | 101.18 | 99.47 |

In other rocks, the following sulfides were identified but not quantitatively analyzed: 22-2, 61-63 cm; pentlandite; 23-1, 127-129 cm; pyrrhotite; 24-3, 112-114 cm; chalcopyrite, pyrite, pentlandite. In many cases the sulfides appear to occur as disseminated blebs enclosed within the primary silicate minerals.

## DISCUSSION

Within the limitations of the visual core descriptions (Aumento and Melson, 1974) and the low degree of core recovery, there appear to be at least nine cycles of peridotite-olivine gabbro-gabbro in the plutonic complex of Site 334. A cycle usually begins with peridotite, but in some cases the most basic member may be olivine gabbro. Also, a cycle usually ends with olivine-poor or olivine-free gabbro, but in some cases the cycle ends while the gabbro is still relatively olivine rich. This kind of rhythmic layering is found in several layered basic intrusions from the terrestrial environment (Wager and Brown, 1968). It remains to be seen what the nature of the cryptic layering is and which terrestrial model most closely applies to the submarine sequence.

In Table 6 the samples are arranged in stratigraphic order and the mineral chemistry is presented in summary form. Samples 22-2, 61-63 cm and 21-1, 47-49 cm are from the same rhythmic unit, and it is apparent that there is normal cryptic variation from the peridotite to the gabbro, i.e., increasing Fs molecule in the pyroxenes. There is also elimination of olivine, presumably through a reaction relationship with the liquid at the 1 atmosphere invariant point, $Ol^- + Opx^+ + Cpx^+ + Plag^+ + Liquid^-$. This reaction is strongly suggested by a careful petrographic examination: among the various episodes of crystallization, there is evidence of intensive replacement, suggested by frequent lobate contacts between olivine relics, pyroxenes, and plagioclase. It is also evident that whereas gabbro 21-1, 47-49 cm is the uppermost gabbro in the sequence, it is not the most differentiated. The most evolved gabbro in terms of its Fs content in the pyroxenes is 23-1, 127-129 cm. A more primitive gabbro, 24-3, 112-114 cm, is found deeper in the sequence.

The reversal in the Fs content of the pyroxenes (and An content of the plagioclase) hints that the nine

TABLE 1
Microprobe Analyses of Olivines

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Fo | 88.506 | 88.495 | 83.157 | 88.637 | 85.283 | 85.746 | 87.512 | 87.804 |
| Fa | 11.254 | 11.279 | 16.446 | 10.884 | 14.295 | 13.989 | 12.382 | 12.116 |
| Larn | 0.240 | 0.227 | 0.397 | 0.479 | 0.422 | 0.265 | 0.106 | 0.080 |
| Fo | 88.719 | 88.696 | 83.489 | 89.063 | 85.644 | 85.463 | 87.274 | 87.551 |
| Fa | 11.281 | 11.304 | 16.511 | 10.937 | 14.356 | 13.943 | 12.348 | 12.081 |
| Niol | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.594 | 0.378 | 0.368 |
| F/M | 0.127 | 0.127 | 0.198 | 0.123 | 0.168 | 0.163 | 0.141 | 0.138 |
| F/FM | 0.113 | 0.113 | 0.165 | 0.109 | 0.144 | 0.140 | 0.124 | 0.121 |

Note: 1 = 26-1, 20-22 cm; olivine 5. 2 = 26-1, 20-22 cm; olivine 6. 3 = 15-2, 20 cm; olivine 1. 4 = 15-2, 20 cm; olivine 2. 5 = 20-2, 140-145 cm; olivine 1. 6 = 24-3, 112-114 cm; olivine 1. 7 = 22-2, 61-63 cm; olivine 1. 8 = 22-2, 61-63 cm; olivine 2.

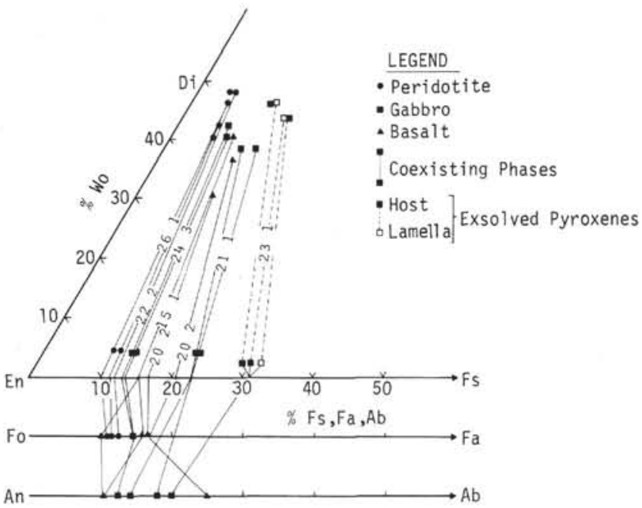


Figure 1. *Mineral analyses for intrusive and extrusive rocks at Site 334.*

rhythmic units are not the result of fractional crystallization of a single magma as is the case in the Skaergaard intrusion. Instead, the cyclical variation of rock types and mineral chemistry suggests that this complex has formed in a manner similar to that described for the Rhum-layered intrusion by Brown (1956). It is believed that these cumulates formed in a magma chamber that acted as a temporary reservoir for magmas en route to the surface. The longer the magma stayed in the reservoir, the more evolved would become both the cumulate pile and the erupted basalt.

There is no compelling mineralogical evidence to prove or disprove a genetic link between the basalts and the underlying intrusives. The basalts are more erratic in their mineral chemistry principally because most phenocrysts in the basalts suggest that, if there is a genetic link, these basalts were erupted from the magma chamber at a stage of evolution between gabbros of the types 24-3, 112-114 cm and 21-1, 47-49 cm. However, more convincing evidence exists against the idea that there is any genetic relationship between the intrusives and extrusives at Site 334. First, the close spatial relationship between the two groups makes unlikely the notion that the coarse-grained intrusives could be in situ cumulates from the same magmas that gave rise to the basalts. Secondly, the numerous breccia zones noted in the core logs, plus the cataclastic textures in the gabbros, suggest that these cumulates were tectonically emplaced. The greater the degree of displacement this type of deformation represents, the less likely it is that the intrusives and extrusives are genetically related. Among the breccias, the mysterious nannofossil chalk matrix could tentatively be explained by a process of "oblique diapirism" of ultramafic lenses being serpentinized. The degree of serpentinization of olivine is a direct function of the amount of olivine in these rocks (i.e., a dunitic layer is totally serpentinized, and an olivine-poor gabbro has fresh olivine). If serpentinization occurred with an increase of volume, it could result in a dislocation of the layered sequence, across an oblique serpentinization front (Loubat, 1973). Lenses of brecciated serpentinites would eventually reach very superficial levels of the oceanic floor (Figure 2).

## CONCLUSIONS

The conclusions listed below are tentative because of the gaps in the core record and because of the limited mineral data.

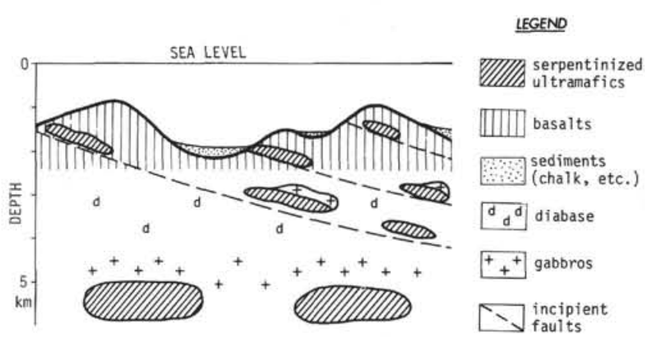


Figure 2. *Proposed shallow cross-section of the oceanic floor at some distance away from the axis of a volcanic ridge. Due to steeply oblique isotherms and serpentinization fronts, a lateral increase of volume and dislocation of ultramafic layers could occur. Some of these bodies in the process of serpentinization will eventually be dragged in a phenomenon of "oblique diapirism," and they could reach levels of superficial basalts and sediments, in a process of incipient dislocation of the oceanic floor. This could account for the differential degree of serpentinization of the layered body, the obvious increase of volume in the serpentinization, and the breccias with chalky fossiliferous matrix.*

**TABLE 2**
**Microprobe Analyses of Pyroxenes**

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.69 | | 53.32 | | 54.37 | | 52.36 | | 52.61 | | 42.33 | | 53.47 | | 53.51 | |
| $TiO_2$ | 0.20 | | 0.32 | | 0.20 | | 0.40 | | 0.30 | | 0.41 | | 0.21 | | 0.37 | |
| $Al_2O_3$ | 1.19 | | 1.75 | | 0.70 | | 1.55 | | 2.24 | | 1.84 | | 1.14 | | 2.97 | |
| $Cr_2O_3$ | 0.07 | | 0.09 | | 0.05 | | 0.09 | | 0.14 | | 0.08 | | 0.06 | | 1.33 | |
| $Fe_2O_3$ | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| FeO | 18.85 | | 7.63 | | 19.53 | | 8.50 | | 7.07 | | 8.54 | | 20.29 | | 2.72 | |
| MnO | 0.23 | | 0.25 | | 0.24 | | 0.22 | | 0.20 | | 0.23 | | 0.29 | | 0.00 | |
| MgO | 25.09 | | 14.85 | | 24.50 | | 14.97 | | 14.94 | | 14.38 | | 23.35 | | 16.35 | |
| CaO | 0.65 | | 22.23 | | 0.72 | | 21.53 | | 21.65 | | 21.62 | | 1.10 | | 21.98 | |
| $Na_2O$ | 0.07 | | 0.26 | | 0.08 | | 0.26 | | 0.27 | | 0.26 | | 0.09 | | 0.90 | |
| $K_2O$ | 0.02 | | 0.04 | | 0.03 | | 0.05 | | 0.05 | | 0.06 | | 0.03 | | 0.03 | |
| Sum | 99.98 | | 100.74 | | 100.42 | | 99.93 | | 99.46 | | 99.75 | | 100.03 | | 100.16 | |
| Si | 1.966 | * | 1.961 | * | 1.985 | * | 1.950 | * | 1.953 | * | 1.952 | * | 1.973 | * | 1.940 | * |
| Al | 0.034 | 2.000 | 0.039 | 2.000 | 0.014 | 2.000 | 0.050 | 2.000 | 0.047 | 2.000 | 0.048 | 2.000 | 0.027 | 2.000 | 0.060 | 2.000 |
| Al | 0.014 | * | 0.037 | * | 0.016 | * | 0.018 | * | 0.051 | * | 0.033 | * | 0.022 | * | 0.067 | * |
| Ti | 0.006 | * | 0.009 | * | 0.005 | * | 0.011 | * | 0.008 | * | 0.012 | * | 0.006 | * | 0.000 | * |
| Cr | 0.002 | * | 0.003 | * | 0.001 | * | 0.003 | * | 0.004 | * | 0.002 | * | 0.002 | * | 0.038 | * |
| Fe3+ | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * |
| Fe | 0.578 | * | 0.235 | * | 0.597 | * | 0.265 | * | 0.220 | * | 0.266 | * | 0.626 | * | 0.082 | * |
| Mn | 0.007 | * | 0.008 | * | 0.007 | * | 0.007 | * | 0.006 | * | 0.007 | * | 0.009 | * | 0.000 | * |
| Mg | 1.369 | 1.975 | 0.814 | 1.105 | 1.334 | 1.961 | 0.831 | 1.134 | 0.827 | 1.116 | 0.800 | 1.120 | 1.284 | 1.949 | 0.884 | 1.081 |
| Ca | 0.026 | * | 0.876 | * | 0.028 | * | 0.859 | * | 0.861 | * | 0.864 | * | 0.043 | * | 0.854 | * |
| Na | 0.005 | * | 0.019 | * | 0.006 | * | 0.019 | * | 0.019 | * | 0.019 | * | 0.006 | * | 0.063 | * |
| K | 0.001 | 0.031 | 0.002 | 0.895 | 0.001 | 0.035 | 0.002 | 0.880 | 0.002 | 0.883 | 0.003 | 0.886 | 0.001 | 0.051 | 0.001 | 0.918 |
| O | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * |
| WO | 1.293 | | 45.512 | | 1.439 | | 43.947 | | 45.149 | | 44.771 | | 2.226 | | 46.917 | |
| EN | 69.426 | | 42.295 | | 68.102 | | 42.510 | | 43.343 | | 41.426 | | 65.729 | | 48.551 | |
| FS | 29.281 | | 12.193 | | 30.459 | | 13.543 | | 11.508 | | 13.804 | | 32.046 | | 4.532 | |
| WO | 1.285 | | 44.898 | | 1.429 | | 43.377 | | 44.548 | | 44.174 | | 2.208 | | 45.341 | |
| HYP | 98.465 | | 54.152 | | 98.284 | | 55.675 | | 54.446 | | 54.865 | | 97.465 | | 51.293 | |
| JD | 0.250 | | 0.950 | | 0.287 | | 0.948 | | 1.005 | | 0.961 | | 0.327 | | 3.360 | |
| F/M | 0.427 | | 0.298 | | 0.453 | | 0.327 | | 0.273 | | 0.431 | | 0.495 | | 0.093 | |
| F/FM | 0.299 | | 0.229 | | 0.312 | | 0.246 | | 0.215 | | 0.255 | | 0.331 | | 0.085 | |

| | 9 | | 10 | | 11 | | 12 | | 13 | | 14 | | 15 | | 16 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 55.73 | | 55.92 | | 50.55 | | 51.20 | | 50.49 | | 50.68 | | 52.59 | | 52.44 | |
| $TiO_2$ | 0.11 | | 0.11 | | 0.22 | | 0.24 | | 0.17 | | 0.25 | | 0.22 | | 0.21 | |
| $Al_2O_3$ | 2.14 | | 2.16 | | 3.69 | | 3.17 | | 2.67 | | 2.24 | | 1.12 | | 1.09 | |
| $Cr_2O_3$ | 0.77 | | 0.74 | | 1.27 | | 1.27 | | 0.39 | | 0.24 | | 0.09 | | 0.10 | |
| $Fe_2O_3$ | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| FeO | 6.79 | | 6.69 | | 3.64 | | 3.36 | | 6.87 | | 7.96 | | 14.14 | | 14.16 | |
| MnO | 0.00 | | 0.00 | | 0.11 | | 0.10 | | 0.17 | | 0.20 | | 0.11 | | 0.11 | |
| MgO | 31.48 | | 32.15 | | 18.52 | | 17.99 | | 17.83 | | 16.98 | | 26.88 | | 27.02 | |
| CaO | 2.53 | | 2.19 | | 19.56 | | 20.75 | | 18.72 | | 18.27 | | 2.03 | | 1.98 | |
| $Na_2O$ | 0.03 | | 0.05 | | 0.15 | | 0.20 | | 0.14 | | 0.14 | | 0.01 | | 0.01 | |
| $K_2O$ | 0.01 | | 0.02 | | 0.06 | | 0.07 | | 0.04 | | 0.05 | | 0.03 | | 0.02 | |
| Sum | 99.59 | | 100.03 | | 97.77 | | 98.35 | | 97.49 | | 97.01 | | 97.22 | | 97.14 | |
| Si | 1.948 | * | 1.944 | * | 1.880 | * | 1.896 | * | 1.904 | * | 1.926 | * | 1.950 | * | 1.947 | * |
| Al | 0.052 | 2.000 | 0.056 | 2.000 | 0.120 | 2.000 | 0.104 | 2.000 | 0.096 | 2.000 | 0.074 | 2.000 | 0.049 | 1.999 | 0.048 | 1.995 |
| Al | 0.036 | * | 0.032 | * | 0.042 | * | 0.034 | * | 0.023 | * | 0.027 | * | 0.000 | * | 0.000 | * |
| Ti | 0.003 | * | 0.003 | * | 0.006 | * | 0.007 | * | 0.005 | * | 0.007 | * | 0.006 | * | 0.006 | * |
| Cr | 0.021 | * | 0.020 | * | 0.037 | * | 0.037 | * | 0.012 | * | 0.007 | * | 0.003 | * | 0.003 | * |
| Fe3+ | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * |
| Fe | 0.198 | * | 0.194 | * | 0.113 | * | 0.014 | * | 0.217 | * | 0.253 | * | 0.439 | * | 0.440 | * |
| Mn | 0.000 | * | 0.000 | * | 0.003 | * | 0.003 | * | 0.005 | * | 0.006 | * | 0.003 | * | 0.003 | * |
| Mg | 1.640 | 1.899 | 1.666 | 1.915 | 1.027 | 1.228 | 0.993 | 1.178 | 1.002 | 1.263 | 0.962 | 1.262 | 1.486 | 1.937 | 1.495 | 1.947 |
| Ca | 0.095 | * | 0.082 | * | 0.779 | * | 0.823 | * | 0.756 | * | 0.744 | * | 0.081 | * | 0.079 | * |
| Na | 0.002 | * | 0.003 | * | 0.011 | * | 0.014 | * | 0.010 | * | 0.010 | * | 0.001 | * | 0.001 | * |
| K | 0.000 | 0.097 | 0.001 | 0.086 | 0.003 | 0.793 | 0.003 | 0.841 | 0.002 | 0.769 | 0.002 | 0.757 | 0.001 | 0.083 | 0.001 | 0.030 |
| O | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * |

1) The sequence of nine rhythmic units in the intrusive rocks at Site 334 appears to be the product of a Rhum, rather than a Skaergaard, type of fractional crystallization.

2) Cryptic variation is present in the uppermost intrusive unit, and it probably exists in each of the rhythmic units. A detailed study of the phase chemistry of each rhythmic unit is suggested in order that the full record of evolution may be understood.

3) There is phase layering in many of the units; olivine and chrome spinel are frequently observed at the bottom, but not the top, of individual rhythmic

TABLE 2 – *Continued*

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| WO | 4.901 | 4.200 | 40.510 | 42.872 | 38.293 | 37.979 | 4.023 | 3.911 |
| EN | 84.833 | 85.784 | 53.491 | 51.709 | 50.738 | 49.105 | 74.105 | 74.255 |
| FS | 10.266 | 10.016 | 5.899 | 5.419 | 10.969 | 12.916 | 21.872 | 21.834 |
| WO | 4 896 | 4.193 | 40.310 | 42.485 | 37.991 | 37.657 | 4.015 | 3.903 |
| HYP | 94.999 | 95.634 | 59.131 | 56.774 | 61.495 | 61.821 | 95.950 | 96.061 |
| JO | 0.105 | 0.173 | 0.559 | 0.741 | 0.514 | 0.522 | 0.036 | 0.036 |
| F/M | 0.121 | 0.117 | 0.114 | 0.108 | 0.222 | 0.270 | 0.297 | 0.295 |
| F/FM | 0.108 | 0.105 | 0.102 | 0.097 | 0.181 | 0.212 | 0.229 | 0.229 |

| | 17 | | 18 | | 19 | | 20 | | 21 | | 22 | | 23 | | 24 | | 25 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52.24 | | 51.12 | | 52.14 | | 54.93 | | 55.20 | | 52.58 | | 52.90 | | 52.41 | | 51.92 | |
| $TiO_2$ | 0.43 | | 0.00 | | 0.00 | | 0.34 | | 0.33 | | 0.40 | | 0.41 | | 0.29 | | 0.33 | |
| $Al_2O_3$ | 3.70 | | 5.58 | | 3.81 | | 1.68 | | 1.80 | | 2.68 | | 2.55 | | 2.61 | | 3.25 | |
| $Cr_2O_3$ | 0.00 | | 0.00 | | 0.00 | | 0.40 | | 0.40 | | 0.66 | | 0.57 | | 0.83 | | 0.72 | |
| $Fe_2O_3$ | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| FeO | 5.80 | | 6.48 | | 6.60 | | 8.47 | | 8.33 | | 4.91 | | 4.29 | | 3.44 | | 3.17 | |
| MnO | 0.15 | | 0.00 | | 0.00 | | 0.38 | | 0.37 | | 0.34 | | 0.34 | | 0.12 | | 0.23 | |
| MgO | 17.88 | | 18.40 | | 20.88 | | 31.13 | | 30.80 | | 18.72 | | 17.35 | | 16.26 | | 16.20 | |
| CaO | 19.90 | | 17.85 | | 14.71 | | 2.42 | | 2.46 | | 19.63 | | 20.27 | | 23.29 | | 23.35 | |
| $Na_2O$ | 0.18 | | 0.14 | | 0.13 | | 0.14 | | 0.15 | | 0.27 | | 0.27 | | 0.40 | | 0.21 | |
| $K_2O$ | 0.06 | | 0.00 | | 0.00 | | 0.08 | | 0.08 | | 0.09 | | 0.09 | | 0.06 | | 0.06 | |
| Sum | 100.34 | | 99.57 | | 98.27 | | 99.97 | | 99.92 | | 100.28 | | 99.04 | | 99.50 | | 99.44 | |
| Si | 1.902 | * | 1.868 | * | 1.913 | * | 1.934 | * | 1.942 | * | 1.913 | * | 1.943 | * | 1.925 | * | 1.909 | * |
| Al | 0.098 | 2.000 | 0.132 | 2.000 | 0.087 | 2.000 | 0.066 | 2.000 | 0.058 | 2.000 | 0.087 | 2.000 | 0.057 | 2.000 | 0.074 | 2.000 | 0.091 | 2.000 |
| Al | 0.060 | * | 0.108 | * | 0.078 | * | 0.004 | * | 0.016 | * | 0.028 | * | 0.053 | * | 0.039 | * | 0.050 | * |
| Ti | 0.012 | * | 0.000 | * | 0.000 | * | 0.009 | * | 0.019 | * | 0.011 | * | 0.011 | * | 0.008 | * | 0.009 | * |
| Cr | 0.000 | * | 0.000 | * | 0.000 | * | 0.011 | * | 0.011 | * | 0.019 | * | 0.017 | * | 0.024 | * | 0.021 | * |
| Fe3+ | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.010 | * | 0.000 | * | 0.000 | * |
| Fe | 0.177 | * | 0.198 | * | 0.202 | * | 0.249 | * | 0.245 | * | 0.149 | * | 0.132 | * | 0.156 | * | 0.097 | * |
| Mn | 0.005 | * | 0.000 | * | 0.000 | * | 0.011 | * | 0.011 | * | 0.010 | * | 0.011 | * | 0.004 | * | 0.007 | * |
| Mg | 0.970 | 1.223 | 1.002 | 1.308 | 1.142 | 1.422 | 1.634 | 1.919 | 1.615 | 1.907 | 1.015 | 1.233 | 0.960 | 1.173 | 0.891 | 1.072 | 0.888 | 1.072 |
| Ca | 0.776 | * | 0.699 | * | 0.578 | * | 0.091 | * | 0.093 | * | 0.765 | * | 2.798 | * | 0.917 | * | 0.920 | * |
| Na | 0.013 | * | 0.010 | * | 0.009 | * | 0.010 | * | 0.010 | * | 0.019 | * | 0.019 | * | 0.014 | * | 0.015 | * |
| K | 0.003 | 0.792 | 0.000 | 0.709 | 0.000 | 0.587 | 0.004 | 0.104 | 0.004 | 0.107 | 0.004 | 0.788 | 0.004 | 0.321 | 0.003 | 0.934 | 0.003 | 0.938 |
| O | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * | 6.000 | * |
| WO | 40.364 | | 36.800 | | 30.076 | | 4.624 | | 4.748 | | 39.653 | | 42.446 | | 47.926 | | 48.283 | |
| EN | 50.453 | | 52.772 | | 59.391 | | 82.744 | | 82.702 | | 52.606 | | 50.542 | | 46.548 | | 46.601 | |
| FS | 9.183 | | 10.428 | | 10.533 | | 12.632 | | 12.558 | | 7.742 | | 7.012 | | 5.525 | | 5.116 | |
| WO | 40.004 | | 36.609 | | 29.932 | | 4.575 | | 4.697 | | 39.055 | | 41.783 | | 47.480 | | 47.728 | |
| HYP | 59.342 | | 62.871 | | 69.589 | | 94.946 | | 94.785 | | 59.973 | | 57.210 | | 51.732 | | 51.495 | |
| JD | 0.655 | | 0.520 | | 0.479 | | 0.479 | | 0.518 | | 0.972 | | 1.007 | | 0.733 | | 0.777 | |
| F/M | 0.187 | | 0.198 | | 0.177 | | 0.160 | | 0.159 | | 0.157 | | 0.150 | | 0.123 | | 0.118 | |
| F/FM | 0.157 | | 0.165 | | 0.151 | | 0.138 | | 0.137 | | 0.136 | | 0.130 | | 0.109 | | 0.105 | |

Note: 1 = 23-1, 127-129 cm; OPX host 1. 2 = 23-1, 127-129 cm; CPX lamella 1A. 3 = 23-1, 127-129 cm; OPX host 2. 4 = 23-1, 127-129 cm; CPX lamella 2A. 5 = 23-1, 127-129 cm; CPX host 3. 6 = 23-1, 127-129 cm; CPX host 4. 7 = 23-1, 127-129 cm; OPX lamella 4A. 8 = 26-1, 20-22 cm; OPX 3. 9 = 26-1, 20-22 cm; OPX 7. 10 = 26-1, 20-22 cm; OPX 8. 11 = 26-1, 20-22 cm; CPX 9. 12 = 26-1, 20-22 cm; CPX 10. 13 = 21-1, 47-49 cm; CPX 1. 14 = 21-1, 47-49 cm; CPX 2. 15 = 21-1, 47-49 cm; OPX 3. 16 = 21-1, 47-49 cm; OPX 4. 17 = 15-2, 30 cm; CPX 1. 18 = 20-2, 140-145 cm; CPX 3. 19 = 20-2, 140-145 cm; CPX 4. 20 = 24-3, 112-144 cm; OPX 2. 21 = 24-3, 112-114 cm; OPX 3. 22 = 24-3, 112-114 cm; CPX 4. 23 = 24-3, 112-114 cm; CPX 5. 24 = 22-2, 61-63 cm; CPX 3. 25 = 22-2, 61-63 cm; CPX 4.

units. This phase layering is attributed to reaction relationships in a fractionating magma rather than settling of dense crystals in rhythmic units developed by "turbidity currents" in the magma chamber.

4) The mineral chemistry alone is not sufficient to establish or disprove a genetic link between the basalts and the underlying intrusives.

5) A genetic link between intrusives and extrusives is unlikely because of the close spatial association of the rocks and because of the deformation of the intrusives suggesting that they have been tectonically emplaced.

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TABLE 3
Microprobe Analyses of Feldspars

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 48.19 | 47.30 | 47.57 | 47.00 | 46.87 | 48.30 | 46.47 | 51.33 | 50.41 | 45.72 |
| $TiO_2$ | 0.05 | 0.05 | 0.04 | 0.04 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 | 0.02 |
| $Al_2O_3$ | 32.13 | 32.46 | 32.65 | 32.93 | 32.73 | 32.11 | 33.68 | 29.39 | 29.98 | 33.39 |
| $Cr_2O_3$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $Fe_2O_3$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| FeO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.29 | 0.75 | 0.74 | 0.00 |
| MnO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MgO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.58 | 0.51 | 0.00 |
| CaO | 16.61 | 15.74 | 16.98 | 17.55 | 17.59 | 16.59 | 18.25 | 14.85 | 15.40 | 18.17 |
| $Na_2O$ | 2.23 | 2.15 | 1.97 | 1.66 | 1.66 | 2.14 | 1.12 | 2.61 | 2.60 | 1.32 |
| $K_2O$ | 0.07 | 0.06 | 0.07 | 0.06 | 0.06 | 0.07 | 0.00 | 0.00 | 0.00 | 0.05 |
| Sum | 99.28 | 99.22 | 99.28 | 99.24 | 98.96 | 99.26 | 100.14 | 99.52 | 99.64 | 98.67 |
| Si | 8.900 * | 8.837 * | 8.795 * | 8.787 * | 8.711 * | 8.916 * | 8.553 * | 9.409 * | 9.259 * | 8.541 * |
| Ti | 0.887 * | 0.317 * | 0.006 * | 0.006 * | 0.007 * | 0.007 * | 0.000 * | 0.000 * | 0.000 * | 0.003 * |
| Al | 6.992 * | 7.072 * | 7.113 * | 7.188 * | 7.168 * | 6.985 * | 7.304 * | 6.348 * | 6.488 * | 7.391 * |
| Fe3+ | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * |
| Fe | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.045 * | 0.117 * | 0.114 * | 0.000 * |
| Mn | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * | 0.000 * |
| Mg | 0.000 15.899 | 0.000 15.916 | 0.000 15.914 | 0.000 15.901 | 0.000 15.866 | 0.000 15.908 | 0.091 15.992 | 0.158 16.033 | 0.140 16.000 | 0.000 15.895 |
| Ca | 3.287 * | 3.308 * | 3.364 * | 3.483 * | 3.603 * | 3.281 * | 3.599 * | 2.917 * | 3.030 * | 3.637 * |
| Na | 0.798 * | 0.771 * | 0.786 * | 0.596 * | 0.598 * | 0.766 * | 0.400 * | 0.928 * | 0.926 * | 0.478 * |
| K | 0.016 4.102 | 0.014 4.093 | 0.017 4.086 | 0.014 4.094 | 0.014 4.115 | 0.016 4.064 | 0.000 3.998 | 0.000 3.844 | 0.000 3.956 | 0.312 4.127 |
| O | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * | 32.000 * |
| Or | 0.402 | 0.346 | 0.484 | 0.346 | 0.346 | 0.406 | 0.000 | 0.000 | 0.000 | 0.283 |
| AB | 19.468 | 18.830 | 17.282 | 14.564 | 14.536 | 18.843 | 9.995 | 24.130 | 23.402 | 11.585 |
| AN | 80.130 | 80.825 | 82.314 | 84.090 | 85.118 | 80.746 | 90.005 | 75.870 | 76.598 | 88.126 |
| QZ | 91.611 | 91.844 | 92.407 | 93.449 | 93.432 | 91.933 | 95.536 | 91.026 | 90.909 | 94.574 |
| NE | 8.219 | 8.000 | 7.420 | 6.399 | 6.416 | 7.897 | 4.464 | 8.974 | 9.091 | 5.294 |
| KS | 0.178 | 0.147 | 0.173 | 0.152 | 0.153 | 0.170 | 0.000 | 0.000 | 0.000 | 0.132 |

Note: 1 = 23-1, 127-129 cm; plagioclase 5. 2 = 23-1, 127-129 cm; plagioclase 6. 3 = 21-1, 47-49 cm; plagioclase 5. 4 = 21-1, 47-49 cm; plagioclase 6. 5 = 21-1, 47-49 cm; plagioclase 7. 6 = 21-1, 47-49 cm; plagioclase 8. 7 = 15-2, 20 cm; plagioclase 1. 8 = 20-2, 140-145 cm; plagioclase 1. 9 = 20-2, 140-145 cm; plagioclase 2. 10 = 24-3, 112-114 cm; plagioclase 6.

TABLE 4
Microprobe Analyses of Spinels

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.01 | | 0.02 | |
| $TiO_2$ | 0.37 | | 0.40 | | 0.66 | | 0.70 | | 0.63 | | 0.52 | |
| $Al_2O_3$ | 24.66 | | 22.10 | | 21.58 | | 21.59 | | 21.64 | | 20.65 | |
| $Fe_2O_3$ | 2.77 | | 3.93 | | 4.73 | | 4.62 | | 5.05 | | 5.16 | |
| FeO | 15.52 | | 18.68 | | 17.51 | | 17.83 | | 19.26 | | 20.62 | |
| $Cr_2O_3$ | 43.12 | | 43.33 | | 42.86 | | 43.50 | | 42.41 | | 42.91 | |
| MnO | 0.29 | | 0.37 | | 0.36 | | 0.36 | | 0.37 | | 0.41 | |
| MgO | 13.39 | | 10.94 | | 11.73 | | 11.74 | | 10.61 | | 9.60 | |
| ZnO | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| CaO | 0.02 | | 0.02 | | 0.02 | | 0.02 | | 0.01 | | 0.02 | |
| Sum | 100.14 | | 99.77 | | 99.45 | | 100.36 | | 99.89 | | 99.91 | |
| Si | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.003 | * | 0.005 | * |
| Ti | 0.068 | * | 0.075 | * | 0.124 | * | 0.131 | * | 0.100 | * | 0.099 | * |
| Al | 7.064 | * | 6.522 | * | 6.369 | * | 6.322 | * | 6.409 | * | 6.181 | * |
| Cr | 8.288 | * | 8.580 | * | 8.486 | * | 8.547 | * | 8.427 | * | 8.618 | * |
| Fe3+ | 0.507 | 15.926 | 0.741 | 15.918 | 0.891 | 15.871 | 0.864 | 15.864 | 0.955 | 15.894 | 0.986 | 15.890 |
| Fe | 3.155 | * | 3.913 | * | 3.667 | * | 3.705 | * | 4.048 | * | 4.380 | * |
| Mn | 0.060 | * | 0.078 | * | 0.076 | * | 0.076 | * | 0.079 | * | 0.088 | * |
| Mg | 4.852 | * | 4.084 | * | 4.379 | * | 4.348 | * | 3.975 | * | 3.635 | * |
| Zn | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * | 0.000 | * |
| Ca | 0.005 | 8.072 | 0.005 | 8.080 | 0.005 | 8.128 | 0.005 | 8.135 | 0.003 | 8.104 | 0.005 | 8.109 |
| O | 32.000 | * | 32.000 | * | 32.000 | * | 32.000 | * | 32.000 | * | 32.000 | * |
| CHRO | 52.260 | | 54.156 | | 53.895 | | 54.324 | | 53.366 | | 54.594 | |
| SPIN | 44.545 | | 41.169 | | 40.444 | | 40.185 | | 40.585 | | 39.158 | |
| MAGN | 3.195 | | 4.675 | | 5.661 | | 5.491 | | 6.048 | | 6.248 | |
| USP | 0.886 | | 1.027 | | 1.683 | | 1.788 | | 1.342 | | 1.367 | |
| SPIN | 92.481 | | 88.880 | | 86.245 | | 86.405 | | 85.862 | | 85.060 | |
| MAGN | 6.634 | | 10.903 | | 12.072 | | 11.807 | | 12.796 | | 13.573 | |
| USP | 0.763 | | 0.082 | | 1.308 | | 1.371 | | 1.056 | | 1.024 | |
| CHRO | 93.519 | | 91.315 | | 89.311 | | 89.574 | | 88.871 | | 88.812 | |
| MAGN | 5.718 | | 7.883 | | 9.381 | | 9.055 | | 10.072 | | 10.165 | |
| F/M | 0.663 | | 0.977 | | 0.855 | | 0.870 | | 1.038 | | 1.229 | |
| F/FM | 0.399 | | 0.494 | | 0.461 | | 0.465 | | 0.509 | | 0.551 | |

Note: 1 = 26-1, 20-22 cm; spinel 1. 2 = 26-1, 20-22 cm; spinel 2. 3 = 26-2, 5-10 cm; spinel 1. 4 = 26-2, 5-10 cm; spinel 2. 5 = 22-2, 61-63 cm; spinel 6. 6 = 22-2, 61 63 cm; spinel 7.

TABLE 5
Summary of Petrography

| Sample (Interval in cm) | Rock Type | Modal Analysis | | Grain Size (mm) | Texture | Alteration |
|---|---|---|---|---|---|---|
| 15-2, 20 | Basalt | Plagioclase<br>Clinopyroxene<br>Olivine | 50<br>45<br>5 | Phenocrysts <3<br>Groundmass <1 | Porphyritic (phenocrysts of Plag, Cpx, Oliv) | Minor chlorite in vesicles |
| 20-2, 140-145 | Basalt | Plagioclase<br>Clinopyroxene<br>Quench crystals<br>Olivine | 5<br>5<br>90<br>Tr | <1 | Microporphyritic rock consisting mainly of quench crystals in variolitic texture | Fresh |
| 21-1, 47-49 | Anorthositic gabbro | Plagioclase<br>Clinopyroxene | 60<br>40 | 1-6 | Plagioclase-Cpx adcumulate; exsolution in Cpx | Minor sericite |
| 22-1, 17-23 | Gabbro | Plagioclase<br>Pyroxene | 60<br>40 | Phenocrysts <3 | Cumulus plagioclase; intercumulus pyroxene | Partially amphibolitized |
| 22-2, 61-63 | Peridotite | Olivine<br>Clinopyroxene<br>Rodingite | 70<br>15<br>15 | Olivine 10-20<br>Cpx 1-4mm | Cumulus olivine; intercumulus Cpx with minor exsolution | Olivine 95% serpentinized |
| 22-2, 80-82 | Perdotite | Olivine<br>Clinopyroxene<br>Orthopyroxene<br>Chromite | 60<br>18<br>22<br>Tr | Olivine 1-2<br>Cpx 8-15 | Cpx exsolved; olivine cumulus pyroxenes intercumulus; mesh | Olivine and orthopyroxene partly serpentinized |
| 23-1, 46-54 | Peridotite | Olivine<br>Iddingsite<br>Opx<br>Cpx<br>Plag | 60<br><br><br>40 | Olivine 10-12 | Olivines corroded; exsolution lamellae in fresh Cpx | Olivine totally serpentinized, Opx-Cpx-Plag serpentinized and rodingitized |
| 23-1, 91-93 | Gabbro | Plagioclase<br>Clinopyroxene | 50<br>50 | <2 | Ophitic; minor cataclasis; plagioclase cumulus; clinopyroxene intercumulus | Fresh |
| 23-1, 127-129 | Noritic gabbro | Plagioclase<br>Pyroxenes | 40<br>60 | 3-15 | Adcumulate; augite and inverted pigeonite both with exsolution lamellae; cataclastized | Fresh |
| 23-2, 78-82 | Peridotite | Olivine<br>Orthopyroxene<br>Plagioclase<br>Chromite | 70<br>15<br>15<br>Tr | <2 | Trace of exsolution in altered Opx | Olivine and orthopyroxene totally serpentinized; plagioclase rodingitized |
| 24-2, 105-107 | Olivine gabbro | Olivine<br>Plagioclase<br>Clinopyroxene | 15<br>50<br>35 | Generally <4 | Plag poikilitic in Cpx | Olivine partly altered to serpentine and iddingsite |
| 24-3, 112-114 | Olivine leucogabbro | Olivine<br>Plagioclase<br>Pyroxenes | 5<br>55<br>40 | 1-6 | Adcumulate | Olivine partly serpentinized |
| 24-4, 100-106 | Olivine gabbro | Olivine<br>Plagioclase<br>Pyroxenes | 35<br>20<br>45 | Olivine <10<br>Plag <2<br>Pyroxene 4 | Opx and Cpx zoned, exsolved and with kink bands; olivine and plagioclase cumulus | Olivine partly serpentinized |
| 26-1, 20-22 | Peridotite | Olivine<br>Pyroxenes<br>Rodingite<br>Spinels | 60<br>30<br>5<br>5 | 3-10 | Cumulus olivine and spinel; intercumulus plagioclase mesh; bastite; pyroxenes with exsolution | Olivine altered to serpentine |

**TABLE 5** – *Continued*

| Sample (Interval in cm) | Rock Type | Modal Analysis | | Grain Size (mm) | Texture | Alteration |
|---|---|---|---|---|---|---|
| 26-1, 70-75 | Peridotite | Olivine<br>Clinopyroxene<br>Orthopyroxene<br>Chromite | 65<br>22<br>13<br>Tr | Generally <10 | Cpx with exsolution lamellae; Olivine cumulus; Cpx intercumulus | Olivine totally serpentinized; Opx partly serpentinized |
| 26-2, 5-10 | Peridotite | Olivine<br>Pyroxenes<br>Rodingite<br>Spinel | 80<br>15<br>5 | 2-3 | Cumulus olivine and spinel; intercumulus pyroxenes and plagioclase; mesh; bastite | Olivine totally serpentinized; Opx partly serpentinized |
| 26-2, 56-71 | Olivine gabbro | Olivine<br>Plagioclase<br>Pyroxenes | 20<br>40<br>40 | <4 | Exsolution lamellae in pyroxenes; cumulus plagioclase (and olivine?) | Olivine partly serpentinized |
| 26-2, 59-64 | Olivine gabbro (Pyroxenite) | Olivine<br>Plagioclase<br>Pyroxenes | 10<br>20<br>70 | <3 | Plagioclase cumulus; pyroxenes with exsolution lamellae | Olivine serpentinized |

TABLE 6
Summary of Mineral Chemistry for Intrusive Rocks at Site 334

| Depth (m) | Cycle | Rock Type | Sample (Interval in cm) | Phase Chemistry | |
|---|---|---|---|---|---|
| 310 - | | | | | |
| - | | | | | |
| - | | | | | |
| - | | | | | |
| - | | G | | Olivine absent | |
| 315 - | | G | 21-1, 47-49 | $Wo_{38}En_{50}Fs_{12}$ | Gabbro |
| - | | G | | $Wo_4En_{74}Fs_{22}$ | |
| - | | G | | $An_{80-85}$ | |
| - | | G | | | |
| - | | G | | | |
| 320 - | | G | | | |
| - | | G | | | |
| - | | G | | | |
| -* | | G | 22-1, 17-23 | | |
| -* | | G | | | |
| 325 - | | P | | $Fo_{87}$ | |
| - | | P | 22-2, 61-63 | $Wo_{48}En_{47}Fs_5$ | Peridotite |
| -* | | P | 22-2, 80-82 | $Cr_{54}Sp_{40}Mt_6$ | |
| - | | G | 23-1, 46-54 | | |
| -* | | G | 23-1, 91-93 | Olivine absent | |
| 330 - | | G | 23-1, 127-129 | $Wo_{44}En_{42}Fs_{14}$ | |
| - | | P | | $Wo_{42}En_{67}Fs_{31}$ | Gabbro |
| - | | G | | $An_{80}$ | |
| | | P | | | |
| -* | | G | | | |
| | | P | | | |
| 335 - | | G | 23-2, 78-82 | | |
| | | P | | | |
| - | | G | | | |
| - | | G | | | |
| - | | G | | | |
| -* | | G | | | |
| 340 -* | | G | | | |
| -* | | OG | 24-2, 105-107 | $Fo_{85}$ | |
| -* | | OG | | $Wo_1En_{51}Fs_8$ | |
| - | | OG | 24-3, 112-114 | $Wo_5En_{83}Fs_{12}$ | Gabbro |
| -* | | OG | | $An_{88}$ | |
| 345 - | | OG | | | |
| - | | OG | | | |
| - | | OG | | | |
| -* | | OG | | | |
| - | | OG | 24-4, 100-106 | | |
| 350 -* | | P | | | |
| - | | P | | | |
| - | | P | | | |
| - | | P | | | |
| - | | G | | | |
| 335 - | | G | | | |
| - | | G | | | |
| - | | G | | | |
| - | | G | | | |
| - | | G | | | |
| 360 - | | G | | $Fo_{88}$ | |
| - | | G | | $Wo_{42}En_{53}Fs_5$ | |
| -* | | P | 26-1, 20-22 | $Wo_4En_{85}Fs_{11}$ | Peridotite |
| -* | | P | | $Cr_{54}Sp_{40}Mt_5$ | |
| - | | P | 26-1, 70-75 | | |
| 365 -* | | P | 26-2, 5-10 | $Cr_{53}Sp_{43}Mt_4$ | Peridotite |
| - | | OG | 26-2, 56-71 | | |
| - | | OG | 26-2, 59-64 | | |
| - | | G | | | |
| - | | G | | | |
| 370 - | | G | | | |
| | | OG | | | |

Note: P = Peridotite; OG = Olivine Gabbro; G = Gabbro; * = Breccia.