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HANFORD BASALT FLOW MINERALOGY

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ABSTRACT

Mineralogy of the core samples from five core wells was examined in some detail. The primary mineralogy study included an optical examination of polished mounts, photomicrographs, chemical analyses of feldspars, pyroxenes, metallic oxides and microcrystalline groundmasses and determination from the chemical analyses of the varieties of feldspars, pyroxenes and metallic oxides. From the primary mineralogy data, a firm understanding of the average Hanford basalt flow primary mineralogy emerged. The average primary feldspar was a laboradorite, the average pyroxene was an augite and the average metallic oxide was a solid solution of ilmenite and magnetite.

Secondary mineralization consisted of vug filling and joint coating, chiefly with a nontronite-beidellite clay, several zeolites, quartz, calcite, and opal.

Specific flow units also were examined to determine the possibility of using the mineralogy to trace flows between core wells. These included units of the Pomona, the Umatilla and a high chromium flow just below the Huntzinger. In the Umatilla, or high barium flow, the compositional variation of the feldspars was unique in range. The pyroxenes in the Pomona were relatively highly zoned and accumulated chromium. The high chromium flow contained chromium spinels that graded in chromium content into simple magnetites very low in chromium content.

A study of the statistical relationships of flow unit chemical constituents showed that flow unit constituents could be roughly correlated between wells. The probable cause of the correlation was on-going physical-chemical changes in the source magma.

INTRODUCTION

From 1969 to 1972, several core wells were drilled at the Department of Energy's Hanford Site under the management of Atlantic Richfield Hanford Company (ARHCO) (a) personnel. The locations of these wells are shown in Plate 1. Further details of borehole samples and locations are given in the appendix. A sixth well, ARH-DC-1, not shown in Plate 1, was drilled on the Hanford site for the purpose of obtaining hydrological information rather than cores. At the request of ARHCO, selected cores from DDH-1, DH-2, DDH-3, DH-4 and DH-5 were examined in respect to their primary mineralization and secondary mineralization common to nearly all of the flow units, and the mineralogy of specific flow units which might prove useful for their correlation between wells.

One objective of the mineralogical work was to furnish a data base for a projected basalt cavern storage program. One of the requirements of such a program is detailed knowledge of the mineralogy in contact with the storage vault, or in its immediate vicinity, with potential use in waste leachate-flow unit mineral reactions. Another use of detailed knowledge of mineral chemistry is to determine whether or not the groundwater is in equilibrium with this chemical environment. The mineralogy of the storage vault area constitutes one of the primary barriers between the radioactive waste and man, and as such, its physics and chemistry should be as well known as is consistent with reasonable research costs and safety consideration.

(a) In July 1977, responsibilities for Waste Management Operations at DOE's Hanford Site were transferred to Rockwell Hanford Operations.

PLATE 1. Core Well Locations

SUMMARY AND CONCLUSIONS

Cores from wells DDH-1, DH-2, DDH-3, DH-4 and DH-5 were examined for the secondary mineralization occurring in the vugs, fissures and cracks of the basalt flows and interbeds. The main secondary mineral was a nontronite-beidellite clay found on fissures and cracks and in vugs. The clay, in common with the quartz and opal associated with it, was formed by late-stage hydrothermal activity generated in the lower units of the still-cooling basalt sequence.

According to Coombs¹, who grouped the calcic zeolites by their field occurrences in environments, supersaturated, saturated or undersaturated in respect to silica, heulandite is typical of a supersaturated or saturated silica environment. Heulandite is the most common zeolite encountered in the basalt units below 1000 feet. The accompanying quartz and opal found with the zeolite tends to confirm that heulandite is typical of silica-rich environments. The top thousand feet of basalts are essentially zeolite-free, as is typical of similar, thick basalt flow sequences.^{2,3}

The primary minerals normally consisted of labradorite feldspar, augite and an ilmenite-magnetite solid solution. Accessory minerals included apatite, occasionally olivine and a small globular sulfide containing iron, cobalt and nickel. An occasional bytownite or andesine could be seen. Pigeonites and subcalcic augites were scarce. Feldspar zoning was usually minimal with the Umatilla member (high barium flows) an exception. In the Umatilla member, feldspars normally were labradorites, but a few crystals ranged from orthoclase to andesine in composition. There was also much exsolution of ilmenite evident from ilmenite-magnetite solid solutions. In the Pomona, zoning of pyroxenes from augites to pigeonites could be identified. Below the Pomona, a flow high in chromium contained metallic oxides that graded from magnetites to chromites.

The statistical correlations of MgO and CaO, and K₂O and MgO were computed from the whole rock analyses of DDH-3 and DH-4 core well samples. Good correlations were obtained. These flow unit constituents are correlated over the well sections as a result of common physical-chemical changes taking place in the source magma through time.

Correlation of flow units between core wells requires the use of all available data on trace element chemistry and distribution, general and specific mineralogy, whole rock chemistry and primary and secondary mineralogy. Normally, no one piece of information or technique uniquely identifies a flow unit.

GENERAL BASALT FLOW MINERALOGY

PRIMARY MINERALIZATION

Feldspars

Most feldspars can be chemically classified as members of the ternary system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - $\text{CaAl}_2\text{Si}_2\text{O}_8$, or albite-orthoclase-anorthite, shown in Figure 1. These feldspars are now called sodium, potassium, and calcium feldspars, respectively, rather than soda, potash and lime feldspars.

In Figure 1, the large vacant area on the right-hand side of the diagram between orthoclase (Or) and anorthite (An) is due to an immiscibility gap in the phase diagram for this system. If a melt did happen to have a 50% KAlSi_3O_8 - 50% $\text{CaAl}_2\text{Si}_2\text{O}_8$ composition, two feldspars would crystallize upon cooling. One would be an anorthite and the other a potassium feldspar phase. One feldspar would not crystallize in the 50% KAlSi_3O_8 - 50% CaAl_2O_8 compositional area.

Sanadine is the high-temperature, monoclinic potassium feldspar occurring in a high and low form; orthoclase is the intermediate, monoclinic feldspar; and microcline is the lowest temperature, triclinic potassium feldspar. Orthoclase and microcline occupy the same compositional area as sanadine in Figure 1. Microcline itself is divided into maximum microcline and intermediate microcline. Maximum and intermediate refer to crystal lattice angles, with maximum microcline showing maximum obliquity, or the closest approach to a monoclinic unit cell. For example, the unit cell angles of triclinic microcline were determined as $\alpha = 90^\circ 41'$ and $\gamma = 87^\circ 30'$, and classified as a maximum microcline because the α angle was so close to 90° that the unit cell was nearly monoclinic. The intermediate microclines are less monoclinic. Sanadine and orthoclase feldspars are, of course, metastable at their present temperatures and pressures. The high temperature forms persist due to adverse kinetics imposed by the cooling rate of the rocks in which they are found. If cooling rate kinetics allow it, the potassium feldspars revert from sanadine to orthoclase and microcline, or intergrowths of orthoclase and microcline called perthites. Adularia is another low-temperature potassium feldspar variety characterized by crystal morphology and restricted paragenesis.

There is also a high-temperature, monoclinic albite and a low-temperature, triclinic albite. Pericline is a rare sodium feldspar that bears the same relation to low albite that

FIGURE 1. Feldspar Classifications

adularia does to microcline. No high or low forms of anorthite are recognized.

Many of the various feldspars are structural modifications, such as microcline-orthoclase-sanadine and high and low sanadine. Others are based primarily on compositional variations, such as the plagioclase series. There is no sodium-potassium compositional nomenclature analogous to the plagioclase series. Anorthoclase is the only intermediate named area between orthoclase and albite. It is so-named because anorthoclase is triclinic while sanadine is monoclinic. The compositional names of the plagioclases were assigned before the structural complexity of the various solid solution series was realized. Usually, the composition of the feldspar in the series can be given in terms of Ab-An "molecular" percentages. But there is also a third "molecule" that must be taken into account, that of orthoclase, or KAlSi_3O_8 . Most feldspars can compositionally be considered as falling on the $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - $\text{CaAl}_2\text{Si}_2\text{O}_8$ diagram. There are some exceptions such as the barium feldspar celsian, $\text{BaAl}_2\text{Si}_2\text{O}_8$, but as solid solution series exist between barium and the other feldspars as well, the addition of celsian to the ternary system shown in Figure 1 is justified. Then we may express the composition of a feldspar as the "molecular" percentage of Ab, An, Or and Cn, or celsian. This procedure of expressing the feldspar in "molecular" percentages allows a rapid comparison of two feldspars of differing composition that is not readily done from chemical analyses alone. In the molecular percentage determinations, 32 oxygens per molecule are required for the formula $(\text{Na}, \text{K}, \text{Ca})_4 (\text{Si}, \text{Al})_{16}\text{O}_{32}$. The reasoning behind the use of the above formula for "molecular" percentage determinations is as follows.

The objective here is to combine the "molecules" $\text{NaAl}(\text{Si}_3\text{O}_8)$, $\text{KAl}(\text{Si}_3\text{O}_8)$ and $\text{CaAl}_2(\text{Si}_2\text{O}_8)$, or to regroup into structural type formulae, $(\text{Na})(\text{Al}, \text{Si})_4\text{O}_8$, $(\text{K})(\text{Al}, \text{Si})_4\text{O}_8$ and $(\text{Ca})(\text{Al}, \text{Si})_4\text{O}_8$. It becomes immediately clear that the Ab and Or "molecules" cannot replace an An "molecule"; i.e., $(\text{Na})^{+1}$ or $(\text{K})^{+1}$ cannot replace a $(\text{Ca})^{+2}$. Hence, it is necessary to multiply by two the $(\text{Na})(\text{Al}, \text{Si})_4\text{O}_8$ and $(\text{K})(\text{Al}, \text{Si})_4\text{O}_8$, or $(\text{Na})_2(\text{Al}, \text{Si})_8\text{O}_{16}$ and $(\text{K})_2(\text{Al}, \text{Si})_8\text{O}_{16}$. In order to combine the three molecules [or four if $(\text{Ba})(\text{Al}, \text{Si})_4\text{O}_8$ is sought], a lowest common denominator for the oxygens is determined; in this case, 32. So we have now $(\text{Na})_4(\text{Al}, \text{Si})_{16}\text{O}_{32}$, $(\text{K})_4(\text{Al}, \text{Si})_{16}\text{O}_{32}$ and $(\text{Ca})_4(\text{Al}, \text{Si})_{16}\text{O}_{32}$ or combining into a single "molecule", $(\text{Na}, \text{K}, \text{Ca})_4(\text{Al}, \text{Si})_{16}\text{O}_{32}$. From this combined "molecule", the molecular percentages making up the Ab, An and Or are easily determined. Since nearly all feldspars contain some Na, K and Ca, this procedure is justified for feldspar comparisons. Normally, the alkali feldspars (Ab-Or) contain

less than 10 Mol% An, and the plagioclases (Ab-An) normally contain less than 10 Mol% Or.

Another advantage of the method is that the percentages of the three "molecules" can be plotted on Figure 1 as percent Ab, An and Or. For example, a feldspar containing 65% Ab, 10% An and 25% Or would fall in the anorthoclase area and be classified as anorthoclase (point "0" in Figure 1). The percentages of Ab, An or Or are indicated on the compositional triangle. If a feldspar were 100% Or, the composition would fall at the apex of the triangle where the sides Ab-Or and An-Or join. There are a series of lines on the diagram with the percent Or indicated that proceed to 0% Or at the triangle base, or line Ab-An. The percentages of Ab and An are read the same way, with 100% Ab or An at their respective angle apices, as marked on Figure 1, and 0% for Ab and An on lines Or-An and Or-Ab, respectively. Hence, the normal feldspars for a basalt series should form a series of points that fall in a small group on the compositional diagram. Any unusual feldspars for the series would fall outside of the normal grouping. As pointed out earlier, sanadine, orthoclase and microcline are all compositionally the same and occupy the same compositional area or field in Figure 1. Potassium feldspars are conventionally referred to as orthoclases in these computations. Albite, oliboclase, andesine, labradorite, bytownite and anorthite are compositional names only, while anorthoclase and sanadine-orthoclase-microcline are so-named because they represent structurally defined species as well as compositions. Historically, the nomenclature of the plagioclase series predates feldspar structural studies. While there is a continuous solid solution series between Ab and An at high temperatures, the series is discontinuous and complex at lower temperatures. If this series were named today, the fields represented by each name would look considerably different than they do in Figure 1 at lower temperatures.

The feldspar molecular percentages are based on the molecule $(\text{Na, K, Ca, Ba})_4 (\text{Si, Al})_{16}\text{O}_{32}$. As an example of how the results of Table 1 were obtained, a hypothetical analysis will suffice. The microprobe analysis gave: Na_2O , 5.4; Al_2O_3 , 30.2; SiO_2 , 54.9; K_2O , 0.2 and CaO , 12.0 weight percent. The above values were corrected to 100% total, divided by their respective molecular equivalent weights and recorrected to a 100% total to yield: Na, 9.19; Al, 31.20; Si, 48.13; K, 0.222 and Ca, 11.25 Mol%. Associated with each cation were atoms of oxygen. For example, the corrected 5.26 wt% Na_2O was divided by its molecular equivalent weight of 31 (its molecular weight of 62/2 because there are two equivalents of Na in Na_2O). The Na, then has 0.5 oxygens associated with it, and 0.5 times 9.19 gives 4.60 associated oxygens. Using 1.5

oxygens for the Al, two oxygens for the Si; 0.5 oxygens for the K and one oxygen for the Ca gives a total of 159.02 oxygens associated with the above cations. The 159.02 is divided by 32 and the atom percents of each cation divided by this number (4.9694) to obtain the atoms/molecule. Another way of doing the same thing is to multiply the atom percentages by the factor 32/159.02. In going through this operation, the following values for atoms/molecule were obtained: Na, 1.85; K, 0.045; Ca, 2.26 (total = 4.155); (Al, Si) 15.97 O_{32} . The percent of albite, anorthite, orthoclase and celsian molecules in the unit cell are easily computed from the sum of Na, K, Ca and Ba.

DDH-3 Feldspar Analyses

The compositions of 143 feldspars from DDH-3 well cores, as determined from the microprobe chemical analyses, are given in Table 1. Fifteen of the 143 analyses were substandard, and are so indicated in Table 1. This group of samples constitutes a survey of DDH-3 well cores. The crystal sizes and molecular percentages of albite, anorthite and orthoclase are given in Table 2. Little BaO was found during the microprobe analysis of this group of samples except for feldspar samples from the Sillusi-Umatilla member. Of the 128 acceptable feldspar analyses, 68 were identified as labradorite, the usual feldspar found in basalt flows, and 53 identified as andesine. There is a tendency of the compositions to lie toward the sodic side of the $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$ 50% dividing line. Another apparent trend is for the smaller feldspar crystals to contain more sodium and fall in the andesine compositional area. This trend is most pronounced in A2123 feldspars that range in composition from labradorite for the largest crystal to oligoclase for the smallest crystal. On the other hand, the feldspars of A2061 are all andesines, although the tendency is again to move toward the albite composition with decreasing crystal size. Apparently all of the flows represented by these samples crystallized two or more generations of feldspars characteristic of different stages of flow chemical differentiation. It is not possible to crystallize labradorite and andesine from the same melt at the same time.

The feldspar compositions are not very useful for differentiating between flow units in this group of samples. Nothing as distinctive as the high barium flow feldspars was found to be prevalent. However, the excellent correlation between crystal size and composition found in sample A2123 suggests that this unit could be located again if this tendency is characteristic of the whole flow unit. The only other possibility for a marker unit is A2061 containing only andesine.

TABLE 1. Well Core DDH-3

Atomic contents of 143 feldspars as computed from the microprobe chemical analyses. The three analyses with $\pm 10\%$ deviation from the ideal 4.0 are marked with asterisks.

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si + Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa,K,Na,Ba</u>
A2024	10.172	5.822	15.994	1.611	0.109	2.475	0.020	4.215
A2024	10.998	5.012	16.010	0.681	0.695	2.756	0.078	4.210
A2024	11.474	4.461	15.935	0.588	1.251	1.956	0.169	3.964
A2024	11.301	4.883	16.184	0.323	0.985	2.135	0.192	3.635
A2028	9.836	6.207	16.043	1.745	0.091	2.398	0.028	4.262
A2028	9.969	6.100	16.069	1.704	0.089	2.269	0.027	4.089
A2028	9.876	6.236	16.112	1.756	0.071	2.163	0.022	4.012
A2028	11.116	5.057	16.173	0.405	0.820	2.530	0.104	3.859
A2028	11.408	4.880	16.288	0.390	1.002	1.467	0.240	3.009*
A2044	9.850	6.259	16.109	2.109	0.045	1.562	---	3.716
A2044	9.792	6.252	16.044	2.116	0.068	1.775	---	3.960
A2050	10.012	6.003	16.015	2.102	0.045	1.691	---	3.838
A2050	10.065	5.973	16.038	2.035	0.069	1.681	---	3.785
A2053	10.257	5.841	16.098	1.822	0.083	1.721	---	3.626
A2053	10.105	5.994	16.099	1.921	0.067	1.690	---	3.678
A2059	9.416	6.698	16.114	1.997	0.058	2.191	---	4.246
A2059	10.522	5.413	15.935	2.201	0.057	1.214	---	3.472*
A2059	9.709	6.430	16.193	1.935	0.060	1.943	---	3.838
A2059	9.332	6.786	16.118	1.976	0.048	2.313	---	4.337
A2059	9.745	6.305	16.050	2.049	0.045	1.960	---	4.054
A2059	10.946	5.204	16.150	1.304	0.121	1.872	---	3.297*
A2059	9.759	6.382	16.141	1.901	0.045	1.969	---	3.915
A2059	9.896	6.176	16.072	1.957	0.044	1.931	---	3.932
A2067	10.036	6.129	16.165	1.794	0.067	1.812	---	3.673
A2067	10.003	6.109	16.112	1.779	0.064	2.043	---	3.886
A2067	9.902	6.092	15.994	1.970	0.067	2.107	---	4.144
A2067	10.024	6.077	16.101	1.755	0.065	2.099	---	3.919
A2067	9.874	6.137	16.011	2.021	0.045	2.005	---	4.066
A2067	10.015	5.994	16.009	1.967	0.068	1.954	---	3.989
A2079	9.676	6.400	16.076	2.176	0.046	1.695	---	3.917
A2079	9.617	6.434	16.051	2.225	0.045	1.732	---	4.002
A2079	9.232	6.868	16.100	2.209	0.046	2.003	---	4.258
A2079	9.560	6.554	16.114	2.066	0.044	1.923	---	4.033

TABLE 1 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si + Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa,K,Na,Ba</u>
A2089	9.465	6.585	16.050	2.123	0.046	2.093	--	4.262
A2089	9.439	6.633	16.072	2.223	0.044	1.852	--	4.119
A2089	9.657	6.502	16.159	2.107	0.070	1.583	--	3.760
A2089	9.683	6.366	16.049	2.019	0.043	2.088	--	4.150
A2089	9.903	6.162	16.065	2.027	0.044	1.803	--	3.874
A2089	9.404	6.661	16.065	2.263	0.045	1.828	--	4.136
A2098	9.969	6.080	16.049	2.060	0.045	1.720	--	3.825
A2098	10.038	6.060	16.098	2.013	0.045	1.599	--	3.657
A2098	9.896	6.178	16.074	2.100	0.044	1.636	--	3.780
A2098	9.829	6.246	16.075	2.123	0.045	1.654	--	3.822
A2105	9.749	6.255	16.004	2.080	0.044	2.038	--	4.162
A2105	10.030	5.949	15.979	1.984	0.043	2.020	--	4.047
A2105	9.841	6.182	16.023	2.111	0.044	1.827	--	3.982
A2105	10.333	5.667	16.000	1.826	0.041	1.975	--	3.842
A2105	9.886	6.179	16.065	1.988	0.044	1.902	--	3.934
A2105	9.649	6.417	16.066	2.022	0.043	2.069	--	4.134
A2105	10.451	5.485	15.936	1.642	0.068	2.387	--	4.097
A2105	9.291	6.779	16.070	2.238	0.046	1.977	--	4.261
A2116	10.157	5.819	15.976	1.968	0.067	1.913	--	3.948
A2116	10.360	5.587	15.947	1.958	0.071	1.810	--	3.839
A2116	10.205	5.817	16.022	1.874	0.067	1.913	--	3.854
A2116	9.973	6.128	16.091	2.002	0.068	1.654	--	3.724
A2128	9.975	6.154	16.129	1.752	0.067	2.069	--	3.888
A2128	9.334	6.848	16.182	2.244	0.045	1.588	--	3.877
A2128	9.188	6.873	16.061	2.464	0.045	1.656	--	4.165
A2128	9.464	6.590	16.054	2.248	0.044	1.833	--	4.125
A2128	9.308	6.790	16.098	2.449	0.045	1.455	--	3.949
A2128	9.266	6.783	16.049	2.350	0.044	1.842	--	4.236

TABLE 1 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa, K, Na, Ba</u>
A2045	10.366	5.564	15.900	1.820	0.138	2.068	<0.2	4.026
A2045	9.991	6.010	16.001	2.119	0.073	1.696	--	3.888
A2045	10.597	5.123	15.720	2.182	0.148	1.730	--	4.060
A2045	10.656	5.313	15.969	1.622	0.180	2.013	--	3.815
A2046	9.963	6.107	16.070	1.912	0.134	1.866	--	3.912
A2046	10.637	5.273	15.910	1.521	0.181	2.408	--	4.110
A2046	10.106	5.872	15.978	1.916	0.089	2.040	--	4.045
A2046	9.846	6.161	16.007	2.025	0.142	1.940	--	4.107
A2048	9.729	6.251	15.980	2.122	0.094	1.992	--	4.208
A2048	10.409	5.490	15.899	1.847	0.126	2.074	--	4.047
A2048	9.866	6.133	15.999	2.145	0.072	1.777	--	3.994
A2048	9.649	6.247	15.896	1.975	0.162	2.547	--	4.684*
A2056	9.934	5.964	15.898	2.030	0.145	2.167	--	4.342*
A2056	10.000	5.936	15.936	2.173	0.096	1.748	--	4.017
A2056	9.969	5.971	15.940	2.131	0.094	1.856	--	4.081
A2056	9.963	5.968	15.931	2.189	0.117	1.748	--	4.054
A2056	10.109	5.864	15.973	1.922	0.124	2.004	--	4.050
A2056	10.222	5.977	16.199	1.492	0.469	1.725	--	3.686*
A2056	10.481	5.475	15.956	1.785	0.158	1.924	--	3.867
A2056	9.461	6.582	16.043	2.199	0.092	1.920	--	4.211
A2056	10.377	5.519	15.896	1.736	0.161	2.304	--	4.201
A2056	9.877	6.015	15.892	2.096	0.089	2.168	--	4.353*
A2060	10.118	5.846	15.964	1.987	0.114	1.902	--	4.003
A2060	11.572	4.636	16.208	0.972	0.272	1.587	--	2.831*
A2060	10.604	5.554	16.158	1.338	0.205	2.041	--	3.584*
A2060	10.021	5.712	15.733	2.153	0.175	2.298	--	4.626*
A2061	10.333	5.560	15.893	1.821	0.117	2.232	--	4.170
A2061	10.005	5.906	15.911	2.062	0.072	2.065	--	4.199
A2061	10.349	5.593	15.942	1.547	0.137	2.593	--	4.277
A2061	10.358	5.237	15.595	2.238	0.120	2.262	--	4.620*

TABLE 1 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa,K, Na,Ba</u>
A2064	10.013	5.964	15.977	2.105	0.116	1.728	--	3.949
A2064	10.045	5.908	15.953	1.935	0.136	2.094	--	4.165
A2064	10.187	5.803	15.990	1.744	0.143	2.213	--	4.100
A2064	9.996	5.823	15.819	1.971	0.096	2.512	--	4.579*
A2064	10.050	5.921	15.971	2.057	0.094	1.825	--	3.976
A2064	10.217	5.831	16.048	1.753	0.136	2.000	--	3.889
A2068	9.730	6.265	15.986	2.269	0.066	1.683	--	4.018
A2068	9.634	6.309	15.943	2.412	0.066	1.645	--	4.123
A2068	10.923	5.099	16.022	1.252	0.245	2.265	--	3.762
A2068	10.339	5.612	15.951	1.669	0.173	2.299	--	4.141
A2072	9.745	6.280	16.025	2.323	0.097	1.438	--	3.858
A2072	10.185	5.798	15.983	1.808	0.139	2.111	--	4.058
A2072	9.950	6.022	15.972	1.972	0.092	2.099	--	4.163
A2072	10.256	5.670	15.926	1.765	0.171	2.266	--	4.202
A2083	9.946	6.000	15.946	2.079	0.070	1.987	--	4.136
A2083	9.949	5.996	15.945	2.123	0.067	1.904	--	4.094
A2083	9.898	6.121	16.019	2.264	0.070	1.448	--	3.782
A2083	10.489	5.458	15.947	1.617	0.128	2.308	--	4.053
A2087	9.707	6.345	16.052	2.258	0.067	1.553	--	3.878
A2087	9.842	6.127	15.969	1.999	0.089	2.164	--	4.252
A2087	9.762	6.154	15.916	2.233	0.089	1.935	--	4.257
A2087	10.692	5.322	16.014	1.447	0.153	2.221	--	3.821
A2092	9.762	6.103	15.865	2.345	0.095	1.841	--	4.290
A2092	10.375	5.082	15.817	1.546	0.291	2.430	--	4.267
A2092	9.754	6.082	15.836	2.183	0.094	2.278	--	4.555*
A2092	9.739	6.077	15.816	2.383	0.071	1.977	--	4.431*
A2094	9.461	6.561	16.022	2.279	0.046	1.868	--	4.193
A2094	10.331	5.586	15.917	1.799	0.090	2.228	--	4.117
A2094	9.578	6.367	15.945	2.225	0.069	2.066	--	4.360*
A2094	10.357	5.558	15.915	1.737	0.120	2.303	--	4.160
A2097	9.987	5.985	15.972	2.037	0.073	1.953	--	4.063
A2097	10.803	5.242	16.045	1.501	0.143	1.919	--	3.563
A2097	9.829	6.148	15.977	2.275	0.073	1.617	--	3.965
A2097	10.630	5.461	16.091	1.516	0.141	1.924	--	3.581

TABLE 1 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa,K, Na,Ba</u>
A2102	9.718	6.214	15.932	2.379	0.048	1.678	--	4.105
A2102	10.503	5.472	15.975	1.598	0.164	2.213	--	3.975
A2102	9.992	6.015	16.007	2.170	0.069	1.578	--	3.817
A2102	9.896	6.042	15.938	2.226	0.069	1.771	--	4.066
A2109	10.269	5.597	15.866	1.924	0.117	2.167	--	4.208
A2109	10.310	5.618	15.928	1.620	0.179	2.488	--	4.287
A2109	10.117	5.971	16.088	1.872	0.114	1.763	--	3.779
A2109	10.357	5.616	15.973	1.845	0.117	1.918	--	3.880
A2123	10.308	5.723	16.031	1.687	0.142	2.083	--	3.912
A2123	9.970	6.051	16.021	1.866	0.096	2.142	--	4.104
A2123	9.995	6.020	16.015	2.001	0.094	1.865	--	3.960
A2123	11.427	4.421	15.848	1.101	0.243	2.583	--	3.927
A2133	9.949	5.962	15.911	2.159	0.121	1.880	--	4.160
A2133	10.190	5.738	15.928	2.073	0.096	1.785	--	3.954
A2133	10.568	5.334	15.902	1.725	0.122	2.155	--	4.002
A2133	10.236	5.564	15.800	2.007	0.115	2.235	--	4.357
A2133	10.358	5.665	16.023	1.716	0.146	1.996	--	3.858
A2133	9.797	6.201	15.998	2.118	0.095	1.880	--	4.093

TABLE 2. Well Core DDH-3

Feldspar compositions based on the molecule (Na, K Ca, Ba)₄ (Si, Al)₁₆O₃₂ as determined from the microprobe chemical analyses. The analyses showing >10% deviation from the unit cell were deleted.

Molecular Percentages					
Sample	Ab	An	Or	Cn	Feldspar
A2024	58.7	38.2	2.6	0.5	Andesine
A2024	65.5	16.2	16.5	1.8	Anorthoclase
A2024	49.3	14.8	31.6	4.3	Orthoclase -andesine mixture
A2024	58.7	8.9	27.1	5.3	Anorthoclase
A2028	56.3	40.9	2.1	0.7	Andesine
A2028	55.5	41.7	2.2	0.6	Andesine
A2028	53.9	43.8	1.8	0.5	Andesine
A2028	65.6	10.5	21.2	2.7	(microphenocryst) Anorthoclase
A2044	42.0	56.8	1.2	---	Labradorite
A2044	44.8	53.4	1.8	---	Labradorite
A2050	44.0	54.8	1.2	---	Labradorite
A2050	44.4	53.8	1.8	---	Labradorite
A2053	47.5	50.2	2.3	---	Labradorite
A2053	46.0	52.2	1.8	---	Labradorite
A2059	51.6	47.0	1.4	---	Andesine
A2059	50.0	50.4	1.6	---	Andesine
A2059	53.3	45.6	1.1	---	Andesine
A2059	48.4	50.5	1.1	---	Labradorite
A2059	50.3	48.6	1.1	---	Andesine
A2059	49.1	49.8	1.1	---	Labradorite
A2067	49.3	48.9	1.8	---	Andesine
A2067	52.6	45.8	1.6	---	Andesine
A2067	50.9	47.5	1.6	---	Andesine
A2067	53.5	44.8	1.7	---	Andesine
A2067	49.3	49.6	1.1	---	Andesine
A2067	49.0	49.3	1.7	---	Labradorite
A2079	43.2	55.6	1.2	---	Labradorite
A2079	43.3	55.6	1.1	---	Labradorite
A2079	47.0	51.9	1.1	---	Labradorite
A2079	47.7	51.2	1.1	---	Labradorite

TABLE 2 (continued)

<u>Sample</u>	<u>Molecular Percentages</u>				<u>Feldspar</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>	<u>Cn</u>	
A2089	49.1	49.8	1.1	---	Labradorite
A2089	44.9	54.0	1.1	---	Labradorite
A2089	42.1	56.0	1.9	---	Labradorite
A2089	50.3	48.6	1.1	---	Andesine
A2089	46.6	53.2	1.1	---	Labradorite
A2089	44.2	54.7	1.1	---	Labradorite
A2098	45.0	53.9	1.1	---	Labradorite
A2098	43.7	55.0	1.2	---	Labradorite
A2098	43.2	55.6	1.1	---	Labradorite
A2098	43.3	55.5	1.2	---	Labradorite
A2105	48.9	50.0	1.1	---	Labradorite
A2105	49.9	49.0	1.1	---	Andesine
A2105	45.9	53.0	1.1	---	Labradorite
A2105	51.4	47.5	1.1	---	Andesine
A2105	48.4	50.5	1.1	---	Labradorite
A2105	50.0	48.9	1.1	---	Andesine
A2105	58.3	40.0	1.7	---	Andesine
A2105	46.4	52.5	1.1	---	Labradorite
A2116	48.5	49.8	1.7	---	Labradorite
A2116	47.1	51.0	1.8	---	Labradorite
A2116	49.6	48.6	1.7	---	Andesine
A2116	44.4	53.8	1.8	---	Labradorite
A2128	53.2	45.1	1.7	---	Andesine
A2128	41.0	57.9	1.1	---	Labradorite
A2128	39.7	59.2	1.1	---	Labradorite
A2128	44.4	54.5	1.1	---	Labradorite
A2128	36.8	62.0	1.2	---	Labradorite
A2128	43.5	55.5	1.0	---	Labradorite

TABLE 2 (continued)

<u>Sample</u>	<u>Molecular %</u>		<u>Or</u>	<u>Cn</u>	<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>				
A2045	51.4	45.2	3.4	--	Andesine	10x90
A2045	43.6	54.5	1.9	--	Labradorite	125x250
A2045	42.6	53.7	3.7	--	Labradorite	50x300
A2045	52.8	42.5	4.7	--	Andesine	10x35
A2046	47.7	48.9	3.4	--	Labradorite	40x300
A2046	58.6	37.0	4.4	--	Andesine	20x75
A2046	50.4	47.4	2.2	--	Andesine	200x400
A2046	47.2	49.3	3.5	--	Labradorite	25x75
A2048	47.4	50.4	2.2	--	Labradorite	25x150
A2048	51.3	45.6	3.1	--	Andesine	10x35
A2048	44.5	53.7	1.8	--	Labradorite	125x325
A2056	43.5	54.1	2.4	--	Labradorite	
A2056	45.5	52.2	2.3	--	Labradorite	
A2056	43.1	54.0	2.9	--	Labradorite	
A2056	49.5	47.5	3.0	--	Andesine	
A2056	49.8	45.2	5.0	--	Andesine	7x50
A2056	45.6	52.2	2.2	--	Labradorite	200x700
A2056	54.9	41.3	3.8	--	Andesine	20x100
A2060	47.5	49.6	2.9	--	Labradorite	30x250
A2061	53.5	43.7	2.8	--	Andesine	25x50
A2061	49.2	49.1	1.7	--	Andesine	100x300
A2061	60.6	36.2	3.2	--	Andesine	15x100
A2064	43.8	53.3	2.9	--	Labradorite	50x200
A2064	50.2	46.5	3.3	--	Andesine	10x200
A2064	54.0	42.5	3.5	--	Andesine	12x25
A2064	45.9	51.7	2.4	--	Labradorite	40x150
A2064	51.4	45.1	3.5	--	Andesine	20x60
A2068	41.9	56.5	1.6	--	Labradorite	100x450
A2068	39.9	58.5	1.6	--	Labradorite	125x750
A2068	60.2	33.3	6.5	--	Andesine	25x75
A2068	55.5	40.3	4.2	--	Andesine	25x125

TABLE 2 (continued)

<u>Sample</u>	<u>Molecular %</u>		<u>Or</u>	<u>Cn</u>	<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>				
A2072	37.3	60.2	2.5	--	Labradorite	25x250
A2072	52.0	44.6	3.4	--	Andesine	10x100
A2072	50.4	47.4	2.2	--	Andesine	75x350
A2072	53.9	42.0	4.1	--	Andesine	25x75
A2083	48.0	50.3	1.7	--	Labradorite	60x300
A2083	46.5	51.9	1.6	--	Labradorite	20x100
A2083	38.2	59.9	1.9	--	Labradorite	75x400
A2083	56.9	39.9	3.2	--	Andesine	10x50
A2087	40.1	58.2	1.7	--	Labradorite	75x400
A2087	50.9	47.0	2.1	--	Andesine	15x75
A2087	45.4	52.5	2.1	--	Labradorite	100x625
A2087	58.1	37.9	4.0	--	Andesine	10x35
A2092	42.9	54.9	2.2	--	Labradorite	125x900
A2092	57.0	36.2	6.8	--	Andesine	10x35
A2094	44.5	54.4	1.1	--	Labradorite	100x375
A2094	54.1	43.7	2.2	--	Andesine	15x100
A2094	47.4	51.0	1.6	--	Labradorite	100x500
A2094	55.3	41.8	2.9	--	Andesine	10x75
A2097	48.1	50.1	1.8	--	Labradorite	25x175
A2097	53.9	42.1	4.0	--	Andesine	10x60
A2097	40.8	57.4	1.8	--	Labradorite	150x750
A2097	53.8	42.3	3.9	--	Andesine	10x100
A2102	40.8	58.0	1.2	--	Labradorite	50x500
A2102	55.7	40.2	4.1	--	Andesine	20x125
A2102	41.3	56.9	1.8	--	Labradorite	60x375
A2102	43.6	54.7	1.7	--	Labradorite	20x75
A2109	51.5	45.7	2.8	--	Andesine	75x175
A2109	58.0	37.8	4.2	--	Andesine	10x80
A2109	46.7	49.5	3.0	--	Labradorite	100x250
A2109	49.4	47.6	3.0	--	Andesine	20x75
A2123	53.3	43.1	3.6	--	Andesine	60x225
A2123	52.2	45.5	2.3	--	Andesine	30x60
A2123	47.1	50.5	2.4	--	Labradorite	100x400
A2123	65.8	28.0	6.2	--	Oligoclase	10x55
A2133	45.2	51.9	2.9	--	Labradorite	12x80
A2133	45.2	52.4	2.4	--	Labradorite	40x400
A2133	53.9	43.1	3.0	--	Andesine	7x40
A2133	51.3	46.1	2.6	--	Andesine	40x350
A2133	51.7	44.5	3.8	--	Andesine	10x40
A2133	46.0	51.7	2.3	--	Labradorite	75x400

The contents of 40 feldspar unit cells from Type Section Feldspars, as determined from microprobe chemical analyses, are given in Table 3. The $\pm 10\%$ limit was exceeded for the sum of the alkalis and alkaline earths in three of the 40 analyses. The "molecular" percentages of albite (Ab), anorthite (An), orthoclase (Or) and celsian (Cn) are given in Table 4. The feldspars are identified and the crystal dimensions given when large size differences were noted. Two question marks were entered for feldspar identifications in sample Al215. Sample Al215 comes from approximately the same zone in the high barium flow as sample A2024 in DDH-3 that also showed a feldspar composition over in the normally vacant solvus region. It was hypothesized that the area under analysis had included two feldspars, such as orthoclase - andesine, that yielded a feldspar composition apparently falling in the solvus area. Another explanation was offered for feldspar compositions falling in the solvus region. If these unusual feldspars are believed to have formed before extrusion, it was possible to obtain such compositions if the system was confined, even temporarily, under high P_{H_2O} . High P_{H_2O} , at least experimentally, reduces the size of the solvus region significantly. It is not known which of the above explanations is correct for the unusual feldspars in the upper parts of the high barium flow. However, the presence of these unusual feldspars makes the flow unit easy to recognize even without the high barium content.

In sample Al216 analyses, toward the base of the high barium flow, the feldspar compositions proceed from large andesine crystals to very small orthoclase crystals. The barium content rises from essentially no barium toward the interior of the large andesine crystals to nearly 5 Mol% Cn in the small orthoclase crystals. However, it should be noted that the large andesine crystal edges contained up to 2.2% Cn, suggesting that feldspar crystal growth continued over a period of time and a range of residual liquid compositions.

Most of the other feldspar samples show a tendency toward increasing orthoclase content with decreasing crystal size. The two compositions from sample Al215 can be seen near the left-hand edge of the solvus region. The vast majority of feldspars fall into the andesine and labradorite areas. There is one orthoclase from sample Al216 of the high barium flow unit representing a late-crystallizing microphenocryst.

Hand-Separated Plagioclase Crystal Fragments

Thirty-two hand-separated main stage feldspar samples were submitted for analysis.

TABLE 3. Type Section Feldspars

Atomic contents of 40 feldspars as computed from the micro-probe chemical analyses. The analyses with $\pm 10\%$ deviation from the ideal 4.0 are marked with asterisks.

Unit Cell C								
<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	<u>ΣCa,K,Na,Ba</u>
K5008	9.761	6.370	16.086	1.969	0.071	2.016	--	4.056
K5008	9.706	6.439	16.145	1.828	0.115	2.089	--	4.032
K5008	9.696	6.338	16.034	2.056	0.070	2.020	--	4.146
K5008	10.666	5.543	16.209	1.054	0.232	2.367	--	3.653
K5010	10.216	5.604	15.820	1.996	0.121	2.111	--	4.228
K5010	9.715	6.106	15.821	2.318	0.071	2.115	--	4.504*
K5010	9.636	6.342	15.978	2.141	0.070	2.038	--	4.249
K5010	10.305	5.751	16.056	1.478	0.124	2.449	--	4.051
K5013	10.077	5.948	16.025	1.683	0.118	2.364	--	4.165
K5013	10.050	5.863	15.913	1.981	0.127	2.121	--	4.229
K5013	9.438	6.582	16.020	2.072	0.071	2.286	--	4.429
K5013	9.397	6.755	16.152	2.020	0.069	2.038	--	4.127
K5026	9.795	6.200	15.995	2.117	0.071	1.916	--	4.104
K5026	9.569	6.456	16.025	2.288	0.047	1.734	--	4.069
K5026	10.031	6.006	16.037	1.949	0.162	1.799	--	3.910
K5026	10.749	5.277	16.026	1.362	0.228	2.221	--	3.811
K5033	9.543	6.488	16.031	2.004	0.117	2.120	--	4.241
K5033	9.825	6.232	16.057	1.894	0.112	2.104	--	4.110
K5033	9.786	6.239	16.025	1.915	0.116	2.193	--	4.224
K5033	9.959	5.834	15.793	2.112	0.121	2.315	--	4.548*
Al215	11.320	4.971	16.291	0.976	0.716	2.137	--	3.829
Al215	11.476	4.986	16.462	0.768	0.594	1.007	--	2.369*
Al215	9.993	6.104	16.097	1.868	0.164	1.815	--	3.847
Al215	10.440	5.514	15.954	1.557	0.452	2.131	--	4.140
Al216	10.318	5.765	16.083	1.692	0.270	1.881	--	3.843
Al216	11.078	4.895	15.973	1.050	0.540	2.273	0.045	3.908
Al216	11.685	4.349	16.034	0.767	0.686	2.300	0.036	3.789
Al216	11.723	4.144	15.867	0.389	1.778	1.723	0.198	4.088
Al268	9.428	6.473	15.901	2.523	0.024	1.798	--	4.345
Al268	9.287	6.661	15.948	2.535	0.023	1.778	--	4.336
Al268	9.871	6.009	15.880	2.145	0.046	2.152	--	4.343
Al268	9.614	6.327	15.941	2.292	0.046	1.933	--	4.271

TABLE 3 (Continued)

<u>Sample</u>	<u>Unit cell contents</u>							<u>ΣCa,K,Na,Ba</u>
	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Ba</u>	
Al278	9.678	6.194	15.962	2.072	0.068	2.133	--	4.273
Al278	9.714	6.349	16.063	2.119	0.047	1.811	--	3.977
Al278	9.839	6.125	15.964	2.087	0.047	2.050	--	4.184
Al278	10.312	5.630	15.942	1.527	0.175	2.631	--	4.333
Al281	9.729	6.249	15.978	2.125	0.045	2.041	--	4.211
Al281	9.592	6.367	15.959	2.135	0.046	2.213	--	4.394
Al281	10.114	5.853	15.967	1.862	0.069	2.189	--	4.120
Al281	10.220	5.949	16.169	1.552	0.067	2.099	--	3.718

TABLE 4. Type Section Feldspars

Feldspar compositions as determined from the microprobe chemical analyses. The analyses showing >10% deviation from the ideal molecular contents were deleted.

Ab = albite, An = anorthite, Or = orthoclase, Cr = celsian

<u>Sample</u>	<u>Molecular Percentages</u>				<u>Feldspar</u>	<u>Crystal Dimensions, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>	<u>Cn</u>		
K5008	49.7	48.5	1.8	--	Andesine	
K5008	51.8	45.3	2.9	--	Andesine	
K5008	48.7	49.6	1.7	--	Labradorite	
K5008	64.8	28.9	6.4	--	Andesine	
K5010	49.9	47.2	2.9	--	Andesine	75x400
K5010	48.0	50.4	1.6	--	Labradorite	50x250
K5010	60.5	36.5	3.0	--	Andesine	10x50
K5013	56.8	40.4	2.8	--	Andesine	
K5013	50.2	46.8	3.0	--	Andesine	
K5013	51.6	46.8	1.6	--	Andesine	
K5013	49.4	48.9	1.7	--	Andesine	
K5026	46.7	51.6	1.7	--	Labradorite	50x225
K5026	42.6	56.2	1.2	--	Labradorite	60x225
K5026	46.1	49.8	4.1	--	Labradorite	10x60
K5026	58.3	35.7	6.0	--	Andesine	10x100
K5033	50.0	47.3	2.7	--	Andesine	
K5033	51.2	46.1	2.7	--	Andesine	
K5033	51.9	45.3	2.7	--	Andesine	
A1215	55.8	25.5	18.7	--	?	
A1215	47.2	48.6	4.3	--	Labradorite	
A1215	51.5	37.6	10.9	--	?	
A1216	48.9	44.1	7.0	--	Andesine	150x675 ^A
A1216	58.2	26.9	13.8	1.1	Anorthoclase	10x50
A1216	60.7	20.2	18.1	1.0	Anorthoclase	10x40
A1216	42.2	9.5	43.5	4.8	Orthoclase	5x5
A1268	41.4	58.0	0.6	--	Labradorite	100x375
A1268	41.0	58.5	0.5	--	Labradorite	160x375
A1268	49.6	49.4	1.0	--	Labradorite	12x125
A1268	45.3	53.7	1.0	--	Labradorite	25x110

TABLE 4 (Continued)

<u>Sample</u>	<u>Molecular Percentages</u>				<u>Feldspar</u>	<u>Crystal Dimensions, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>	<u>Cn</u>		
A1278	49.9	48.5	1.6	--	Andesine	40x225
A1278	45.5	53.3	1.2	--	Labradorite	225x600
A1278	49.0	49.9	1.1	--	Labradorite	25x100
A1278	60.8	35.2	4.0	--	Andesine	50x175
A1281	48.5	50.5	1.0	--	Labradorite	75x350
A1281	50.4	48.6	1.0	--	Andesine	150x675
A1281	53.1	45.2	1.7	--	Andesine	30x200
A1281	56.5	41.7	1.8	--	Andesine	25x125

A = Cn approached 2.2% on outer edge of this feldspar crystal.

About ten chemical analyses were obtained on different feldspar fragments of each sample. In addition, up to five scans across feldspar fragments in each sample were made for sodium, potassium and calcium.

The results of the 315 feldspar chemical analyses are presented in terms of a feldspar molecule of $(\text{Na,Ca,K,Fe})_4 (\text{Si,Al})_{16} \text{O}_{32}$ in Table 5. Note that 15 of the analyses are labeled with an asterisk, denoting a substandard analysis. "Substandard" was defined as a cation sum value exceeding or below 10% of the four or 16 required in the feldspar "unit cell" given above. The sum of calcium, potassium, sodium and iron is the value that is responsible for the substandard analyses. Of the above four cations, sodium is chiefly the cause of the high or low cation sums. This circumstance is the result of poor sodium counting statistics because most of the added energy goes to rearrangement of the sodium atom rather than production of characteristic x-radiation, and is inherent in the use of the microprobe for sodium analysis. For example, the sodium counts in these feldspars averaged about 450 per minute including a background of 160 counts per minute. For comparison, the electron-excited calcium gave counts of from 15,000 to 19,000 per minute including a background count of 200 per minute. The errors in sodium values are inherent in the low count rate, which in turn is due to long sodium wave length x-radiation ($\text{NaK} = 11.885\text{\AA}$) absorption in the less-than-perfect vacuum of the microprobe unit. Sodium is the element of lowest atomic weight that the microprobe can analyze for with any degree of precision.

The iron content was included in the analyses of Table 5 because in most cases it is present in the feldspar in larger amounts than the potassium. It is definitely within the feldspar crystal structure because the iron content is nearly a constant steady value in all analyses. These are two possible positions for the iron in the plagioclase structure according to Deer, Howie and Zussman.⁴ These include substitution of Fe^{+3} for Al^{+3} in the tetrahedral position, and Fe^{+2} for Ca^{+2} . For this study, the iron was placed in the second position, as seen in Table 5. The iron is probably distributed between both positions, but it is not possible to determine what the actual distribution is without a feldspar structural analysis. These crystal fragments have been mounted and sliced, and do not include the common exterior iron coating in the chemical analysis.

The similarity of composition of the feldspar analyses is apparent from an examination of Table 6. These are all labradorites with the exception of the fourth analysis of sample K5140, an adesite feldspar. Perhaps this similarity should be

TABLE 5. Hand-separated Plagioclase Crystal Fragments

Atomic contents of 315 feldspars as computed from the microprobe chemical analyses. The analyses marked with asterisks are substandard. All feldspars contained less than 0.2 wt% BaO.

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,NaFe</u>
K5140	9.956	6.016	15.972	2.304	0.070	1.236	0.107	3.717
K5140	9.371	5.986	15.857	2.419	0.069	1.436	0.106	4.030
K5140	9.974	5.920	15.894	2.355	0.070	1.350	0.107	3.882
K5140	10.469	5.363	15.832	1.774	0.163	2.081	0.122	4.140
K5140	9.729	6.110	15.839	2.472	0.070	1.526	0.107	4.175
K5140	9.825	5.987	15.812	2.500	0.071	1.448	0.109	4.128
K5140	9.835	6.052	15.887	2.437	0.070	1.376	0.091	3.974
K5140	9.782	6.103	15.885	2.445	0.069	1.394	0.105	4.013
K5140	9.856	6.064	15.920	2.434	0.070	1.233	0.106	3.843
K5140	9.760	6.101	15.861	2.453	0.069	1.468	0.105	4.095
K5139	9.733	6.131	15.864	2.474	0.070	1.445	0.106	4.095
K5139	9.787	6.076	15.863	2.449	0.069	1.442	0.106	4.066
K5139	9.843	6.057	15.900	2.381	0.070	1.413	0.107	3.971
K5139	9.788	6.079	15.867	2.507	0.070	1.311	0.107	3.995
K5139	9.830	6.021	15.851	2.418	0.094	1.471	0.108	4.091
K5139	9.744	6.112	15.856	2.488	0.069	1.431	0.105	4.093
K5139	9.930	5.917	15.847	2.385	0.072	1.463	0.110	4.030
K5139	9.708	6.151	15.859	2.471	0.070	1.490	0.107	4.138
K5139	9.780	6.084	15.864	2.433	0.070	1.479	0.106	4.088
K5139	9.797	6.068	15.865	2.459	0.092	1.391	0.105	4.047
K5137	9.814	6.125	15.939	2.393	0.070	1.303	0.106	3.872
K5137	9.791	6.091	15.882	2.503	0.070	1.274	0.107	3.954
K5137	9.734	6.313	16.047	2.302	0.096	1.206	0.110	3.714
K5137	9.679	6.262	15.941	2.522	0.070	1.168	0.107	3.867
K5137	9.894	6.039	15.930	2.343	0.068	1.345	0.104	3.860
K5137	9.923	5.975	15.898	2.402	0.093	1.272	0.107	3.874
K5137	9.739	6.135	15.874	2.456	0.070	1.446	0.106	4.078
K5137	9.972	5.949	15.921	2.231	0.092	1.532	0.090	3.945
K5137	9.798	6.123	15.921	2.415	0.069	1.328	0.106	3.918
K5137	9.954	5.886	15.840	2.420	0.093	1.378	0.107	3.998

TABLE 5 (continued)

Contento								
<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5136	9.592	6.264	15.856	2.474	0.098	1.567	0.113	4.252
K5136	9.484	6.386	15.870	2.458	0.096	1.677	0.110	4.341
K5136	9.758	6.107	15.865	2.373	0.068	1.593	0.119	4.153
K5136	9.939	5.909	15.848	2.298	0.069	1.642	0.105	4.114
K5136	9.808	6.119	15.927	2.297	0.069	1.537	0.105	4.008
K5136	9.945	5.923	15.868	2.345	0.092	1.461	0.105	4.003
K5136	9.806	6.082	15.888	2.267	0.068	1.690	0.119	4.144
K5136	9.819	6.185	16.004	2.201	0.094	1.458	0.107	3.860
K5136	10.059	5.895	15.954	2.181	0.091	1.419	0.104	3.795
K5136	10.012	5.847	15.859	2.133	0.111	1.828	0.102	4.174
K5135	9.897	6.040	15.937	2.403	0.072	1.196	0.109	3.780
K5135	9.723	6.289	16.012	2.397	0.071	1.157	0.109	3.734
K5135	9.746	6.184	15.930	2.369	0.093	1.417	0.107	3.986
K5133	10.146	5.672	15.818	2.280	0.068	1.560	0.105	4.013
K5133	10.048	5.765	15.849	2.159	0.095	1.737	0.109	4.100
K5133	9.898	5.945	15.843	2.371	0.074	1.530	0.113	4.088
K5133	9.988	5.907	15.895	2.289	0.070	1.464	0.108	3.931
K5133	10.057	5.850	15.907	2.250	0.069	1.439	0.106	3.864
K5133	10.051	5.900	15.951	2.152	0.093	1.487	0.107	3.839
K5133	9.944	5.881	15.825	2.328	0.096	1.575	0.126	4.125
K5133	9.944	5.937	15.881	2.227	0.073	1.664	0.112	4.076
K5133	10.060	5.885	15.945	2.196	0.091	1.382	0.119	3.788
K5133	9.577	6.354	15.931	2.402	0.072	1.534	0.110	4.118
K5132	9.977	5.944	15.921	2.257	0.072	1.422	0.126	3.877
K5132	9.864	5.967	15.831	2.338	0.072	1.641	0.126	4.177
K5132	9.600	6.384	15.984	2.340	0.073	1.473	0.111	3.997
K5132	9.975	5.919	15.894	2.196	0.068	1.645	0.118	4.027
K5132	10.124	5.709	15.833	2.226	0.069	1.646	0.106	4.047
K5132	9.972	6.074	15.866	2.359	0.073	1.559	0.128	4.119
K5132	9.776	6.136	15.912	2.383	0.074	1.388	0.129	3.974
K5132	9.707	6.247	15.954	2.254	0.075	1.586	0.130	4.045
K5132	10.133	5.737	15.870	2.162	0.072	1.609	0.126	3.969
K5132	10.370	5.514	15.884	2.084	0.072	1.487	0.125	3.768

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5131	9.886	6.042	15.928	2.271	0.071	1.501	0.108	3.951
K5131	9.975	5.963	15.938	2.241	0.070	1.446	0.106	3.863
K5131	9.848	5.957	15.805	2.425	0.072	1.596	0.109	4.202
K5131	9.970	5.917	15.887	2.315	0.070	1.456	0.107	3.948
K5131	9.882	6.007	15.889	2.314	0.071	1.539	0.108	4.032
K5131	10.055	5.807	15.862	2.231	0.069	1.615	0.106	4.021
K5131	9.988	5.917	15.905	2.315	0.070	1.385	0.107	3.877
K5131	10.017	5.837	15.854	2.223	0.070	1.694	0.106	4.093
K5131	10.081	5.864	15.945	2.197	0.069	1.408	0.106	3.780
K5131	10.038	5.936	15.974	2.141	0.071	1.471	0.108	3.791
K5126	9.852	6.026	15.878	2.254	0.072	1.712	0.110	4.148
K5126	9.816	6.102	15.918	2.313	0.071	1.516	0.109	4.009
K5126	9.991	5.973	15.964	2.222	0.071	1.388	0.107	3.787
K5126	9.803	6.118	15.921	2.216	0.069	1.688	0.121	4.094
K5126	9.849	6.038	15.887	2.210	0.069	1.789	0.106	4.174
K5126	9.877	6.015	15.892	2.257	0.071	1.613	0.124	4.065
K5126	9.888	6.043	15.931	2.251	0.071	1.501	0.123	3.946
K5126	9.827	6.057	15.884	2.275	0.069	1.689	0.106	4.139
K5126	9.770	6.058	15.828	2.311	0.070	1.808	0.122	4.311
K5126	9.810	6.026	15.836	2.271	0.069	1.827	0.121	4.288
K5101	9.934	5.990	15.924	2.453	0.068	1.110	0.105	3.736
K5101	9.862	6.054	15.916	2.263	0.066	1.598	0.100	4.027
K5101	9.941	5.937	15.878	2.219	0.064	1.698	0.113	4.094
K5101	9.873	5.969	15.842	2.232	0.066	1.869	0.101	4.268
K5101	10.338	5.539	15.877	2.233	0.090	1.267	0.103	3.693
K5101	10.154	5.686	15.840	2.285	0.092	1.425	0.120	3.922
K5101	10.185	5.566	15.751	2.294	0.067	1.701	0.103	4.165
K5101	10.093	5.675	15.768	2.275	0.068	1.750	0.118	4.211
K5101	9.910	5.973	15.883	2.235	0.067	1.699	0.103	4.104
K5101	10.004	5.937	15.941	2.387	0.069	1.088	0.121	3.665
K5099	9.844	5.971	15.815	2.420	0.070	1.589	0.107	4.008
K5099	9.937	5.897	15.843	2.307	0.070	1.663	0.107	4.147
K5099	9.868	6.000	15.868	2.384	0.071	1.512	0.124	4.055
K5099	9.631	6.334	15.965	2.487	0.071	1.229	0.109	3.887
K5099	9.705	6.107	15.812	2.461	0.072	1.643	0.110	4.286
K5099	9.733	6.122	15.855	2.429	0.070	1.560	0.107	4.166
K5099	9.870	5.990	15.860	2.483	0.071	1.294	0.108	3.956
K5099	9.910	5.979	15.889	2.412	0.070	1.313	0.107	3.902
K5099	9.887	6.073	15.924	2.426	0.070	1.098	0.107	3.701
K5099	9.820	5.960	15.780	2.510	0.071	1.502	0.123	4.206

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5098	9.781	6.158	15.939	2.409	0.069	1.301	0.106	3.885
K5098	10.119	5.664	15.783	2.323	0.072	1.594	0.109	4.098
K5098	10.049	5.866	15.915	2.389	0.071	1.143	0.108	3.711
K5098	10.094	5.795	15.889	2.248	0.094	1.463	0.092	3.897
K5098	10.034	5.778	15.812	2.443	0.072	1.352	0.110	3.977
K5098	10.073	5.734	15.807	2.230	0.069	1.739	0.120	4.158
K5098	10.072	5.755	15.827	2.249	0.069	1.670	0.105	4.093
K5098	9.811	6.154	15.965	2.271	0.069	1.440	0.121	3.901
K5098	9.892	6.036	15.928	2.288	0.068	1.472	0.103	3.931
K5098	9.663	6.421	16.084	2.225	0.072	1.342	0.110	3.749
K5096	9.800	6.046	15.846	2.281	0.068	1.823	0.104	4.276
K5096	9.794	6.155	15.949	2.388	0.069	1.300	0.106	3.863
K5096	9.844	6.081	15.925	2.233	0.068	1.643	0.103	4.047
K5096	9.788	6.073	15.861	2.241	0.068	1.837	0.120	4.266
K5096	9.940	5.877	15.817	2.200	0.067	1.939	0.103	4.309
K5096	9.851	6.093	15.944	2.417	0.070	1.199	0.106	3.792
K5096	10.088	5.706	15.794	2.376	0.070	1.493	0.107	4.046
K5096	9.783	6.155	15.938	2.383	0.069	1.356	0.105	3.913
K5096	9.760	6.032	15.792	2.333	0.068	1.922	0.104	4.427*
K5096	9.775	6.122	15.897	2.361	0.071	1.521	0.109	4.062
K5095	9.850	6.116	15.966	2.367	0.070	1.204	0.122	3.763
K5095	9.821	6.005	15.826	2.273	0.068	1.851	0.118	4.310
K5095	9.869	6.041	15.910	2.352	0.070	1.383	0.122	3.927
K5095	9.798	6.012	15.810	2.344	0.068	1.779	0.118	4.309
K5095	9.906	6.057	15.963	2.293	0.068	1.314	0.119	3.794
K5095	9.927	6.047	15.974	2.254	0.068	1.337	0.118	3.777
K5095	9.872	6.136	16.008	2.265	0.069	1.261	0.121	3.716
K5095	9.838	5.985	15.823	2.281	0.068	1.824	0.119	4.292
K5095	9.822	6.176	15.998	2.214	0.068	1.451	0.119	3.852
K5095	10.020	5.955	15.975	2.202	0.067	1.351	0.116	3.736
K5089	9.814	6.064	15.878	2.282	0.070	1.673	0.123	4.148
K5089	9.821	6.043	15.864	2.239	0.070	1.797	0.122	4.228
K5089	9.799	6.161	15.960	2.329	0.070	1.346	0.122	3.867
K5089	9.935	5.983	15.918	2.327	0.070	1.345	0.122	3.864
K5089	9.617	6.305	15.922	2.404	0.072	1.486	0.125	4.087
K5089	9.720	6.224	15.944	2.356	0.070	1.421	0.123	3.970
K5089	9.650	6.136	15.786	2.339	0.093	1.975	0.122	4.529*
K5089	9.785	6.174	15.959	2.287	0.070	1.450	0.122	3.929
K5089	9.695	6.155	15.850	2.434	0.072	1.565	0.126	4.197
K5089	9.742	6.156	15.898	2.266	0.073	1.736	0.111	4.186

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5086	9.682	6.155	15.837	2.357	0.071	1.771	0.125	4.324
K5086	9.820	6.011	15.831	2.321	0.070	1.730	0.122	4.243
K5086	9.815	6.105	15.920	2.340	0.072	1.423	0.126	3.961
K5086	9.870	5.988	15.858	2.337	0.070	1.564	0.123	4.094
K5086	9.693	6.210	15.903	2.357	0.072	1.531	0.141	4.101
K5086	9.852	6.031	15.883	2.368	0.070	1.417	0.137	3.992
K5086	9.764	6.083	15.847	2.463	0.072	1.450	0.125	4.110
K5086	9.863	6.057	15.920	2.437	0.073	1.176	0.127	3.813
K5086	9.840	5.994	15.834	2.306	0.071	1.727	0.124	4.157
K5086	9.938	6.005	15.943	2.397	0.070	1.093	0.137	3.697
K5078	9.667	6.324	15.991	2.381	0.070	1.282	0.123	3.856
K5078	9.867	6.059	15.926	2.315	0.070	1.443	0.106	3.934
K5078	9.675	6.256	15.940	2.362	0.069	1.472	0.121	4.024
K5078	9.862	6.144	16.006	2.303	0.070	1.201	0.122	3.696
K5078	9.826	6.098	15.924	2.389	0.072	1.272	0.141	3.874
K5078	9.743	6.260	16.003	2.432	0.072	1.091	0.110	3.705
K5078	10.034	5.762	15.796	2.346	0.069	1.544	0.136	4.095
K5078	9.829	6.058	15.887	2.266	0.072	1.685	0.111	4.134
K5078	9.971	5.896	15.867	2.282	0.071	1.544	0.124	4.021
K5078	9.864	5.987	15.851	2.212	0.071	1.839	0.124	4.246
K5076	9.815	6.186	16.001	2.375	0.071	1.146	0.108	3.700
K5076	9.608	6.407	16.015	2.498	0.070	1.068	0.107	3.743
K5076	9.516	6.443	15.959	2.330	0.069	1.638	0.120	4.157
K5076	9.891	6.009	15.900	2.273	0.069	1.582	0.106	4.030
K5076	9.712	6.210	15.922	2.253	0.069	1.707	0.120	4.149
K5076	9.438	6.496	15.943	2.463	0.070	1.521	0.122	4.176
K5076	9.566	6.383	15.949	2.457	0.070	1.387	0.107	4.021
K5076	9.664	6.232	15.896	2.438	0.069	1.494	0.105	4.106
K5076	9.707	6.276	15.983	2.433	0.070	1.197	0.106	3.806
K5076	9.634	6.378	16.012	2.414	0.069	1.223	0.105	3.811
K5074	9.742	6.139	15.881	2.416	0.072	1.458	0.126	4.072
K5074	9.769	6.212	15.981	2.328	0.071	1.286	0.139	3.824
K5074	9.792	6.122	15.914	2.421	0.071	1.303	0.125	3.920
K5074	9.758	6.174	15.932	2.398	0.073	1.324	0.127	3.922
K5074	9.797	6.150	15.947	2.380	0.072	1.278	0.126	3.856
K5074	9.815	6.174	15.989	2.337	0.073	1.214	0.127	3.751
K5074	9.722	6.209	15.931	2.364	0.071	1.438	0.124	3.997
K5074	9.669	6.277	15.946	2.383	0.070	1.414	0.122	3.989
K5074	9.738	6.164	15.902	2.403	0.071	1.402	0.139	4.015
K5074	9.620	6.273	15.893	2.320	0.071	1.737	0.125	4.253

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5072	9.853	6.033	15.886	2.228	0.070	1.748	0.108	4.154
K5072	9.843	6.076	15.919	2.305	0.069	1.507	0.106	3.987
K5072	9.814	6.091	15.905	2.351	0.074	1.468	0.114	4.007
K5072	9.588	6.350	15.938	2.467	0.075	1.362	0.114	4.018
K5072	9.802	6.206	16.008	2.291	0.070	1.311	0.107	3.779
K5072	9.500	6.517	16.017	2.477	0.072	1.203	0.110	3.862
K5072	9.751	6.160	15.911	2.540	0.071	1.149	0.108	3.868
K5072	9.417	6.570	15.987	2.515	0.071	1.301	0.109	3.996
K5072	9.634	6.228	15.862	2.448	0.072	1.561	0.125	4.206
K5072	9.609	6.408	15.960	2.408	0.071	1.404	0.109	3.992
K5070	9.461	6.395	15.856	2.473	0.070	1.741	0.070	4.391*
K5070	9.801	6.063	15.864	2.521	0.092	1.229	0.092	3.963
K5070	9.574	6.418	15.992	2.468	0.071	1.225	0.071	3.873
K5070	9.463	6.564	16.027	2.390	0.071	1.358	0.071	3.942
K5070	9.493	6.441	15.934	2.438	0.070	1.518	0.122	4.148
K5070	9.646	6.406	16.050	2.375	0.072	1.129	0.126	3.702
K5070	9.709	6.200	15.909	2.512	0.072	1.247	0.111	3.942
K5070	9.634	6.270	15.904	2.498	0.071	1.338	0.125	4.032
K5070	9.664	6.289	15.953	2.406	0.072	1.343	0.125	3.946
K5070	9.794	6.202	15.996	2.314	0.096	1.275	0.110	3.795
K5068	9.755	6.202	15.957	2.518	0.074	1.008	0.129	3.729
K5068	9.743	6.168	15.911	2.393	0.073	1.407	0.128	4.001
K5068	9.445	6.424	15.979	2.387	0.072	1.379	0.141	3.979
K5068	9.494	6.513	16.007	2.335	0.072	1.493	0.126	4.026
K5068	9.400	6.443	15.843	2.444	0.073	1.821	0.144	4.482*
K5068	9.593	6.234	15.827	2.490	0.074	1.614	0.130	4.308
K5068	9.491	6.422	15.913	2.253	0.120	1.893	0.126	4.329*
K5068	9.553	6.461	16.014	2.268	0.071	1.548	0.124	4.013
K5068	9.435	6.504	15.939	2.376	0.095	1.468	0.156	4.217
K5068	9.462	6.489	15.951	2.434	0.071	0.727	0.139	4.112
K5066	9.464	6.543	16.007	2.407	0.075	1.364	0.131	3.977
K5066	9.537	6.447	15.984	2.496	0.074	1.157	0.145	3.872
K5066	9.506	6.427	15.933	2.453	0.072	1.431	0.142	4.098
K5066	9.709	6.230	15.939	2.346	0.074	1.453	0.128	4.001
K5066	9.502	6.537	16.039	2.466	0.073	1.116	0.128	3.783
K5066	9.739	6.271	16.010	2.243	0.072	1.389	0.142	3.846
K0566	9.686	6.072	15.758	2.489	0.074	1.764	0.113	4.440*
K5066	9.742	6.103	15.845	2.346	0.069	1.719	0.121	4.255
K5066	9.816	6.141	15.957	2.331	0.068	1.314	0.134	3.847
K5066	9.719	6.204	15.923	2.323	0.072	1.572	0.110	4.077

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5037	9.675	6.292	15.967	2.225	0.069	1.666	0.120	4.080
K5037	9.741	6.167	15.908	2.179	0.070	1.866	0.121	4.236
K5037	9.663	6.223	15.886	2.140	0.094	2.060	0.123	4.417*
K5037	9.738	6.314	16.052	2.196	0.071	1.396	0.123	3.786
K5037	9.677	6.145	15.822	2.221	0.070	2.099	0.123	4.513*
K5037	9.705	6.077	15.712	2.296	0.071	2.041	0.124	4.532*
K5037	9.448	6.437	15.885	2.363	0.072	1.849	0.125	4.409*
K5037	9.691	6.335	16.026	2.232	0.070	1.453	0.070	3.877
K5037	9.597	6.358	15.955	2.307	0.069	1.614	0.069	4.111
K5037	9.666	6.335	16.001	2.188	0.070	1.641	0.070	4.022
K5035	9.427	6.595	16.022	2.389	0.071	1.441	0.071	4.010
K5035	9.754	6.076	15.830	2.389	0.074	1.677	0.112	4.252
K5035	9.725	6.157	15.882	2.312	0.069	1.722	0.106	4.209
K5035	9.668	6.288	15.956	2.349	0.071	1.477	0.109	4.006
K5035	9.484	6.503	15.987	2.269	0.071	1.735	0.107	4.181
K5035	9.851	6.093	15.944	2.242	0.070	1.552	0.106	3.970
K5035	9.587	6.418	16.005	2.277	0.071	1.554	0.109	4.011
K5035	9.610	6.447	16.057	2.282	0.068	1.377	0.104	3.831
K5035	9.809	6.067	15.876	2.368	0.069	1.546	0.106	4.089
K5035	9.672	6.362	16.034	2.125	0.068	1.697	0.105	3.995
K5033	9.485	6.411	15.896	2.357	0.068	1.838	0.105	4.368*
K5033	9.557	6.399	15.956	2.352	0.068	1.592	0.105	4.111
K5033	9.572	6.360	15.932	2.254	0.069	1.847	0.104	4.275
K5033	9.497	6.514	16.011	2.270	0.069	1.650	0.106	4.095
K5033	9.743	6.278	16.021	2.285	0.070	1.343	0.107	3.805
K5033	9.646	6.350	15.996	2.173	0.069	1.740	0.105	4.087
K5033	9.778	6.129	15.907	2.342	0.070	1.531	0.107	4.050
K5033	9.618	6.371	15.989	2.264	0.070	1.603	0.108	4.045
K5033	9.588	6.379	15.967	2.303	0.070	1.624	0.107	4.104
K5033	9.668	6.336	16.004	2.248	0.069	1.543	0.106	3.966
K5020	9.620	6.348	15.968	2.315	0.070	1.562	0.107	4.054
K5020	9.517	6.547	16.064	2.271	0.072	1.455	0.110	3.908
K5020	9.677	6.291	15.968	2.223	0.071	1.688	0.108	4.090
K5020	9.583	6.341	15.924	2.210	0.047	1.964	0.108	4.329*
K5020	9.562	6.396	15.958	2.223	0.070	1.835	0.107	4.235
K5020	9.745	6.307	16.052	2.174	0.071	1.466	0.108	3.819
K5020	9.751	6.251	16.002	2.180	0.071	1.592	0.109	3.889
K5020	9.772	6.249	16.021	2.184	0.071	1.509	0.108	3.872
K5020	9.606	6.444	16.050	2.186	0.070	1.589	0.107	3.952
K5020	9.767	6.207	15.974	2.252	0.070	1.524	0.107	3.953

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5018	9.643	6.412	16.055	2.140	0.047	1.649	0.108	3.944
K5018	9.864	6.054	15.918	2.185	0.068	1.734	0.105	4.092
K5018	9.690	6.386	16.076	2.113	0.046	1.599	0.105	3.863
K5018	9.744	6.166	15.910	2.144	0.069	1.958	0.106	4.277
K5018	9.676	6.313	15.989	2.206	0.069	1.666	0.105	4.046
K5018	9.398	6.348	15.746	2.652	0.075	1.752	0.115	4.594*
K5018	9.664	6.290	15.954	2.241	0.067	1.724	0.102	4.134
K5018	9.841	5.958	15.799	2.328	0.069	1.826	0.106	4.329*
K5018	9.643	6.469	16.112	2.185	0.069	1.400	0.091	3.745
K5018	10.023	5.852	15.875	2.169	0.069	1.737	0.105	4.080
K5017	9.591	6.337	15.928	2.284	0.069	1.806	0.090	4.249
K5017	9.394	6.659	16.053	2.331	0.069	1.534	0.090	4.024
K5017	9.557	6.472	16.029	2.254	0.070	1.596	0.092	4.012
K5017	9.680	6.349	16.029	2.229	0.070	1.522	0.092	3.913
K5017	9.628	6.376	16.004	2.267	0.069	1.578	0.091	4.005
K5017	9.714	6.274	15.988	2.253	0.069	1.568	0.090	3.980
K5017	9.864	6.004	15.868	2.276	0.073	1.522	0.192	4.063
K5017	9.746	6.213	15.959	2.200	0.070	1.726	0.091	4.087
K5017	9.525	6.522	16.047	2.328	0.069	1.428	0.090	3.915
K5017	9.585	6.415	16.000	2.382	0.069	1.402	0.091	3.944
K5015	9.656	6.440	16.096	2.126	0.070	1.553	0.091	3.840
K5015	9.684	6.361	16.045	2.187	0.070	1.555	0.091	3.903
K5015	9.619	6.428	16.047	2.025	0.070	1.938	0.091	4.124
K5015	9.676	6.302	15.978	2.034	0.067	2.079	0.088	4.268
K5015	9.674	6.427	16.101	2.111	0.047	1.571	0.092	3.821
K5015	9.713	6.368	16.081	2.189	0.070	1.380	0.107	3.746
K5015	9.693	6.430	16.123	2.133	0.069	1.426	0.090	3.718
K5015	9.674	6.423	16.097	2.126	0.069	1.504	0.106	3.805
K5015	9.665	6.266	15.931	2.154	0.069	1.984	0.090	4.297
K5015	9.654	6.344	15.998	2.133	0.069	1.808	0.105	4.115
K5009	9.713	6.313	16.026	2.185	0.070	1.554	0.107	3.916
K5009	9.425	6.576	16.001	2.354	0.071	1.575	0.108	4.108
K5009	9.634	6.339	15.973	2.268	0.096	1.598	0.110	4.090
K5009	9.597	6.416	16.013	2.253	0.071	1.573	0.108	4.005
K5009	9.468	6.517	15.985	2.313	0.070	1.668	0.107	4.158
K5009	9.531	6.396	15.927	2.364	0.070	1.675	0.108	4.217
K5009	9.557	6.391	15.948	2.370	0.071	1.573	0.108	4.122
K5009	9.847	6.059	15.906	2.284	0.067	1.593	0.102	4.046
K5009	9.564	6.397	15.961	2.360	0.070	1.553	0.107	4.090
K5009	9.813	6.062	15.875	2.234	0.070	1.809	0.107	4.220
K5009	9.882	6.079	15.961	2.120	0.093	1.689	0.106	4.008
K5009	9.703	6.330	16.033	2.269	0.070	1.345	0.122	3.806

(The last two analyses of K5009 are of the black-colored fragments)

TABLE 5 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K,Na,Fe</u>
K5008	9.638	6.292	15.930	2.349	0.070	1.559	0.122	4.100
K5008	9.322	6.613	15.935	2.355	0.071	1.842	0.125	4.393*
K5008	9.587	6.295	15.882	2.409	0.070	1.631	0.122	4.232
K5008	9.576	6.336	15.912	2.366	0.070	1.641	0.123	4.200
K5008	9.459	6.537	15.996	2.415	0.070	1.410	0.122	4.017
K5008	9.724	6.212	15.936	2.288	0.068	1.587	0.119	4.062
K5008	9.442	6.589	16.031	2.434	0.070	1.279	0.123	3.906
K5008	9.453	6.584	16.037	2.334	0.070	1.455	0.122	3.981
K5008	9.728	6.159	15.887	2.235	0.069	1.828	0.121	4.253
K5008	9.597	6.300	15.897	2.405	0.071	1.582	0.124	4.182

TABLE 6. Hand-separated Plagioclase Crystal Fragments

Feldspar compositions as determined from the microprobe chemical analyses. This listing is in the same order as that of Table 1 except the substandard analyses were deleted. Molecular percent is based on the sum of Na, K and Ca only. Ab = albite,; An = anorthite; Or = orthoclase.

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5140	34.3	63.8	1.9	Labradorite	900x1050
K5140	36.6	61.6	1.8	Labradorite	1725x2025
K5140	35.8	62.3	1.9	Labradorite	112x225
K5140	51.8	44.2	4.0	Andesine	600x1200
K5140	37.5	60.8	1.7	Labradorite	1500x1500
K5140	36.0	62.2	1.8	"	1125x1875
K5140	35.4	62.8	1.8	"	1650x2250
K5140	35.7	62.6	1.8	"	900x900
K5140	33.0	65.1	1.9	"	600x900
K5140	36.8	61.5	1.7	"	1725x2850
K5139	36.2	62.1	1.7	"	900x1050
K5139	36.4	61.8	1.8	"	675x1425
K5139	36.6	61.6	1.8	"	450x1500
K5139	33.7	64.5	1.8	"	750x1500
K5139	36.9	60.7	2.4	"	1500x2700
K5139	35.9	62.4	1.7	"	600x975
K5139	37.3	60.9	1.8	"	450x1500
K5139	37.0	61.3	1.7	"	750x750
K5139	37.2	61.1	1.7	"	225x525
K5139	35.3	62.4	2.3	"	900x900
K5137	34.6	63.6	1.8	"	900x1125
K5137	33.1	65.1	1.8	"	785x1500
K5137	33.5	63.8	2.7	"	1125x1650
K5137	31.1	67.0	1.9	"	450x1500
K5137	35.8	62.4	1.8	"	1125x1500
K5137	33.8	63.7	2.5	"	675x1500
K5137	36.4	61.8	1.8	"	750x2400
K5137	39.7	57.9	2.4	"	900x900
K5137	34.8	63.4	1.8	"	750x1800
K5137	35.4	62.2	2.4	"	225x600

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5136	37.9	59.7	2.4	Labradorite	1275x1950
K5136	39.6	58.1	2.3	"	787x1200
K5136	39.5	58.8	1.7	"	900x1050
K5136	41.0	57.3	1.7	"	825x2025
K5136	39.4	58.8	1.8	"	900x1350
K5136	37.5	60.2	2.3	"	600x1500
K5136	42.0	56.3	1.7	"	1500x1575
K5136	38.9	58.6	2.5	"	1425x2625
K5136	38.5	59.0	2.5	"	1875x2325
K5136	44.9	52.4	2.7	"	1310x1425
K5135	32.6	65.5	1.9	"	225x487
K5135	31.9	66.1	2.0	"	2400x3000
K5135	36.5	61.1	2.4	"	1050x2475
K5133	39.9	58.3	1.8	"	550x600
K5133	43.5	54.1	2.4	"	860x1275
K5133	38.5	59.6	1.9	"	1050x2625
K5133	38.3	59.9	1.8	"	787x1425
K5133	38.3	59.9	1.8	"	1200x1725
K5133	39.8	57.7	2.5	"	1050x1350
K5133	39.4	58.2	2.4	"	1500x1800
K5133	42.0	56.2	1.8	"	375x600
K5133	37.7	59.8	2.5	"	600x675
K5133	38.3	59.9	1.8	"	375x525
K5132	37.9	60.2	1.9	"	825x1275
K5132	40.5	57.7	1.8	"	900x1575
K5132	37.9	60.2	1.9	"	1575x1725
K5132	42.1	56.2	1.7	"	1125x900
K5132	41.8	56.7	1.8	"	600x750
K5132	39.1	59.1	1.8	"	975x1200
K5132	36.1	62.0	1.9	"	825x1350
K5132	40.5	57.6	1.9	"	525x750
K5132	41.9	56.2	1.9	"	1725x1840
K5132	40.8	57.2	2.0	"	1500x1575

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5131	39.1	59.1	1.8	Labradorite	860x1050
K5131	38.5	59.6	1.9	"	1050x2250
K5131	39.0	59.3	1.7	"	1200x2175
K5131	37.9	60.3	1.8	"	450x675
K5131	39.2	59.0	1.8	"	600x900
K5131	41.2	57.0	1.8	"	525x1500
K5131	36.7	61.4	1.9	"	1125x1500
K5131	42.5	55.8	1.7	"	975x1800
K5131	38.3	59.8	1.9	"	525x1575
K5131	39.9	58.2	1.9	"	600x900
K5126	42.4	55.8	1.8	"	300x600
K5126	38.9	59.3	1.8	"	375x450
K5126	37.7	60.4	1.9	"	375x750
K5126	42.5	55.8	1.7	"	525x675
K5126	44.0	54.3	1.7	"	225x750
K5126	40.9	57.3	1.8	"	450x600
K5126	39.3	58.9	1.8	"	600x900
K5126	41.9	56.4	1.7	"	450x525
K5126	43.2	55.1	1.7	"	900x1125
K5126	43.8	54.5	1.7	"	300x412
K5101	30.6	67.5	1.9	"	530x825
K5101	40.7	57.6	1.7	"	975x1275
K5101	42.6	55.8	1.6	"	675x1275
K5101	44.9	53.5	1.6	"	450x525
K5101	35.3	62.2	2.5	"	487x675
K5101	37.5	60.1	2.4	"	375x450
K5101	41.9	56.4	1.7	"	825x1200
K5101	42.8	55.5	1.7	"	600x900
K5101	42.5	55.8	1.7	"	375x675
K5101	30.7	67.3	2.0	"	600x675
K5099	39.0	59.3	1.7	"	750x1425
K5099	41.2	57.1	1.7	"	620x1050
K5099	38.5	59.7	1.8	"	600x1500
K5099	32.5	65.6	1.9	"	300x1050
K5099	39.3	59.0	1.7	"	375x2025
K5099	38.4	59.9	1.7	"	750x1275
K5099	33.6	64.6	1.8	"	750x1800
K5099	34.6	63.6	1.8	"	300x750
K5099	30.5	67.6	1.9	"	675x1650
K5099	36.8	61.5	1.7	"	600x750

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5098	34.4	63.8	1.8	Labradorite	300x750
K5098	40.0	58.2	1.8	"	566x1125
K5098	31.7	66.3	2.0	"	900x1500
K5098	38.5	59.0	2.5	"	675x1350
K5098	35.0	63.1	1.9	"	975x1050
K5098	43.1	55.2	1.7	"	300x750
K5098	41.9	56.4	1.7	"	375x900
K5098	38.1	60.1	1.8	"	450x750
K5098	38.4	59.8	1.8	"	600x900
K5098	36.9	61.1	2.0	"	450x900
K5096	43.7	54.7	1.6	"	723x1200
K5096	34.6	63.6	1.8	"	900x1275
K5096	41.7	56.6	1.7	"	1050x1650
K5096	44.3	54.0	1.7	"	600x1500
K5096	46.1	52.3	1.6	"	300x1650
K5096	32.5	65.6	1.9	"	375x1575
K5096	37.9	60.3	1.8	"	300x1425
K5096	35.6	62.6	1.8	"	375x1050
K5096	38.5	59.7	1.8	"	675x1875
K5095	33.1	65.0	1.9	"	420x750
K5095	44.2	54.2	1.6	"	480x1275
K5095	36.4	61.8	1.8	"	1350x2400
K5095	42.5	55.9	1.6	"	487x1350
K5095	35.8	62.3	1.9	"	675x975
K5095	36.5	61.7	1.8	"	450x525
K5095	35.1	63.0	1.9	"	300x900
K5095	43.7	54.7	1.6	"	600x1125
K5095	38.9	59.3	1.8	"	373x1275
K5095	37.3	60.9	1.8	"	375x1050
K5089	41.6	56.7	1.7	"	340x1500
K5089	43.8	54.5	1.7	"	220x300
K5089	35.9	62.2	1.9	"	750x1500
K5089	35.9	62.2	1.9	"	600x1050
K5089	35.7	60.7	1.8	"	150x225
K5089	36.9	61.3	1.8	"	150x525
K5089	38.1	60.1	1.8	"	225x375
K5089	38.4	59.8	1.8	"	75x225
K5089	42.6	55.6	1.8	"	600x750

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5086	42.2	56.1	1.7	Labradorite	900x1650
K5086	42.0	56.3	1.7	"	900x975
K5086	37.1	61.0	1.9	"	300x675
K5086	39.4	58.8	1.8	"	975x1125
K5086	38.7	59.5	1.8	"	1125x1500
K5086	36.8	61.4	1.8	"	1425x2625
K5086	36.4	61.8	1.8	"	1500x1650
K5086	31.9	66.1	2.0	"	675x1200
K5086	42.1	56.2	1.7	"	900x2625
K5086	30.7	67.3	2.0	"	1725x1950
K5078	34.3	63.8	1.9	"	521x1275
K5078	37.7	60.5	1.8	"	250x750
K5078	37.7	60.5	1.8	"	1500x2775
K5078	33.6	64.4	2.0	"	525x750
K5078	34.1	64.0	1.9	"	900x1125
K5078	30.4	67.6	2.0	"	675x1950
K5078	39.0	59.3	1.7	"	300x600
K5078	41.9	56.3	1.8	"	2700x3750
K5078	39.6	58.6	1.8	"	1050x1725
K5078	44.6	53.7	1.7	"	975x1050
K5076	31.9	66.1	2.0	"	750x975
K5076	29.4	68.7	1.9	"	825x1050
K5076	40.6	57.7	1.7	"	900x975
K5076	40.3	57.9	1.8	"	1050x1425
K5076	42.4	55.9	1.7	"	750x1875
K5076	37.5	60.8	1.7	"	975x1050
K5076	35.4	62.8	1.8	"	675x1050
K5076	37.3	61.0	1.7	"	375x675
K5076	32.4	65.7	1.9	"	900x1425
K5076	33.0	65.1	1.9	"	900x1650
K5074	36.9	61.3	1.8	"	528x750
K5074	34.9	63.2	1.9	"	975x1050
K5074	34.3	63.8	1.9	"	150x225
K5074	34.9	63.2	1.9	"	1200x1425
K5074	34.3	63.8	1.9	"	375x525
K5074	33.5	64.5	2.0	"	150x338
K5074	37.1	61.1	1.8	"	1725x3450
K5074	36.6	61.6	1.8	"	600x675
K5074	36.2	62.0	1.8	"	750x1950
K5074	42.1	56.2	1.7	"	1125x2250

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5072	43.2	55.1	1.7	Labradorite	450x600
K5072	38.8	59.4	1.8	"	333x750
K5072	37.7	60.4	1.9	"	1425x1725
K5072	34.9	63.2	1.9	"	525x1350
K5072	35.7	62.4	1.9	"	975x1050
K5072	32.1	66.0	1.9	"	675x975
K5072	30.6	67.5	1.9	"	600x1125
K5072	33.5	64.7	1.8	"	1465x1275
K5072	38.2	60.0	1.8	"	600x1350
K5072	36.2	62.0	1.8	"	712x1200
K5070	32.0	65.6	2.4	"	600x1350
K5070	32.5	65.6	1.9	"	375x525
K5070	35.6	62.6	1.8	"	1050x1125
K5070	37.7	60.6	1.7	"	1125x1725
K5070	31.6	66.4	2.0	"	750x1725
K5070	32.5	65.6	1.9	"	900x1125
K5070	34.2	64.0	1.8	"	675x675
K5070	35.1	63.0	1.9	"	225x375
K5070	34.6	62.8	2.6	"	600x675
K5068	28.0	70.0	2.0	"	408x750
K5068	36.3	61.8	1.9	"	410x900
K5068	35.9	62.2	1.9	"	675x750
K5068	38.3	59.9	1.8	"	750x1425
K5068	38.6	59.6	1.8	"	2100x3000
K5068	39.8	58.4	1.8	"	900x1500
K5068	39.1	58.6	2.3	"	750x1800
K5068	37.0	61.2	1.8	"	600x1350
K5066	35.5	62.6	1.9	"	330x1050
K5066	31.0	67.0	2.0	"	975x1500
K5066	36.2	62.0	1.8	"	975x2025
K5066	37.5	60.6	1.9	"	825x1500
K5066	30.5	67.5	2.0	"	675x1125
K5066	37.5	60.6	1.9	"	1275x1500
K5066	41.6	56.7	1.7	"	750x1725
K5066	35.4	62.8	1.8	"	1050x1800
K5066	39.6	58.6	1.8	"	1125x2325

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5037	42.1	56.2	1.7	Labradorite	568x1650
K5037	45.3	53.0	1.7	"	525x375
K5037	38.1	60.0	1.9	"	450x600
K5037	38.7	59.4	1.9	"	225x450
K5037	40.4	57.9	1.7	"	750x975
K5037	42.1	56.1	1.8	"	525x600
K5035	36.9	61.3	1.8	"	750x1200
K5035	40.5	57.7	1.8	"	1050x2175
K5035	42.0	56.3	1.7	"	900x1200
K5035	37.9	60.3	1.8	"	375x525
K5035	42.6	55.7	1.7	"	100x600
K5035	40.2	58.0	1.8	"	300x450
K5035	39.8	58.4	1.8	"	150x150
K5035	36.9	61.3	1.8	"	150x375
K5035	38.8	59.5	1.7	"	300x600
K5035	43.6	54.6	1.8	"	150x525
K5033	39.7	58.6	1.7	"	510x900
K5033	44.3	54.0	1.7	"	225x750
K5033	41.4	56.9	1.7	"	825x1125
K5033	36.3	61.8	1.9	"	1200x1200
K5033	43.7	54.6	1.7	"	600x1050
K5033	38.8	59.4	1.8	"	450x675
K5033	40.7	57.5	1.8	"	600x675
K5033	40.6	57.7	1.7	"	225x450
K5033	40.0	58.2	1.8	"	300x600
K5020	39.6	58.6	1.8	"	950x2250
K5020	38.3	59.8	1.9	"	1500x2350
K5020	42.4	55.8	1.8	"	450x900
K5020	44.5	53.8	1.7	"	1050x1600
K5020	39.5	58.6	1.9	"	600x825
K5020	41.4	56.7	1.9	"	600x750
K5020	40.8	58.0	1.9	"	900x1275
K5020	41.3	56.9	1.8	"	900x1200
K5020	39.6	58.6	1.8	"	225x900
K5018	43.0	55.8	1.2	"	600x750
K5018	43.5	54.8	1.7	"	300x1050
K5018	42.6	56.2	1.2	"	750x900
K5018	46.9	51.4	1.7	"	480x1600
K5018	42.3	56.0	1.7	"	375x700
K5018	42.8	55.5	1.7	"	260x750
K5018	38.3	59.8	1.9	"	450x1350
K5018	43.7	54.6	1.7	"	380x750

TABLE 6 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Fragment Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
K5017	43.4	55.0	1.6	Labradorite	375x625
K5017	39.0	59.3	1.7	"	1125x1125
K5017	40.7	57.5	1.8	"	225x1125
K5017	39.8	58.4	1.8	"	75x675
K5017	40.3	57.9	1.8	"	1500x1800
K5017	40.3	57.9	1.8	"	675x825
K5017	39.3	58.8	1.9	"	2250x2400
K5017	43.2	55.1	1.7	"	975x1050
K5017	37.3	60.9	1.8	"	750x1050
K5017	36.4	61.8	1.8	"	600x900
K5015	41.4	56.7	1.9	"	900x1500
K5015	40.8	57.4	1.8	"	750x1650
K5015	48.1	50.2	1.7	"	750x950
K5015	49.7	48.7	1.6	"	1125x1500
K5015	42.1	56.6	1.3	"	750x2875
K5015	37.9	60.2	1.9	"	750x900
K5015	39.3	58.8	1.9	"	675x900
K5015	40.7	57.4	1.9	"	1050x1050
K5015	47.2	51.2	1.6	"	450x1350
K5015	45.1	53.2	1.7	"	900x1050
K5009	40.8	57.4	1.8	"	480x1425
K5009	39.4	58.8	1.8	"	975x1200
K5009	40.3	57.3	2.4	"	675x1500
K5009	40.4	57.8	1.8	"	300x900
K5009	41.2	57.1	1.7	"	450x750
K5009	40.8	57.5	1.7	"	675x1800
K5009	39.2	59.0	1.8	"	375x375
K5009	40.4	57.9	1.7	"	225x450
K5009	39.0	59.3	1.7	"	150x225
K5009	44.0	54.3	1.7	"	750x1650
K5009	43.3	54.3	2.4	"	975x1650
K5009	36.5	61.6	1.9	"	900x2400
K5008	39.2	59.0	1.8	"	720x900
K5008	39.7	58.6	1.7	"	750x1500
K5008	40.3	58.0	1.7	"	975x1800
K5008	36.2	62.0	1.8	"	825x1200
K5008	40.3	58.0	1.7	"	1050x1650
K5008	33.8	64.3	1.9	"	525x750
K5008	37.7	60.5	1.8	"	1650x2100
K5008	44.2	54.1	1.7	"	300x825
K5008	39.0	59.3	1.7	"	750x975

expected, since these are hand-picked, main stage feldspar crystal fragments. The smaller and later feldspars tend to be the more sodic in composition.

Summarizing the chemical analysis work, the chemical analyses given as standard (300 out of 315) are of very good quality. Taking the number of cations in our "unit cell", 20, the largest error is $0.4/20 = 2\%$. The largest error in the standard analyses is then 2%. In a comparable oxide wt% analysis, this would be a range of from 98% to 102%. Even with the analyses that are called substandard, the largest overall error is less than 4%.

In addition to the chemical analyses, up to five crystal fragments were traversed for determination of their calcium, sodium and potassium contents with distance from the fragment boundary. A typical microprobe scan for a feldspar fragment from each sample is given in Figures 2 through 33.

Counting statistics are superimposed on oxide wt% for Na₂O and CaO in Figure 2.

By replicate counting of a known sodium standard, the mean (μ) and standard deviation (σ) may be obtained by the usual methods. Two sigma (2σ), the sample variance, may be imposed on the counts represented by the CaO and Na₂O wt% in the sample. Values for Na₂O or CaO falling outside (below or above) plus or minus two sigma are 95% certain to represent real Na₂O or CaO values. The standard deviation for potassium x-ray emission counting statistics is nearly the same as that for calcium. Thus, there may be a small amount of real sodium and calcium spatial variation or zoning in these feldspars, but almost certainly no real potassium variation. These same 2σ values may be imposed on the other samples since they have the same scales for oxide wt%.

The change in the distance scales in Figures 2 through 32 should be noted. Where there is a change in scale, or the end of a scale, the ticks representing distance values move from the top of the distance line to the bottom. In Figure 2, for example, 300 μm represents the end of the 50 μm to the inch scale, and the beginning of the 300 μm to the inch scale. Most of the scans, went to the middle of the fragment from the edge, and if nothing unusual was found in compositional variation, proceeded to the opposite edge at a longer scan interval. The 50 μm to the inch scales were scanned to 10 μm intervals, with longer intervals following.

FIGURE 2. Microprobe Scan of a Typical Feldspar of Sample K5140

FIGURE 3. Microprobe Scan of a Typical Feldspar of Sample K5139

FIGURE 4. Microprobe Scan of a Typical Feldspar of Sample K5137

FIGURE 5. Microprobe Scan of a Typical Feldspar of Sample K5136

FIGURE 6. Microprobe Scan of a Typical Feldspar Sample of K5135

FIGURE 7. Microprobe Scan of a Typical Feldspar Sample of K5133

FIGURE 8. Microprobe Scan of a Typical Feldspar Sample of K5132

FIGURE 9. Microprobe Scan of a Typical Feldspar of Sample K5131

FIGURE 10. Microprobe Scan of a Typical Feldspar of Sample K5126

FIGURE 11. Microprobe Scan of a Typical Feldspar Sample of K5101

FIGURE 12. Microprobe Scan of a Typical Feldspar of Sample K5099

FIGURE 13. Microprobe Scan of a Typical Feldspar of Sample K5098

FIGURE 14. Microprobe Scan of a Typical Feldspar of Sample K5096

FIGURE 15. Microprobe Scan of a Typical Feldspar of Sample K5095

FIGURE 16. Microprobe Scan of a Typical Feldspar of Sample K5089

FIGURE 17. Microprobe Scan of a Typical Feldspar of Sample K5086

FIGURE 18. Microprobe Scan of a Typical Feldspar of Sample K5079

FIGURE 19. Microprobe Scan of a Typical Feldspar of Sample K5076

FIGURE 20. Microprobe Scan of a Typical Feldspar of Sample K5074

FIGURE 21. Microprobe Scan of a Typical Feldspar of Sample K5072

FIGURE 22. Microprobe Scan of a Typical Feldspar of Sample K5070

FIGURE 23. Microprobe Scan of a Typical Feldspar of Sample K5068

FIGURE 24. Microprobe Scan of a Typical Feldspar of Sample K5066

FIGURE 25. Microprobe Scan of a Typical Feldspar of Sample K5037

FIGURE 26. Microprobe Scan of a Typical Feldspar of Sample K5035

FIGURE 27. Microprobe Scan of a Typical Feldspar of Sample K5033

FIGURE 28. Microprobe Scan of a Typical Feldspar of Sample K5020

FIGURE 29. Microprobe Scan of a Typical Feldspar of Sample K5018

FIGURE 30. Microprobe Scan of a Typical Feldspar of Sample K5017

FIGURE 31. Microprobe Scan of a Typical Feldspar of Sample K5015

FIGURE 32. Microprobe Scan of a Typical Feldspar of Sample K5009 (Yellow)

FIGURE 33. Microprobe Scan of a Typical Feldspar of Sample K5008

The scanning interval points were connected to yield a continuous line. This line is given in each figure rather than unconnected points to facilitate figure comparisons.

To summarize the compositional variation work, these samples of feldspars show very little compositional zoning, and that for CaO and Na₂O only. This might be expected because the chemical analyses of Table 5 also showed little chemical variation between feldspar.

Pyroxenes

The general formula for a pyroxene has been given as:

where W = Ca, Na,

X = Mg, Fe⁺², Mn, Li, Ni,

Y = Al, Fe⁺³, Cr, Ti,

and Z = Al, Si.

Structurally, the pyroxenes are divided into orthorhombic and monoclinic pyroxenes. The various solid solution series and general formulae are given in Table 7. The essential feature of all pyroxenes is the sharing of two corners of each SiO₄ tetrahedra to form a continuous chain. These chains are linked laterally in several ways by cations that give rise to the main divisions of ortho- and clinopyroxenes.

The value of "p" given in the pyroxene general formula is quite important. The content of Y cations is small in the orthopyroxene series while "p" approximately equals one. The value of p varies from 0 (diopside in which Y is very small and aegirine and jadeite in which X is very small) to 1.0 (spodumene). The role of Al is interesting because it can be assigned to either "Y" or "Z" positions. The practice has been to assign Al to "Z" position until Si + Al = 2.000. The "excess" Al is then assigned to position "Y".

The atoms/molecule as determined from the microprobe analyses of DDH-3 well samples are given in Table 8. The limits on the X-Y-W and Z cations are usually much less than plus or minus 5%. The percentages of magnesium, iron and calcium silicate "molecules" making up the pyroxenes are given in Table 9. All of the pyroxene analyses, except two, are in the normal augite compositional area. A2038, a

TABLE 7

Solid Solution Series and
End-Members of the Pyroxenes

Orthorhombic Pyroxenes

Enstatite-Ferrosilite	$(\text{Mg}, \text{Fe}^{+2})_2\text{Si}_2\text{O}_6$
-----------------------	--

Monoclinic Pyroxenes

Diopside-Hedenbergite	$\text{Ca}(\text{Mg}, \text{Fe}^{+2})\text{Si}_2\text{O}_6$
Johannsenite	$\text{CaMnSi}_2\text{O}_6$
Aegirine	$\text{NaFe}^{+3}\text{Si}_2\text{O}_6$
Spodumene	$\text{LiAlSi}_2\text{O}_6$
Jadeite	$\text{NaAlSi}_2\text{O}_6$
Augite	$(\text{Ca}, \text{Mg}, \text{Fe}^{+2}, \text{Al})_2(\text{Si}, \text{Al})_2\text{O}_6$
Pigeonite	$(\text{Mg}, \text{Fe}^{+2}, \text{Ca})(\text{Mg}, \text{Fe}^{+2})\text{Si}_2\text{O}_6$
Omphacite	$(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}^{+2}, \text{Fe}^{+3}, \text{Al})\text{Si}_2\text{O}_6$
Fassaite	$\text{Ca}(\text{Mg}, \text{Fe}^{+2}, \text{Fe}^{+3}, \text{Al})(\text{Si}, \text{Al})_2\text{O}_6$

TABLE 8. DDH-3 Pyroxene Analyses

Pyroxene Compositions, based on the molecule $[(K,Na,Ca,Mg,Fe^{+2},Ti,Al)_2][(Al,Si)_2]O_6$,
as determined from the microprobe chemical analyses

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Na	Mn	Cr	Co	Al	Σ	Crystal Size, μm
A2002	1.905	0.105	2.000	0.756	0.375	0.781	0.047	-----	-----	--	--	--	0.027	1.986	
A2002	1.971	0.029	2.000	0.670	0.525	0.579	0.030	0.016	-----	--	--	--	0.116	1.936	
A2006	1.972	0.028	2.000	0.822	0.395	0.726	0.025	-----	-----	--	--	--	0.015	1.983	
A2009	1.995	0.005	2.000	0.642	0.629	0.658	0.020	0.002	-----	--	--	--	0.020	1.971	
A2012	1.998	0.002	2.000	0.961	0.318	0.639	0.011	-----	-----	--	--	--	0.040	1.969	
A2012*	2.063	-----	2.063	0.947	0.379	0.504	0.011	-----	-----	--	--	--	0.013	1.854	
A2018	1.905	0.124	2.029	0.797	0.379	0.721	0.023	-----	0.102	--	--	--	0.007	2.029	
A2024	1.938	0.051	1.989	0.742	0.589	0.598	0.025	-----	0.134	--	--	--	--	2.088	
A2024	2.020	-----	2.020	0.669	0.706	0.485	0.014	0.005	-----	--	--	--	0.046	1.925	
A2028	1.946	0.054	2.000	0.788	0.431	0.709	0.023	0.002	-----	--	--	--	0.034	1.987	
A2028	1.918	0.082	2.000	0.772	0.407	0.748	0.030	-----	-----	--	--	--	0.037	1.994	
A2033	1.982	0.018	2.000	0.802	0.383	0.775	0.025	-----	-----	--	--	--	--	1.985	
A2033	1.928	0.022	1.950	0.824	0.424	0.683	0.022	0.004	-----	--	--	--	--	1.957	
A2033	1.981	0.019	2.000	0.750	0.444	0.746	0.020	-----	-----	--	--	--	0.020	1.979	
A2038*	2.042	-----	2.042	0.872	0.553	0.377	0.016	-----	-----	--	--	--	0.056	1.874	
A2038	1.928	0.014	1.942	0.781	0.476	0.809	0.027	0.004	-----	--	--	--	--	2.097	
A2041	1.980	0.020	2.000	0.702	0.523	0.728	0.023	-----	-----	--	--	--	0.008	1.984	
A2041	1.952	0.045	1.997	0.895	0.525	0.570	0.018	0.004	-----	--	--	--	--	2.012	
A2044	1.875	0.056	1.931	0.844	0.526	0.730	0.033	--	--	--	--	--	--	2.133	
A2044	1.934	0.058	1.992	0.918	0.540	0.571	0.008	--	--	--	--	--	--	2.037	
A2044	1.887	0.050	1.937	0.670	0.786	0.613	0.038	0.011	--	--	--	--	--	2.118	
A2050	1.961	0.046	2.007	0.794	0.688	0.491	0.018	--	--	--	--	--	--	1.991	
A2050	2.125	--	2.125	0.573	0.877	0.059	--	0.027	--	--	--	--	0.285	1.821*	
A2053	1.913	0.047	1.960	0.968	0.805	0.282	0.024	--	--	--	--	--	--	2.077	
A2053	1.955	0.079	2.034	0.772	0.426	0.712	0.030	0.002	--	--	--	--	--	1.942	
A2059	1.911	0.045	1.956	0.837	0.498	0.732	0.017	--	--	0.010	--	--	--	2.094	
A2059	1.921	--	1.921	0.998	0.459	0.626	0.032	--	--	0.010	--	--	--	2.125	
A2059	1.939	--	1.939	1.062	0.525	0.496	0.014	--	--	0.010	--	--	--	2.117	
A2059	1.904	0.040	1.944	0.896	0.420	0.742	0.031	--	--	0.010	--	--	--	2.099	
A2059	1.939	0.039	1.978	0.858	0.472	0.680	0.022	--	--	0.009	--	--	--	2.041	

* = analyses that exceeded $\pm 5\%$ error when rounded off to the first decimal place.

TABLE 8 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Na	Mn	Cr	Co	Al	Σ	Crystal Size, μm
A2045	2.007	--	2.007	0.793	0.415	0.695	0.021	--	--	--	--	--	0.028	1.952	
A2045	2.006	--	2.006	0.757	0.408	0.620	0.024	0.020	--	--	0.002	--	0.092	1.923	
A2045	1.970	0.030	2.000	0.735	0.479	0.682	0.030	--	--	0.007	--	--	0.036	1.939	
A2045	1.943	0.057	2.000	0.818	0.390	0.738	0.028	--	--	0.006	--	--	0.013	1.993	
A2045	1.956	0.044	2.000	0.730	0.428	0.752	0.031	--	--	0.006	--	--	0.028	1.975	
A2045	1.993	0.007	2.000	0.701	0.387	0.756	0.029	--	--	0.006	--	--	0.065	1.944	
A2046	2.018	--	2.018	0.744	0.453	0.663	0.020	--	--	0.010	--	--	0.036	1.926	35x40
A2046	2.064	--	2.064	0.940	0.696	0.208	0.006	--	--	0.016	--	--	--	1.866	35x45
A2046	1.903	0.097	2.000	0.834	0.388	0.752	0.029	--	--	0.006	--	--	0.007	2.010	300x500
A2046	1.909	0.091	2.000	0.873	0.406	0.690	0.023	--	--	0.010	--	--	0.014	2.016	125x225
A2046	1.942	0.058	2.000	0.544	0.719	0.644	0.023	0.005	--	0.006	--	--	0.045	1.986	75x75
A2048	1.789	0.211	2.000	0.459	0.521	0.575	0.097	0.029	0.265	0.006	--	--	0.134	2.086	
A2048	1.936	0.064	2.000	0.845	0.435	0.554	0.037	--	--	0.010	--	--	0.076	1.957	
A2048	1.953	0.047	2.000	0.715	0.422	0.681	0.031	--	--	0.010	--	--	0.088	1.947	
A2048	1.890	0.110	2.000	0.699	0.429	0.743	0.048	--	--	0.010	--	--	0.051	1.980	
*A2056	1.664	0.039	1.703	1.042	1.291	0.232	0.009	0.004	--	0.021	0.002	--	--	2.601	
A2056	1.923	0.051	1.974	0.885	0.387	0.792	0.027	0.003	--	0.006	0.004	--	--	2.041	
A2056	1.961	0.039	2.000	0.827	0.406	0.703	0.021	--	--	0.007	0.002	--	0.018	1.984	
A2056	1.932	0.040	1.972	0.967	0.422	0.643	0.023	0.003	--	0.006	--	--	--	2.055	
A2056	1.907	0.086	1.993	0.897	0.390	0.694	0.023	--	--	0.007	0.007	--	--	2.018	
A2056	1.982	0.018	2.000	0.766	0.445	0.695	0.020	--	--	0.007	--	--	0.037	1.970	125x250
A2056	1.933	0.065	1.998	0.866	0.404	0.719	0.021	--	--	0.007	--	--	--	2.017	125x125
A2056	2.069	--	2.069	0.588	0.742	0.185	0.017	0.029	--	0.013	--	--	0.191	1.765	10x30
A2056	1.918	0.078	1.996	0.840	0.452	0.708	0.020	--	--	0.007	--	--	--	2.027	25x40
A2056	1.895	0.105	2.000	0.930	0.663	0.400	0.009	0.021	--	0.007	--	--	0.016	2.046	10x10
A2060	1.957	0.043	2.000	0.867	0.364	0.700	0.019	--	--	0.003	0.004	--	0.024	1.981	
A2060	1.962	0.038	2.000	0.820	0.463	0.605	0.014	0.010	--	0.010	0.004	--	0.050	1.976	
A2060	1.981	0.019	2.000	0.918	0.578	0.465	0.014	--	--	0.010	--	--	0.008	1.993	
A2060	1.976	0.024	2.000	0.803	0.476	0.610	0.026	--	--	0.010	--	--	0.040	1.965	

*Poor analysis

TABLE 8 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Na	Mn	Cr	Co	Al	Σ	Crystal Size, μm
A2061	2.014	--	2.014	0.769	0.516	0.578	0.009	--	--	0.010	--	--	0.055	1.937	100x200
A2061	1.969	0.031	2.000	0.790	0.412	0.701	0.025	--	--	0.007	--	--	0.037	1.972	40x100
A2061	2.000	--	2.000	0.769	0.438	0.611	0.020	--	--	0.010	--	--	0.087	1.935	
A2061	1.936	0.064	2.000	0.692	0.557	0.704	0.024	0.012	--	0.008	--	--	0.012	2.009	100x150
A2064	1.965	0.035	2.000	0.899	0.350	0.701	0.012	--	--	0.010	0.002	--	0.017	1.991	50x50
A2064	1.874	0.126	2.000	0.659	0.423	0.798	0.066	--	--	0.007	0.002	--	0.024	1.979	25x100
A2064	1.844	0.156	2.000	0.494	0.531	0.719	0.102	0.020	--	0.007	0.002	--	0.070	1.945	15x20
A2064	1.779	0.221	2.000	0.625	0.387	0.173	--	0.018	--	0.003	--	--	0.591	1.824	10x10
A2064	1.931	0.069	2.000	0.580	0.370	0.619	0.064	0.044	--	0.003	--	--	0.208	1.888	5x5
A2064	1.877	0.123	2.000	0.562	0.665	0.497	0.097	0.037	--	0.004	--	--	0.082	1.944	100x100
A2068	2.064	--	2.064	1.064	0.581	0.195	0.011	--	--	0.009	--	--	--	1.860	25x100
A2068	2.003	--	2.003	0.915	0.491	0.505	0.017	--	--	0.010	--	--	0.026	1.964	25x25
A2068	2.059	--	2.059	1.121	0.498	0.167	0.005	0.009	--	0.009	--	--	0.047	1.856	
A2068	1.953	0.047	2.000	0.874	0.391	0.700	0.021	--	--	0.010	--	--	0.004	2.000	
A2072	1.965	0.035	2.000	0.583	0.740	0.580	0.032	--	--	0.011	0.003	--	0.021	1.970	65x65
A2072	1.979	0.021	2.000	0.782	0.597	0.522	0.025	--	--	0.010	--	--	0.033	1.969	30x100
A2072	2.023	--	2.023	0.796	0.380	0.585	0.015	0.020	--	0.007	0.002	--	0.093	1.898	500x500
A2072	2.007	--	2.007	0.895	0.559	0.425	0.015	0.004	--	0.010	--	--	0.042	1.950	50x100
A2083	2.097	--	2.097	1.056	0.543	0.200	--	--	--	--	0.002	--	--	1.801	60x120
A2083	1.953	0.047	2.000	0.951	0.346	0.659	0.011	--	--	--	0.005	--	0.020	1.992	150x350
A2083	1.979	0.021	2.000	0.900	0.393	0.594	0.023	0.004	--	--	0.002	--	0.046	1.962	100x125
A2083	1.946	0.054	2.000	0.818	0.465	0.617	0.023	--	--	--	0.002	--	0.049	1.974	80x100
A2087	1.965	0.035	2.000	0.929	0.470	0.521	0.019	--	--	0.009	--	--	0.033	1.981	
A2087	2.056	--	2.056	1.060	0.573	0.186	0.008	0.004	--	0.012	--	--	0.026	1.869	
A2087	1.954	0.046	2.000	0.942	0.285	0.700	0.013	--	--	0.006	0.004	--	0.034	1.984	
A2087	1.901	0.099	2.000	0.867	0.509	0.623	0.015	0.015	--	0.007	--	--	0.004	2.040	
A2092	1.971	0.029	2.000	0.893	0.342	0.692	0.018	0.003	--	0.007	--	0.003	0.027	1.985	75x100
A2092	2.018	--	2.018	0.803	0.347	0.694	0.015	0.005	--	0.007	--	--	0.055	1.926	30x30
A2092	1.937	0.041	1.978	1.008	0.373	0.653	0.012	--	--	0.007	--	--	--	2.053	50x50
A2092	2.012	--	2.012	0.831	0.314	0.699	0.014	--	--	0.006	--	0.003	0.063	1.930	50x75

TABLE 8 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Mg</u>	<u>Fe</u>	<u>Ca</u>	<u>Ti</u>	<u>K</u>	<u>Na</u>	<u>Mn</u>	<u>Cr</u>	<u>Co</u>	<u>Al</u>	<u>Σ</u>	<u>Crystal Size, μm</u>
A2094	2.052	--	2.052	0.894	0.396	0.496	0.014	--	--	0.006	--	--	0.051	1.857	
A2094	2.056	--	2.056	0.902	0.302	0.587	0.013	--	--	0.006	--	--	0.042	1.852	
A2094	2.045	--	2.045	1.163	0.536	0.205	--	--	--	0.006	--	--	--	1.910	
A2094	2.031	--	2.031	0.907	0.352	0.594	0.008	--	--	0.006	--	--	0.042	1.909	
A2097	1.944	0.056	2.000	0.971	0.374	0.661	0.012	--	--	0.007	0.002	--	0.008	2.008	
A2097	2.059	--	2.059	1.098	0.525	0.227	0.006	0.003	--	0.010	0.002	--	--	1.871	
A2097	1.996	0.004	2.000	0.829	0.353	0.658	0.017	0.010	--	0.007	0.002	--	0.073	1.949	
A2097	1.953	0.047	2.000	0.876	0.336	0.731	0.014	--	--	0.010	0.002	--	0.024	1.993	
A2097	1.964	0.036	2.000	0.929	0.319	0.672	0.011	0.036	--	--	--	--	0.040	2.007	
A2102	1.952	0.048	2.000	0.929	0.377	0.660	0.012	0.003	--	0.010	--	--	0.015	2.006	
A2102	1.953	0.047	2.000	0.773	0.510	0.659	0.021	--	--	0.010	--	--	0.019	1.992	
A2102	1.993	0.007	2.000	0.828	0.383	0.678	0.012	--	--	0.010	0.005	--	0.043	1.962	
A2102	2.000	--	2.000	0.917	0.459	0.529	0.012	--	--	0.010	--	--	0.042	1.969	
A2109	1.942	0.058	2.000	0.683	0.650	0.548	0.037	0.026	--	0.010	0.002	--	0.029	1.985	5x25
A2109	2.064	--	2.064	0.522	0.556	0.495	0.018	0.041	--	0.010	--	--	0.155	1.797	3x5
A2109	1.991	0.009	2.000	0.958	0.691	0.246	0.012	0.005	--	0.010	--	--	0.050	1.972	10x20
A2109	2.005	--	2.005	0.628	0.677	0.572	0.021	0.005	--	0.010	--	--	0.038	1.951	25x25
A2123	2.021	--	2.021	1.074	0.593	0.191	0.016	--	--	0.009	--	--	0.039	1.922	40x40
A2123	2.016	--	2.016	0.703	0.508	0.647	0.018	--	--	0.010	--	--	0.042	1.928	35x35
A2123	2.079	--	2.079	0.780	0.757	0.217	0.014	--	--	0.016	--	--	0.030	1.814	30x30
A2123	1.912	0.088	2.000	0.764	0.495	0.737	0.017	0.003	--	0.010	--	--	0.002	2.028	180x200
A2133	1.889	0.111	2.000	0.878	0.493	0.583	0.025	0.016	--	0.007	0.002	--	0.020	2.024	5x5
A2133	1.856	0.144	2.000	0.693	0.482	0.609	0.035	0.015	--	0.007	--	--	0.137	1.978	5x5
A2133	1.901	0.094	1.995	0.960	0.435	0.608	0.024	--	--	0.007	--	--	--	2.034	5x5
A2133	1.968	0.032	2.000	0.815	0.505	0.523	0.028	0.021	--	0.007	--	--	0.066	1.965	5x5
A2133	1.857	0.143	2.000	0.855	0.553	0.524	0.033	0.019	--	0.006	--	--	0.039	2.029	5x5
A2133	1.944	0.056	2.000	0.892	0.461	0.500	0.035	0.020	--	0.007	--	--	0.059	1.974	5x5

TABLE 8 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Na	Mn	Cr	Co	Al	Σ	Crystal Size, μm
A2067	2.058	--	2.058	0.547	0.883	0.131	0.014	0.080	--	0.013	--	--	0.162	1.830*	
A2067	2.062	--	2.062	0.543	1.037	0.046	0.010	0.044	--	0.015	--	--	0.128	1.823*	
A2067	1.944	0.036	1.980	0.823	0.516	0.665	0.020	--	--	0.013	--	--	--	2.037	
A2067	1.894	0.060	1.954	0.935	0.464	0.668	0.022	--	--	0.012	--	--	--	2.101	
A2067	2.198	--	2.198	0.676	0.781	0.117	0.012	0.036	--	0.010	--	--	0.252	1.884	
A2079	2.004	--	2.004	1.038	0.655	0.047	--	0.028	--	--	--	--	0.159	1.927	
A2079	1.866	0.073	2.000	0.950	0.371	0.559	0.022	0.014	--	0.009	--	--	--	1.975	
A2079	1.815	0.036	1.939	1.078	0.370	0.655	0.023	--	--	0.010	--	--	--	2.136	
A2079	1.872	0.086	1.958	0.842	0.622	0.577	0.037	0.002	--	0.010	--	--	--	2.090	
A2089	1.958	0.013	1.971	0.850	0.527	0.655	0.011	0.002	--	0.009	--	--	--	2.054	
A2089	1.917	0.039	1.956	0.915	0.485	0.662	0.017	--	--	0.013	--	--	--	2.092	
A2089	1.924	0.048	1.972	0.860	0.535	0.654	0.011	--	--	0.009	--	--	--	2.069	
A2089	2.086	--	2.086	0.628	0.783	0.080	--	0.030	--	0.007	--	--	0.343	1.871	
A2098	1.996	--	1.996	0.924	0.827	0.035	--	0.104	--	--	--	--	0.381	1.890	
A2098	1.933	0.014	1.947	0.881	0.633	0.557	0.018	--	--	0.007	--	--	--	2.096	
A2098	1.907	0.067	1.974	0.915	0.378	0.747	0.020	--	--	0.006	--	--	--	2.066	
A2098	1.932	0.014	1.946	0.992	0.436	0.651	0.015	0.002	--	0.007	--	--	--	2.103	
A2105	1.875	0.025	1.900	1.170	0.402	0.598	0.019	0.009	--	--	--	--	--	2.198*	
A2105	1.888	0.050	1.938	1.104	0.330	0.671	0.019	0.009	--	--	--	--	--	2.133	
A2105	1.917	0.058	1.975	1.090	0.405	0.542	0.019	0.009	--	--	--	--	--	2.065	
A2105	1.929	0.065	1.994	0.627	0.680	0.684	0.024	0.010	--	--	--	--	--	2.025	
A2116	1.885	0.089	1.974	1.043	0.569	0.397	0.037	0.014	--	0.006	--	--	--	2.066	
A2116	1.965	0.031	1.996	1.200	0.561	0.240	0.011	0.002	--	--	--	--	--	2.014	
A2116	1.943	0.022	1.965	1.248	0.585	0.224	0.011	--	--	--	--	--	--	2.068	
A2116	1.964	0.023	1.987	1.146	0.636	0.232	0.012	--	--	--	--	--	--	2.026	
A2128	2.024	--	2.024	1.005	0.708	0.210	0.011	--	--	0.006	--	--	--	1.940	
A2128	1.873	0.064	1.937	1.084	0.310	0.728	0.015	--	--	0.006	--	--	--	2.143	
A2128	1.892	0.072	1.964	1.015	0.365	0.697	0.012	0.002	--	0.006	--	--	--	2.097	
A2128	1.934	0.037	1.971	1.067	0.282	0.700	0.010	--	--	0.006	--	--	--	2.065	
A2128	1.919	0.014	1.933	0.895	0.639	0.562	0.018	0.002	--	0.007	--	--	--	2.123	
A2128	1.885	0.038	1.923	1.064	0.507	0.553	0.022	--	--	0.006	--	--	--	2.130	
A2128	1.921	0.042	1.963	1.027	0.321	0.719	0.011	--	--	0.006	--	--	--	2.084	

* = analyses that exceeded $\pm 5\%$ error when rounded off to the first decimal place.

TABLE 9. DDH-3 Pyroxene Analyses

Percentages of magnesium, iron and calcium silicate
"molecules" making up the pyroxenes

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2002	39.54	19.61	40.85	Augite
A2002	37.77	29.59	32.64	Augite
A2006	42.31	20.33	37.36	Augite
A2009	33.28	32.61	34.11	Augite
A2012	51.38	20.56	27.35	Augite
A2012	50.10	16.58	33.32	Augite
A2018	42.01	19.98	38.01	Augite
A2024	38.47	30.53	31.00	Augite
A2024	35.97	37.96	26.08	Ferroaugite
A2028	40.87	22.35	36.77	Augite
A2028	40.06	21.12	38.82	Augite
A2033	40.92	19.54	39.54	Augite
A2033	42.67	21.96	35.37	Augite
A2033	38.66	22.89	38.45	Augite
A2038	48.39	30.69	20.92	Subcalcic Augite
A2038	37.80	23.04	39.16	Augite
A2041	35.94	26.78	37.28	Augite
A2041	44.97	26.38	28.64	Augite

TABLE 9 (continued)

<u>Sample</u>	<u>MgSiO₃</u>	<u>Mole Percent</u>		<u>Pyroxene Identification</u>
		<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2044	40.2	34.8	25.0	Augite
A2044	45.3	28.1	26.6	Augite
A2044	32.4	29.6	38.0	Augite
A2050	40.2	34.9	24.9	Subcalcic augite
A2050	38.0	58.1	3.9	Ferrohypersthene
A2053	47.1	39.2	13.7	Intermediate pigeonite
A2053	40.4	22.3	37.3	Augite
A2059	40.5	24.1	35.4	Augite
A2059	47.9	22.0	30.1	Augite
A2059	51.0	25.2	23.8	Subcalcic augite
A2059	43.5	20.4	36.1	Augite
A2059	33.8	23.5	42.7	Augite
A2067	35.0	56.6	8.4	Intermediate pigeonite
A2067	33.4	63.8	2.8	Ferrohypersthene
A2067	41.1	25.7	33.2	Augite
A2067	45.2	22.5	32.3	Augite
A2067	43.0	49.6	7.4	Intermediate pigeonite
A2079	59.7	37.6	2.7	Ferrohypersthene
A2079	50.5	19.7	29.8	Augite
A2079	51.3	17.6	31.1	Augite
A2079	41.2	28.3	30.5	Augite
A2089	42.1	25.8	32.1	Augite
A2089	44.4	23.5	32.1	Augite
A2089	42.0	26.1	31.9	Augite
A2089	42.1	52.5	5.4	Intermediate pigeonite
A2098	51.7	46.3	2.0	Ferrohypersthene
A2098	42.5	30.6	26.9	Augite
A2098	44.9	18.5	36.6	Augite
A2098	47.7	21.0	31.3	Augite
A2105	53.9	18.5	27.6	Augite
A2105	52.4	15.7	31.6	Augite
A2105	53.5	19.9	26.6	Augite
A2105	31.5	34.2	34.3	Ferroaugite

TABLE 9 (continued)

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2116	51.9	28.3	19.8	Subcalcic Augite
A2116	60.0	28.0	12.0	Magnesium pigeonite
A2116	60.7	28.4	10.9	Magnesium pigeonite
A2116	56.9	31.6	11.5	Magnesium pigeonite
A2128	52.3	10.9	36.8	Augite
A2128	51.1	14.6	34.3	Augite
A2128	48.9	17.6	33.5	Augite
A2128	52.1	13.8	34.1	Augite
A2128	42.7	30.5	26.8	Augite
A2128	50.1	23.9	26.0	Augite
A2128	49.7	15.5	34.8	Augite
A2045	41.7	21.8	36.5	Augite
A2045	42.4	22.9	34.7	Augite
A2045	38.8	25.2	36.0	Augite
A2045	42.0	20.1	37.9	Augite
A2045	38.2	22.4	39.4	Augite
A2045	38.0	21.0	41.0	Augite
A2046	40.0	24.4	35.6	Augite
A2046	51.0	37.7	11.3	Intermediate Pigeonite
A2046	42.2	19.7	38.1	Augite
A2046	44.4	20.6	35.0	Augite
A2046	28.5	37.7	33.8	Ferroaugite
A2048	29.5	33.5	37.0	Ferroaugite
A2048	46.1	23.7	30.2	Augite
A2048	39.3	23.2	37.5	Augite
A2048	37.4	22.9	39.7	Augite
A2056	44.3	19.3	36.4	Augite
A2056	42.7	21.0	36.3	Augite
A2056	47.8	20.9	31.3	Augite
A2056	45.3	19.7	35.0	Augite
A2056	40.2	23.3	36.5	Augite
A2056	43.5	20.3	36.1	Augite
A2056	38.8	49.0	12.2	Intermediate Pigeonite
A2056	42.0	22.6	35.4	Augite
A2056	46.7	33.2	20.1	Subcalcic Augite

TABLE 9 (continued)

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2060	44.9	18.9	36.3	Augite
A2060	43.5	24.5	32.0	Augite
A2060	46.8	29.5	23.7	Subcalcic Augite
A2060	42.5	25.2	32.3	Augite
A2061	41.3	27.7	31.0	Augite
A2061	41.5	21.7	36.8	Augite
A2061	42.3	24.1	33.6	Augite
A2061	35.4	28.5	36.1	Augite
A2064	46.1	18.0	35.9	Augite
A2064	35.1	22.5	42.4	Augite
A2064	28.3	30.5	41.2	Ferroaugite
A2064	53.8	31.9	14.3	Magnesium Pigeonite
A2064	37.0	23.5	39.5	Augite
A2064	32.6	38.6	28.8	Ferroaugite
A2068	57.8	31.6	10.6	Magnesium Pigeonite
A2068	47.9	25.7	26.4	Augite
A2068	62.7	27.9	9.4	Magnesium Pigeonite
A2068	44.5	19.9	35.6	Augite
A2072	30.6	38.9	30.5	Ferroaugite
A2072	41.4	31.4	27.5	Augite
A2072	45.2	21.6	33.2	Augite
A2072	47.6	29.8	22.6	Subcalcic Augite
A2083	58.7	30.2	11.1	Magnesium Pigeonite
A2083	48.6	17.7	33.7	Augite
A2083	47.7	20.8	31.5	Augite
A2083	43.1	24.4	32.5	Augite
A2087	48.4	24.5	27.1	Augite
A2087	58.3	31.5	10.2	Magnesium Pigeonite
A2087	48.9	14.8	36.3	Augite
A2087	43.4	25.4	31.2	Augite
A2092	46.3	17.8	35.9	Augite
A2092	43.6	18.8	37.6	Augite
A2092	49.6	18.3	32.1	Augite
A2092	45.1	17.0	37.9	Augite

TABLE 9 (continued)

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2094	50.0	22.2	27.8	Augite
A2094	50.4	16.8	32.8	Augite
A2094	61.1	28.1	10.8	Magnesium Pigeonite
A2094	48.9	19.0	32.1	Augite
A2097	49.1	17.5	33.4	Augite
A2097	59.4	28.3	12.3	Magnesium Pigeonite
A2097	45.1	19.2	35.7	Augite
A2097	45.1	17.3	37.6	Augite
A2097	48.4	16.6	35.0	Augite
A2102	47.3	19.1	33.6	Augite
A2102	39.8	26.3	33.9	Augite
A2102	43.8	20.3	35.9	Augite
A2102	48.1	24.1	27.8	Augite
A2109	36.3	34.6	29.1	Augite
A2109	33.2	35.3	31.5	Ferroaugite
A2109	50.6	36.4	13.0	Intermediate Pigeonite
A2109	33.5	36.0	30.5	Ferroaugite
A2123	57.8	31.9	10.3	Magnesium Pigeonite
A2123	37.8	27.4	34.8	Augite
A2123	44.5	43.1	12.4	Intermediate Pigeonite
A2123	38.3	24.8	36.9	Augite
A2133	44.9	25.2	29.8	Augite
A2133	38.8	27.0	34.2	Augite
A2133	47.9	21.7	30.4	Augite
A2133	44.2	27.4	28.4	Augite
A2133	44.3	28.6	27.1	Augite
A2133	48.1	24.9	27.0	Subcalcic Augite

substandard analysis, falls in the subcalcic augite area, and the last A2024 analysis barely falls into the ferroaugitic compositional area.

Normally two pyroxene phases are formed during the early stages of the fractional crystallization of a basic magma; usually a calcium-rich augite and a calcium-poor pigeonite or orthopyroxene. During the initial period of crystallization, the calcium-rich phase composition is close to $\text{Ca}_{45}\text{Mg}_{45}\text{Fe}_{10}$ and the calcium-poor phase is an orthopyroxene about $\text{Ca}_4\text{Mg}_{77}\text{Fe}_{19}$. As cooling proceeds, the melt becomes enriched in iron and a monoclinic calcium-poor pyroxene, pigeonite, begins to crystallize instead of the orthopyroxene. Both the calcium-rich and calcium-poor phases become increasingly iron-rich. Finally, the calcium-poor phase ceases to crystallize, and the final, single pyroxene is represented by a ferroaugite.

It is to be noted that the calcium-poor phases, either an orthopyroxene or pigeonite, are not represented in the pyroxene analyses. Only the calcium-rich augite phase is represented. The reason for the deviation of these basalts and andesites from the above normal pyroxene crystallization sequence is that the cooling rate may have been too rapid to allow two phases to develop.

The composition of additional pyroxene unit cells from Type Section samples is given in Table 10. In no case did the sum of the cations exceed $\pm 10\%$ of the theoretical 2.0, and in only four cases out of a total of 45 analyses did the sum of the cations exceed $\pm 5\%$ of the theoretical 2.0.

The mole percentages of MgSiO_3 , FeSiO_3 and CaSiO_3 are given in Table 11 along with an identification of the pyroxene from the analysis. There were six subcalcic augites, three magnesium pigeonites and one ferrohypersthene. The majority of pyroxenes were augites. The majority of subcalcic augites occurred in samples K5010 and K5013. The single ferrohypersthene was found in sample A1216.

Metallics

The composition of the unit cells of the titanium and iron-bearing metallics in selected basalt samples is given in Table 12. The molecular reference, $(\text{Fe}, \text{Ti})_2\text{O}_6$, is that used for ilmenite. This particular cell is used because ilmenite is a titanate of ferrous iron ($\text{Fe}^{+2}\text{Ti}^{+4}\text{O}_3$) rather than a double oxide of ferric iron and titanium ($\text{Fe}^{+2}\text{Ti}^{+3}\text{O}_3$). Consequently, there is a continuous FeTiO_3 - Fe_3O_4 solid solution series above

TABLE 10. DDH-3 Pyroxene Analyses

Pyroxene compositions, based on the molecule $[(\text{Mg}, \text{Fe}^{+2}, \text{Ca}, \text{Ti}, \text{K}, \text{Mn}, \text{Al})_2][(\text{Al}, \text{Si})_2]\text{O}_6$, as determined from the microprobe chemical analyses.

Sample	Atoms										$\Sigma \text{Mg, Fe, Ca, Ti, K, Mn, Al}$
	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	
K5008	1.895	0.062	1.957	0.984	0.445	0.630	0.023	---	0.013	---	2.095
K5008	1.884	0.064	1.948	0.991	0.426	0.658	0.023	---	0.013	---	2.111
K5008	1.856	0.065	1.921	0.941	0.449	0.710	0.039	---	0.013	---	2.152
K5008	1.929	0.066	1.995	0.849	0.459	0.666	0.027	0.005	0.013	---	2.019
K5010	1.978	0.022	2.000	1.055	0.443	0.453	0.015	---	---	0.020	1.986
K5010	1.921	0.056	1.979	1.068	0.390	0.585	0.015	---	---	---	2.058
K5010	1.983	0.017	2.000	1.014	0.474	0.454	0.015	---	---	0.024	1.981
K5010	1.935	0.065	2.000	1.066	0.369	0.543	0.015	---	---	0.017	2.010
K5013	2.015	---	2.015	0.920	0.519	0.439	0.017	0.003	0.010	0.031	1.939
K5013	1.971	0.029	2.000	0.879	0.435	0.601	0.022	---	0.009	0.031	1.977
K5013	1.984	0.016	2.000	0.856	0.623	0.461	0.017	---	0.013	0.015	1.985
K5013	1.943	0.029	1.972	1.009	0.527	0.491	0.016	---	0.012	---	2.054
K5026	2.031	0.018	2.049	1.153	0.547	0.205	---	---	0.006	0.018	1.911
K5026	1.954	0.046	2.000	0.891	0.376	0.674	0.015	0.004	0.007	0.029	1.996
K5026	1.947	0.056	2.003	0.914	0.424	0.640	0.018	0.004	0.007	---	2.007
K5026	2.087	---	2.087	1.112	0.563	0.144	---	---	0.006	---	1.825
K5026	1.941	0.059	2.000	1.078	0.356	0.541	0.014	0.003	0.006	0.012	2.010
K5033	1.866	0.115	1.981	0.981	0.471	0.552	0.040	0.003	0.010	---	2.057
K5033	1.847	0.017	1.864	1.398	0.610	0.252	---	---	0.010	---	2.243
K5033	1.813	0.070	1.883	1.147	0.447	0.596	0.034	---	0.009	---	2.233
K5033	1.866	0.074	1.940	0.657	0.625	0.767	0.047	0.005	0.010	---	2.111
K5033	1.847	0.129	1.976	1.084	0.494	0.476	0.023	0.014	0.006	---	2.097
K5033	1.829	0.116	1.945	0.983	0.431	0.658	0.045	---	0.006	---	2.123

TABLE 10 (continued)

Sample	Atoms										$\Sigma \text{Mg, Fe, Ca}$ Ti, K, Mn, Al
	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	
Al215	1.972	0.014	1.986	0.806	0.558	0.637	0.012	0.016	---	---	2.029
Al215	2.015	---	2.015	0.785	0.434	0.650	0.014	0.010	---	0.045	1.938
Al215	1.991	0.009	2.040	0.686	0.575	0.622	0.025	0.026	---	0.040	1.974
Al215	2.034	---	2.034	0.704	0.488	0.621	0.021	0.015	---	0.047	1.896
Al216	1.984	0.016	2.000	0.508	0.504	0.650	---	0.017	0.015	0.216	1.910
Al216	2.197	---	2.197	0.528	0.929	0.027	---	0.151	---	0.164	1.799
Al216	2.001	---	2.001	0.751	0.443	0.683	0.020	---	0.009	0.048	1.954
Al216	1.966	0.034	2.000	0.833	0.402	0.714	0.017	---	0.010	0.016	1.992
Al216	1.998	0.002	2.000	0.689	0.452	0.742	0.018	---	0.010	0.049	1.960
Al216	2.001	---	2.001	0.733	0.493	0.654	0.022	---	0.010	0.043	1.955
Al268	1.941	0.062	2.003	1.016	0.242	0.742	0.008	---	0.006	---	2.014
Al268	1.953	0.047	2.000	0.956	0.242	0.750	0.015	---	0.007	0.026	1.996
Al268	1.973	0.027	2.000	0.980	0.246	0.750	0.009	---	0.007	0.009	2.001
Al268	1.991	0.009	2.000	0.926	0.238	0.718	0.011	---	0.006	0.062	1.961
Al278	1.959	0.041	2.000	0.767	0.504	0.668	0.027	---	0.010	0.011	1.987
Al278	1.995	0.005	2.000	0.758	0.513	0.601	0.024	---	0.010	0.047	1.953
Al278	1.988	0.012	2.000	0.795	0.613	0.529	0.018	---	0.010	0.016	1.981
Al278	1.995	0.005	2.000	0.700	0.640	0.541	0.021	---	0.010	0.046	1.958
Al281	1.954	0.046	2.000	0.823	0.394	0.715	0.029	---	0.007	0.018	1.986
Al281	1.989	0.011	2.000	0.804	0.445	0.653	0.018	---	0.010	0.039	1.969
Al281	1.962	0.038	2.000	0.711	0.531	0.693	0.024	---	0.007	0.019	1.985
Al281	1.972	0.028	2.000	0.832	0.421	0.685	0.020	---	0.007	0.022	1.982

TABLE 11. DDH-3 Pyroxene Analyses

Percentages of magnesium, iron and calcium silicate "molecules" comprising the pyroxenes in the same order as that given in Table 10.

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
K5008	47.8	21.6	30.6	Augite
K5008	47.8	20.5	31.7	Augite
K5008	44.8	21.4	33.8	Augite
K5008	43.0	23.3	33.7	Augite
K5010	54.1	22.7	23.2	Subcalcic Augite
K5010	52.3	19.1	28.6	Augite
K5010	52.2	24.4	23.4	Subcalcic Augite
K5010	53.9	18.6	27.5	Augite
K5013	49.0	27.6	23.4	Subcalcic Augite
K5013	45.9	22.7	31.4	Augite
K5013	44.1	32.1	23.8	Subcalcic Augite
K5013	49.8	26.0	24.2	Subcalcic Augite
K5026	60.5	28.7	10.8	Magnesium Pigeonite
K5026	45.9	19.4	34.7	Augite
K5026	46.2	21.4	32.4	Augite
K5026	61.1	31.0	7.9	Magnesium Pigeonite
K5026	54.6	18.0	27.4	Augite
K5033	49.0	23.5	27.5	Augite
K5033	61.9	27.0	11.1	Magnesium Pigeonite
K5033	52.4	20.4	27.2	Augite
K5033	32.1	30.5	37.4	Augite
K5033	52.8	24.0	23.2	Subcalcic Augite
K5033	47.4	20.8	31.8	Augite
A1215	40.3	27.9	31.8	Augite
A1215	42.0	23.2	34.8	Augite
A1215	36.4	30.6	33.0	Augite
A1215	38.8	26.9	34.3	Augite
A1216	30.6	30.3	39.1	Augite
A1216	35.6	62.8	1.8	Ferrohypersthene
A1216	40.0	23.6	36.4	Augite
A1216	42.8	20.6	36.6	Augite
A1216	36.6	24.0	39.4	Augite
A1216	39.0	26.2	34.8	Augite

TABLE 11 (continued)

<u>Sample</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
Al268	50.8	12.1	37.1	Augite
Al268	49.1	12.4	38.5	Augite
Al268	49.6	12.4	38.0	Augite
Al268	49.2	12.6	38.2	Augite
Al278	39.6	26.0	34.4	Augite
Al278	40.5	27.4	32.1	Augite
Al278	41.0	31.7	27.3	Augite
Al278	37.2	34.0	28.8	Augite
Al281	42.6	20.4	37.0	Augite
Al281	42.3	23.4	34.3	Augite
Al281	36.7	27.5	35.8	Augite
Al281	43.0	21.8	35.2	Augite

TABLE 12

Microprobe Analyses of Metallics referred to molecule of
 $(\text{Fe}^{+2}, \text{Ti}^{+4})_2\text{O}_6$

Sample	Ti	Mg	Fe	Mn	Cr	Co	$\Sigma\text{Mg, Fe, Mn, Cr, Co}$	Mineral
A2002	2.032	--	1.936	--	--	--	--	Ilmenite
A2002	1.249	--	3.503	--	--	--	--	Ilmenite-magnetite
A2006	2.017	--	1.965	--	--	--	--	Ilmenite
A2009	2.028		1.944	--	--	--	--	Ilmenite
A2018	1.992	--	2.016	--	--	--	--	Ilmenite
A2024	1.003	--	3.994	--	--	--	--	Ilmenite-magnetite
A2024	1.110	--	2.780	--	--	--	--	Ilmenite-magnetite
A2028	1.056	--	3.888	--	--	--	--	Ilmenite-magnetite
A2028	1.995	--	2.010	--	--	--	--	Ilmenite
A2033	1.211	--	3.557	--	--	--	--	Ilmenite-magnetite
A2033	1.211	--	3.557	--	--	--	--	Ilmenite-magnetite
A2038	2.066	--	1.868	--	--	--	--	Ilmenite
A2038	2.018	--	1.964	--	--	--	--	Ilmenite
A2041	1.276	--	3.446	--	--	--	--	Ilmenite-magnetite
A2041	2.013	--	1.974	--	--	--	--	Ilmenite
A2044	2.009	0.031	1.951	--	--	--	1.982	Ilmenite
A2044	1.997	0.046	1.960	--	--	--	2.006	Ilmenite
A2050	1.275	--	3.449	--	--	--	3.449	Ilmenite-magnetite
A2050	1.185	--	3.629	--	--	--	3.629	Ilmenite-magnetite
A2053	1.683	0.157	2.477	--	--	--	2.634	Ilmenite-magnetite
A2053	1.268	0.040	3.424	--	--	--	3.464	Ilmenite-magnetite
A2059	1.935	0.144	1.958	0.027	--	--	2.129	Ilmenite
A2059	1.990	0.062	1.932	0.026	--	--	2.020	Ilmenite
A2059	1.998	0.137	1.849	0.017	--	--	2.003	Ilmenite
A2059	1.969	0.140	1.895	0.027	--	--	2.062	Ilmenite
A2067	1.080	--	3.824	0.017	--	--	3.841	Ilmenite-magnetite
A2067	1.958	0.190	1.882	0.013	--	--	2.085	Ilmenite
A2067	2.052	0.130	1.752	0.013	--	--	1.895	Ilmenite
A2067	1.959	0.129	1.939	0.013	--	--	2.081	Ilmenite

TABLE 12 (continued)

<u>Sample</u>	<u>Ti</u>	<u>Mg</u>	<u>Fe</u>	<u>Mn</u>	<u>Cr</u>	<u>Co</u>	<u>ΣMg, Fe, Mn, Cr, Co</u>	<u>Mineral</u>
A2045	1.114	0.138	3.593	0.017	0.008	--	3.756	Ilmenite-magnetite
A2045	1.859	0.121	2.120	0.028	0.005	--	2.274	Ilmenite-magnetite
A2045	2.027	0.104	1.803	0.021	0.006	--	1.934	Ilmenite
A2045	1.793	0.172	2.223	0.020	--	--	2.415	Ilmenite-magnetite
A2045	1.281	0.270	3.138	0.031	--	--	3.439	Ilmenite-magnetite
A2046	1.939	0.172	1.905	0.022	0.006	0.004	2.109	Ilmenite
A2046	1.204	0.131	3.402	0.032	0.008	0.005	3.578	Ilmenite-magnetite
A2046	1.289	0.200	3.115	0.036	0.022	0.005	3.378	Ilmenite-magnetite
A2046	1.245	0.152	3.289	0.030	0.011	0.005	3.487	Ilmenite-magnetite
A2048	(Small crystallites in groundmass)							
A2056	1.913	0.228	1.903	0.017	0.009	--	2.157	Ilmenite
A2056	1.919	0.207	1.912	0.017	0.009	--	2.145	Ilmenite
A2056	1.940	0.207	1.870	0.017	0.009	--	2.103	Ilmenite
A2056	1.913	0.223	1.903	0.018	0.010	--	2.136	Ilmenite
A2056	1.897	0.182	1.996	0.014	0.003	0.004	2.119	Ilmenite
A2056	1.919	0.264	1.858	0.018	0.006	0.004	2.150	Ilmenite
A2056	1.247	0.201	3.226	0.031	0.015	0.005	3.478	Ilmenite-magnetite
A2056	1.242	0.186	3.233	0.037	0.019	0.005	3.480	Ilmenite-magnetite
A2060	1.921	0.188	1.924	0.018	0.006	0.008	2.144	Ilmenite
A2060	1.921	0.188	1.920	0.018	0.006	0.013	2.145	Ilmenite
A2060	1.152	0.202	3.382	0.006	0.012	0.010	3.672	Ilmenite-magnetite
A2060	1.899	0.185	1.967	0.020	0.007	0.009	2.188	Ilmenite
A2061	1.954	0.087	1.962	0.023	0.006	--	2.078	Ilmenite
A2061	1.135	0.104	3.549	0.032	0.015	--	3.700	Ilmenite-magnetite
A2061	1.209	0.107	3.413	0.039	0.008	--	3.567	Ilmenite-magnetite
A2061	1.196	0.105	3.430	0.027	0.015	--	3.577	Ilmenite-magnetite
A2064	(Small crystallites in groundmass)							

TABLE 12 (continued)

<u>Sample</u>	<u>Ti</u>	<u>Mg</u>	<u>Fe</u>	<u>Mn</u>	<u>Cr</u>	<u>Co</u>	<u>EMg,Fe, Mn,Cr,Co</u>	<u>Mineral</u>
A2068	1.291	0.206	3.105	0.069	0.011	0.005	3.396	Ilmenite-magnetite
A2068	1.334	--	3.214	0.066	0.016	0.005	3.301	Ilmenite-magnetite
A2068	1.314	0.102	3.163	0.058	0.015	0.005	3.343	Ilmenite-magnetite
A2068	1.324	0.102	3.128	0.073	0.015	0.005	3.323	Ilmenite-magnetite
A2072	(Small crystallites in groundmass)							
A2083	1.299	0.081	3.210	0.086	0.008	--	3.385	Ilmenite-magnetite
A2083	1.277	0.132	3.210	0.081	0.008	--	3.431	Ilmenite-magnetite
A2087	1.924	0.190	1.916	0.014	0.006	0.013	2.139	Ilmenite
A2087	1.212	0.252	3.233	0.048	0.010	0.013	3.556	Ilmenite-magnetite
A2087	1.204	0.244	3.262	0.040	0.009	0.019	3.574	Ilmenite-magnetite
A2087	1.247	0.237	3.184	0.038	0.009	0.018	3.486	Ilmenite-magnetite
A2092	(Small crystallites in groundmass)							
A2094	(Small crystallites in groundmass)							
A2097	1.232	0.133	3.309	0.065	0.008	0.005	3.520	Ilmenite-magnetite
A2097	2.006	0.109	1.840	0.022	0.003	0.008	1.982	Ilmenite
A2097	1.210	0.204	3.275	0.063	0.011	0.005	3.558	Ilmenite-magnetite
A2097	1.193	0.208	3.303	0.064	0.011	0.005	3.591	Ilmenite-magnetite
A2097	1.936	0.197	1.894	0.018	0.018	0.006	2.115	Ilmenite
A2102	1.310	0.169	3.054	0.107	0.015	0.005	3.350	Ilmenite-magnetite
A2102	1.916	0.187	1.940	0.018	0.006	0.004	2.155	Ilmenite
A2102	1.960	0.160	1.880	0.017	0.006	0.004	2.067	Ilmenite
A2102	1.959	0.166	1.876	0.018	0.006	0.004	2.070	Ilmenite
A2109	(Small crystallites in groundmass)							
A2123	1.963	0.191	1.847	0.017	0.006	--	2.061	Ilmenite
A2123	1.014	0.169	3.732	0.023	0.016	--	3.940	Ilmenite-magnetite
A2123	2.006	0.112	1.856	0.009	0.003	--	1.980	Ilmenite
A2123	1.958	0.176	1.871	0.018	0.006	--	2.071	Ilmenite
A2133	(Small crystallites in groundmass)							

TABLE 12 (continued)

<u>Sample</u>	<u>Ti</u>	<u>Mg</u>	<u>Fe</u>	<u>Mn</u>	<u>Cr</u>	<u>Co</u>	<u>ΣMg,Fe, Mn,Cr,Co</u>	<u>Mineral</u>
A2079	(no metallic found in sample)							
A2089	1.982	0.156	1.858	0.022	--	--	2.036	Ilmenite
A2089	1.043	0.139	3.712	0.062	--	--	3.913	Ilmenite-magnetite
A2089	1.095	0.166	3.600	0.044	--	--	3.810	Ilmenite-magnetite
A2089	1.975	0.083	1.946	0.021	--	--	2.050	Ilmenite
A2089	1.156	0.104	3.472	0.112	--	--	3.688	Ilmenite-magnetite
A2098	1.313	--	3.315	0.059	--	--	3.374	Ilmenite-magnetite
A2098	1.976	0.133	1.894	0.022	--	--	2.049	Ilmenite
A2098	1.309	0.107	3.247	0.028	--	--	3.382	Ilmenite-magnetite
A2098	1.346	0.106	3.153	0.049	--	--	3.308	Ilmenite-magnetite
A2098	1.967	0.110	1.934	0.022	--	--	2.066	Ilmenite
A2098	1.949	0.130	1.951	0.018	--	--	2.102	Ilmenite
A2098	1.951	0.134	1.947	0.018	--	--	2.099	Ilmenite
A2105	1.312	0.108	3.235	0.033	--	--	3.376	Ilmenite-magnetite
A2105	1.238	0.107	3.384	0.033	--	--	3.524	Ilmenite-magnetite
A2105	1.988	0.088	1.912	0.023	--	--	2.023	Ilmenite
A2105	1.289	0.109	3.280	0.034	--	--	3.423	Ilmenite-magnetite
A2105	1.280	0.106	3.306	0.027	--	--	3.439	Ilmenite-magnetite
A2105	1.250	0.110	3.361	0.028	--	--	3.499	Ilmenite-magnetite
A2105	1.274	0.107	3.322	0.022	--	--	3.451	Ilmenite-magnetite
A2105	1.227	0.191	3.326	0.029	--	--	3.546	Ilmenite-magnetite
A2105	1.257	0.109	3.349	0.028	--	--	3.486	Ilmenite-magnetite
A2116	(no metallics found in sample)							
A2128	1.972	0.108	1.935	0.013	--	--	2.056	Ilmenite
A2128	1.964	0.138	1.920	0.013	--	--	2.071	Ilmenite
A2128	1.189	--	3.605	0.016	--	--	3.621	Ilmenite-magnetite
A2128	1.964	0.128	1.931	0.014	--	--	2.073	Ilmenite
A2128	2.018	0.091	1.865	0.009	--	--	1.965	Ilmenite
A2128	1.087	0.076	3.735	0.016	--	--	3.827	Ilmenite-magnetite

600°C. Two ferrous ions are required to replace one titanate ion. To compensate for this, the cell $(\text{Fe,Ti})_2\text{O}_6$ is used.

In an ideal ilmenite, the number of titanate ions must equal the number of ferrous ions. If there is an excess of iron, then magnetite is probably present as exsolution lamellae at room temperature.

Another possibility to account for the high iron samples is the presence of a magnetite ($\text{Fe}^{+2}\text{Fe}_2^{+3}\text{O}_4$)-ulvospinel ($\text{Fe}_2^{+2}\text{Ti}^{+4}\text{O}_4$) mixture, or a so-called titanomagnetite. This is considered a less likely possibility than the ilmenite-magnetite mixture because it was shown in several instances that ilmenite alone is present.

The mineralogy derived from the metallics microprobe analyses is given in Table 12. Note that most of the metallics were identified as ilmenites because the divalent ferrous iron atoms were equal to the number of tetravalent titanium atoms when referred to six oxygens. This circumstance happens with no iron titanium mineral except ilmenite. Note also that the number of trace elements analyzed for, such as manganese and cobalt, increased as the work progressed.

The composition of additional metallics from Type Section samples, referred to an ilmenite unit cell, is shown in Table 13. Out of a total of 36 analyses, 13 were ilmenites and the remainder were ilmenite-magnetite solid solutions. No normal metallics were located in samples K5026 and A1268. The groundmass analyses of samples K5026 and A1268 are relatively high in iron and titanium. In addition, both samples contain areas of "mineraloid", high in iron and titanium content, that will be discussed in the Accessory Minerals section of this report.

Note that chromium is fairly common in the metallics of these samples, and cobalt was found in two of four metallics analyses from sample K5010. Ilmenite contains Fe^{+2} with an atomic radius of 0.74 Å and magnetite contains Fe^{+3} with an atomic radius of 0.64 Å. The atomic radius of Cr^{+3} is 0.63 Å and of Co^{+2} , 0.72 Å. Trace amounts of Cr^{+3} easily substitute for Fe^{+3} in the magnetite and Co^{+2} for Fe^{+2} in the ilmenite when sufficient amounts of cobalt and chromium are present in the melt during crystallization of the metallics. Cr^{+3} is the most stable state for chromium and Co^{+2} is the most stable state for cobalt. The microprobe detection limit for chromium, reported as CrO_3 , is 0.1 wt%, and 0.09 wt% for CoO . Anything above these limits, the microprobe operator reported as a positive value.

TABLE 13. Metallics in Type Section Samples

Microprobe Chemical Analyses of Metallics Referred to a Molecule of $(\text{Fe}^{+2}, \text{Mg}, \text{Mn}, \text{Cr}, \text{Co})_2 (\text{Ti}^{+4})_2 \text{O}_6$.

Sample	Ti	Mg	Fe	Mn	Cr	Co	$\Sigma \text{Mg, Fe, Mn, Cr, Co}$	Mineral
K5008	1.184	0.293	3.317	0.022	---	---	3.632	Ilmenite-magnetite
K5008	1.905	0.243	1.933	0.013	---	---	2.189	Mainly ilmenite
K5008	1.956	0.245	1.829	0.013	---	---	2.087	Ilmenite
K5008	1.192	0.282	3.313	0.021	---	---	3.616	Ilmenite-magnetite
K5010	1.635	0.125	2.559	0.015	0.007	0.010	2.716	Ilmenite-magnetite
K5010	1.961	0.157	1.880	0.022	0.006	---	2.065	Ilmenite
K5010	1.946	0.137	1.929	0.023	0.006	---	2.095	Ilmenite
K5010	1.339	0.168	3.081	0.039	0.008	0.011	3.307	Ilmenite-magnetite
K5013	1.933	0.199	1.893	0.023	0.003	---	2.121	Ilmenite
K5013	1.993	0.203	1.774	0.037	---	---	2.014	Ilmenite
K5013	1.936	0.161	1.940	0.027	---	---	2.128	Ilmenite
K5013	1.967	0.136	1.903	0.027	---	---	2.066	Ilmenite
K5026	(no metallics large enough for analysis)							
K5033	1.287	---	3.395	0.030	---	---	3.425	Ilmenite-magnetite
K5033	1.272	0.118	3.308	0.030	---	---	3.456	Ilmenite-magnetite
K5033	1.207	0.118	3.441	0.028	---	---	3.587	Ilmenite-magnetite
K5033	1.243	0.151	3.340	0.023	---	---	3.514	Ilmenite-magnetite
K5033	1.249	0.205	3.277	0.021	---	---	3.503	Ilmenite-magnetite
A1215	1.152	---	3.636	0.035	0.008	---	3.679	Ilmenite-magnetite
A1215	1.688	---	2.575	0.029	0.007	---	2.611	Ilmenite-magnetite
A1215	1.058	0.119	3.714	0.028	0.008	---	3.869	Ilmenite-magnetite
A1215	1.066	---	3.802	0.041	0.008	---	3.851	Ilmenite-magnetite
A1215	1.217	0.133	3.381	0.030	0.007	---	3.551	Ilmenite-magnetite
A1216	1.927	0.208	1.874	0.035	0.009	---	2.126	Ilmenite
A1216	0.719	0.096	4.328	0.097	0.013	---	4.534	Ilmenite-magnetite
A1216	1.919	0.189	1.917	0.027	0.010	---	2.143	Ilmenite
A1216	0.937	0.177	3.885	0.028	0.012	---	4.102	Ilmenite-magnetite
A1216	0.879	0.184	3.992	0.029	0.012	---	4.217	Ilmenite-magnetite
A1216	0.781	0.127	4.129	0.145	0.013	---	4.414	Ilmenite-magnetite
A1268	(no metallics large enough for analysis)							
A1278	1.209	0.160	3.360	0.027	0.011	---	3.558	Ilmenite-magnetite
A1278	1.987	0.173	1.816	0.018	0.006	---	2.013	Ilmenite
A1278	1.245	0.132	3.327	0.016	0.011	---	3.486	Ilmenite-magnetite
A1278	1.969	0.169	1.852	0.013	0.009	---	2.043	Ilmenite
A1281	1.961	0.109	1.947	0.022	---	---	2.078	Ilmenite
A1281	1.167	0.133	3.455	0.032	0.015	---	3.635	Ilmenite-magnetite
A1281	1.929	0.210	1.892	0.021	0.006	---	2.129	Ilmenite
A1281	1.086	0.161	3.606	0.027	0.011	---	3.805	Ilmenite-magnetite

Olivines

The olivine analyses were referred to four oxygens, or $(\text{Mg, Fe})_2 \text{SiO}_4$. To review the method used, the first analysis of A2038 olivine can serve as an example. The reported chemical analysis was: MgO, 16.8; SiO₂, 34.0; and FeO, 51.5, for a total of 102.3 wt%. These values were corrected to 100% by multiplying by a factor to give: MgO, 16.42; SiO₂, 33.24; and FeO, 50.34. Dividing the above values by their respective molecular equivalent weights (MgO, 40.32; SiO₂, 60.06; and FeO, 71.9) yielded molecular or atomic equivalent fractions (MgO, 0.407; SiO₂, 0.553; and FeO, 0.700). Recalculating to 100% gave: Mg, 24.52; Si, 33.31; and FeO, 42.17. Then these values were referred to the four oxygens of the molecule, $(\text{Mg, Fe})_2 \text{SiO}_4$. This is done by referring back to the original constituent. MgO has one oxygen; SiO₂, two oxygens; and FeO, one oxygen. Multiplying these by the molecular equivalent percentages given earlier, we obtain the number of associated oxygens, or: MgO, 24.52; SiO₂, 66.62; and FeO, 42.17. The associated oxygen total is, then, 133.31, which divided by 4.0 yields 33.3275. If the molecular or atomic equivalent percentages are divided by 33.3275, the resulting cation values are those referred to the four oxygens of our unit cell, $(\text{Mg, Fe})_2 \text{SiO}_4$. In this case the Mg, 0.736, plus Fe, 1.265, sum to 2.001. The Si is 0.999, for a unit cell of $(\text{Mg, Fe})_{2.001} \text{Si}_{0.999} \text{O}_4$. The relative percentages of forsterite and fayalite in this molecule are 36.78 and 63.22%, respectively. Since the analytical errors involved in microprobe analysis impose an accuracy of plus or minus 5% on the chemical analysis, the results are analytically valid if the value for Si falls between or on 0.950 and 1.050, and the value for Mg plus Fe falls between or on 1.900 to 2.100.

The olivine analyses are given in Table 14. There were 11 cases out of the 31 where poor analytical results were indicated due to inclusion of extraneous material in the microprobe beam. These two cases were one analysis of A2012 olivine, and the olivine in A2024. There were several other cases that were discarded due to migration of magnesium out of the olivine. High silica indicates that there has been migration of magnesium and iron from the olivine. These are cases where the cation and oxygen balances falls outside of the plus or minus 5% limit of the analytical method.

The fact that extensive cation migration from the olivines in this portion of the section has occurred is noteworthy. The alteration of the olivines probably has occurred as a result of late-stage hydrothermal action rather than alteration by groundwater.

TABLE 14. DDH-3 Olivine Compositions

Olivine Compositions, Based on the Molecule $(\text{Mg}, \text{Fe})_2 \text{SiO}_4$, as Determined from the Chemical Analyses. Cation migration has occurred when the mole percentages are given in brackets or is omitted.

<u>Sample</u>	<u>Atoms/Unit Cell</u>				<u>Mole Percent</u>	
	<u>Mg</u>	<u>Fe</u>	<u>Mg+Fe</u>	<u>Si</u>	<u>Forsterite</u>	<u>Fayalite</u>
A2002	0.753	1.178	1.931	1.034	39.00	61.00
A2002	0.911	1.115	2.026	0.987	44.97	55.03
A2006	0.586	1.402	1.988	1.006	29.48	70.52
A2009	0.529	1.435	1.964	1.018	26.93	73.07
A2012	1.363	0.654	2.017	0.991	67.58	32.42
A2012	(analysis showed Al; discarded)					
A2018	1.005	1.008	2.013	1.008	49.93	50.07
A2024	(analysis showed Na and Al; discarded)					
A2028	0.336	0.803	1.139	1.430	(loss of Mg and Fe indicated)	
A2028	0.484	1.472	1.956	1.022	24.74	75.26
A2033	0.714	1.185	1.899	1.050	37.60	62.40
A2033	0.805	1.218	2.023	0.989	39.79	60.21
A2038	0.736	1.265	2.001	0.999	36.78	63.22
A2038	0.716	1.183	1.899	1.050	37.70	62.30
A2041	(no olivines located for analysis)					

TABLE 14 (continued)

<u>Sample</u>	<u>Mg</u>	<u>Fe</u>	<u>Mg+Fe</u>	<u>Si</u>	<u>Mole %</u>	
					<u>Forsterite</u>	<u>Fayalite</u>
A2044	0.841	1.172	2.013	0.993	41.8	58.2
A2044	0.768	1.125	1.893	1.053	40.6	59.4
A2050	0.756	1.177	1.933	1.033	39.1	60.9
A2050	0.182	1.311	1.493	1.253	(12.2)	(87.8)
A2053	0.730	1.168	1.898	1.051	38.5	61.5
A2053	0.118	0.801	0.919	1.540	(12.8)	(87.2)
A2059	0.412	0.591	1.003	1.498	(41.1)	(58.9)
A2059	0.423	0.503	1.006	1.497	(42.0)	(58.0)
A2059	0.416	0.617	1.033	1.483	(40.3)	(59.7)
A2059	0.673	1.205	1.878	1.061	35.8	64.2
K5008	0.801	1.162	1.963	1.018	40.8	59.2
K5013	0.108	1.029	1.137	1.431	----	----
K5013	0.193	1.342	1.535	1.233	----	----
K5033	1.327	0.751	2.078	0.961	63.9	36.1
K5033	1.573	0.731	2.304	0.848	----	----
A1268	1.425	0.554	1.979	1.010	72.0	28.0
A1268	1.188	0.620	1.808	1.096	----	----

Also, notice that most of the olivine analyses in Table 14 are iron-rich, varying from Fo₅₀ to Fo₂₅.

Prider and Cole⁶ reported the alteration of an Australian occurrence of olivine to nontronite and a magnesium-beidellite.

Groundmass Compositions

The groundmass compositions and whole rock analyses are presented in Table 15. The whole rock analyses were obtained from your well logs for DDH-3. The reported weight percent oxides are given rather than correcting these results to 100% to allow comparison between whole rock and groundmass total weight percents.

Most of the groundmass analyses show that the flow units represented by these samples are extensively chemically differentiated. The MgO, FeO, TiO₂ and Na₂O have all decreased considerably in the groundmass as compared to the whole rock. K₂O and SiO₂, on the other hand, have increased. Samples A2048, A2064, A2072, A2092, A2094, A2109, and A2133 showed small metallic crystallites throughout the groundmass. Of the above samples, A2048, A2064, A2072, and A2133 also show very little silica enrichment of the groundmass. The above samples also tend to be higher in content of Na₂O, MgO and CaO than the remaining groundmass analyses. Samples A2048, A2064 and A2133 show groundmasses nearly as high in FeO as the original melt as represented by the whole rock analysis. Sample A2072 groundmass is much lower in FeO content than the whole rock, but about the same TiO₂ as the whole rock. Samples A2082, A2094 and A2109 also show high groundmass FeO contents. The K₂O content of the groundmasses of A2048, A2064, A2072, A2092, A2094, A2109 and A2133 seems to be enriched in the groundmass, just as it is with the other samples. The results would indicate that not all of the flow units chemically differentiated to the same extent. In fact, the groundmass compositions and their changes in relation to the whole rock analyses may prove to be more diagnostic and useful in flow unit identification than much of the mineralogy. The groundmass furnishes a relatively good sample of the residual liquid composition remaining after crystallization of the main mineral phases. For comparative purposes, an average plutonic granite composition is as follows in weight percent: SiO₂, 69.6; Al₂O₃, 14.4; Na₂O, 3.5; K₂O, 4.1; MgO, 0.9; CaO, 2.0; FeO, 5.3 and TiO₂, 0.4. Most of the groundmass chemical compositions approximate the granitic composition given above with some exceptions. Most of the magnesium is <0.3 wt% in the groundmass analyses, removed during early

TABLE 15. DDH-3 Groundmass and Whole Rock Analyses

Groundmass compositions from electron microprobe chemical analyses. "W" analyses are whole rock analyses.

Sample	Wt. %									Total Wt. %
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	
A2045	70.1	13.3	<1.3	7.5	<0.3	0.8	<0.2	2.2	0.4	97.7
A2045	66.6	12.1	--	6.8	--	4.0	--	3.1	0.4	93.6
A2045	72.5	15.6	--	6.0	--	1.0	--	2.7	0.3	98.2
A2045	74.5	15.0	--	5.8	--	1.7	--	3.4	0.2	100.9
A2045W	53.5	12.9	2.9	1.2	3.7	7.5	--	13.8	2.5	98.0
A2046	73.2	12.5	3.5	6.1	--	0.5	--	2.4	0.3	98.5
A2046	77.6	11.9	--	8.4	--	0.2	--	1.7	0.6	100.4
A2046	81.1	12.2	--	7.5	--	0.6	--	1.3	0.5	103.2
A2046	72.0	12.9	--	8.0	--	0.4	--	1.4	0.4	95.1
A2046W	53.5	12.4	2.7	1.4	4.1	7.8	--	13.4	2.5	97.8
A2048	48.6	9.4	2.5	2.5	2.8	10.8	--	13.5	3.2	95.1
A2048	53.0	9.4	3.4	3.9	2.2	8.3	--	11.4	3.8	96.3
A2048	61.7	12.3	--	3.0	--	5.2	--	7.6	2.0	92.2
A2048W	52.0	12.5	2.5	1.2	4.6	7.7	--	13.6	2.5	96.6
A2056	70.0	12.0	--	7.4	--	3.0	--	3.4	1.0	99.8
A2056	71.5	9.3	--	7.8	--	0.5	--	6.1	0.7	96.8
A2056	68.7	13.4	2.5	6.0	--	2.0	--	4.3	1.0	97.9
A2056	67.5	12.6	--	8.4	--	1.1	--	7.6	0.8	98.0
A2056	68.1	12.5	--	6.5	0.9	1.7	--	6.1	0.3	96.5
A2056	65.5	11.9	--	7.7	--	2.0	--	5.2	1.2	94.0
A2056	68.1	13.0	--	4.9	--	2.2	0.4	5.2	1.0	95.1
A2056	71.5	12.4	--	7.7	--	2.9	--	2.7	0.6	99.0
A2056W	55.0	13.3	2.8	1.3	4.7	8.0	--	14.6	2.5	102.2
A2060	75.0	13.3	--	7.5	--	0.7	--	2.4	0.6	99.5
A2060	71.5	12.9	--	7.5	--	0.6	--	2.3	0.3	95.1
A2060	75.3	14.9	--	8.6	--	1.1	--	2.3	0.4	102.6
A2060W	55.0	12.1	2.8	1.1	4.3	7.4	--	14.3	2.3	99.3

TABLE 15 (continued)

Sample	Wt. %									Total Wt. %
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	
A2061	77.5	14.1	---	6.3	---	0.4	---	2.2	0.7	101.2
A2061	74.0	15.9	---	6.8	---	0.4	---	1.9	0.8	99.8
A2061	73.0	15.5	---	5.8	---	2.2	---	2.9	0.7	99.1
A2061	73.4	15.6	---	6.4	---	0.4	---	1.7	0.7	98.2
A2061W	55.8	12.5	2.7	1.1	4.4	7.7	---	14.6	2.4	101.2
A2064	54.1	12.2	2.8	9.5	1.6	2.7	---	6.6	0.9	91.2
A2064	57.5	9.3	3.3	3.3	---	5.0	---	11.0	0.9	91.5
A2064	54.0	11.2	3.0	3.3	0.8	8.1	---	12.0	1.7	95.8
A2064	57.4	11.4	---	5.5	1.1	8.0	---	9.7	2.4	99.8
A2064	52.5	7.7	---	4.4	---	2.0	---	19.0	8.0	93.9
A2064W	59.2	12.3	2.0	1.0	4.3	7.5	---	15.2	2.4	103.9
A2068	81.0	14.8	---	6.7	---	0.8	---	0.9	<0.2	105.0
A2068	78.8	13.1	---	6.2	---	0.7	---	1.4	0.6	101.1
A2068	71.5	14.2	---	5.2	---	1.1	---	1.7	0.4	94.8
A2068	80.0	12.5	---	6.1	---	0.3	---	1.1	0.3	100.3
A2068W	58.0	13.0	3.1	1.0	5.2	8.0	---	12.9	1.7	102.9
A2072	55.4	13.0	4.1	1.6	1.8	7.2	---	<0.1	1.7	98.1
A2072	50.0	14.6	4.8	3.0	1.8	5.0	---	0.3	2.3	97.7
A2072W	56.0	12.9	2.8	1.0	5.1	8.2	---	12.5	1.6	100.1
A2083	70.2	12.3	---	3.0	---	3.1	---	6.4	0.5	95.7
A2083	73.2	15.3	---	3.8	---	2.0	---	2.4	0.4	97.6
A2083	62.6	12.5	---	8.0	0.9	2.2	---	9.2	0.8	96.6
A2083W	54.5	12.9	2.8	0.6	5.3	8.1	---	14.3	1.6	100.1
A2087	71.5	12.1	---	6.3	---	1.7	---	4.9	0.6	97.4
A2087	74.4	13.9	---	3.2	---	1.8	---	5.3	0.8	98.9
A2087	71.5	12.1	---	5.5	---	1.8	---	4.3	0.8	96.4
A2087	68.6	12.1	---	2.5	---	2.3	---	7.3	0.4	93.5
A2087W	59.0	13.7	2.8	0.8	5.9	8.2	---	13.6	1.8	105.8
A2092	62.5	11.1	3.1	7.5	3.1	2.7	---	4.8	0.3	96.2
A2092	62.9	13.5	3.1	10.1	3.1	2.3	---	6.5	0.5	100.5
A2092	57.6	10.3	---	11.5	---	5.2	---	11.9	2.8	101.6
A2092	70.0	15.2	2.8	9.5	2.8	1.9	---	2.2	0.4	103.0
A2092W	52.0	12.6	2.8	0.9	5.3	7.9	---	12.6	1.6	95.7

TABLE 15 (continued)

Sample	Wt. %									Total Wt. %
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	
A2094	55.1	9.9	---	2.9	---	4.4	---	13.5	3.0	89.6
A2094	73.0	12.5	---	3.8	---	1.2	---	3.7	1.0	95.2
A2094	73.0	12.8	---	4.2	---	1.3	---	4.8	1.1	97.7
A2094	62.8	14.5	5.2	2.3	---	3.7	---	7.4	1.0	97.6
A2094W	55.0	12.9	2.9	0.7	5.0	8.2	---	12.4	1.7	98.8
A2097	72.2	12.4	---	12.2	---	0.8	---	3.7	0.6	101.9
A2097	67.5	15.0	2.9	2.5	---	3.0	---	4.4	0.4	95.7
A2097	69.1	10.9	3.8	3.9	---	3.5	---	13.6	2.0	106.8
A2097	64.7	14.2	---	10.8	---	2.8	---	5.0	0.4	97.9
A2097	81.5	13.2	---	8.8	---	1.2	0.3	0.3	---	105.3
A2097	64.0	15.0	5.8	8.2	0.5	3.0	0.3	6.0	0.4	103.2
A2097W	53.0	13.2	2.7	0.6	5.4	8.4	---	13.0	1.7	98.0
A2102	75.5	12.4	---	5.6	---	0.5	---	1.8	---	95.8
A2102	73.8	13.4	---	5.5	---	0.7	---	1.4	---	94.8
A2102	74.5	12.7	---	5.7	---	0.5	---	1.4	0.4	95.3
A2102	76.5	12.7	---	5.0	---	0.3	---	1.5	0.3	96.3
A2102W	52.5	13.2	2.9	0.7	6.0	7.9	---	12.1	1.7	97.0
A2109	47.6	11.7	---	4.3	---	2.6	---	23.4	8.0	98.7
A2109	72.6	12.5	---	8.5	---	1.4	---	1.8	---	96.8
A2109	70.1	11.8	---	4.4	---	3.6	---	3.2	1.1	96.2
A2109W	56.0	11.9	2.8	1.2	3.2	6.6	---	11.7	1.8	95.2
A2123	60.5	12.7	3.1	8.5	2.4	0.3	---	7.9	0.4	95.4
A2123	69.0	11.5	3.8	6.5	0.7	1.2	---	2.7	---	95.4
A2123	79.1	12.8	2.3	9.0	1.7	0.3	---	5.1	0.3	110.6
A2123	76.0	12.7	3.4	6.5	0.7	0.3	---	4.7	1.6	106.1
A2123W	54.0	12.4	3.1	1.0	5.7	7.8	---	12.2	1.8	98.0
A2133	45.8	10.7	3.0	3.0	5.7	5.3	0.3	16.1	1.9	91.9
A2133	56.1	13.0	5.5	5.7	1.5	4.6	0.3	9.7	1.9	98.4
A2133	50.1	13.2	5.2	4.0	0.9	4.9	0.3	10.5	2.2	91.4
A2133	52.2	14.1	4.1	5.1	1.7	5.6	0.3	9.2	2.3	95.5
A2133W	52.0	12.9	2.6	1.9	4.2	5.0	---	12.4	1.7	92.7

TABLE 15 (continued)

<u>Sample</u>	<u>Wt%</u>								
	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>MgO</u>	<u>CaO</u>	<u>BaO</u>	<u>FeO</u>	<u>TiO₂</u>
K5008	69.2	18.8	5.6	5.2	<0.3	0.4	<0.2	0.8	<0.2
K5008	64.7	23.0	5.3	5.3	---	1.0	---	0.6	---
K5008	77.6	14.1	2.3	4.3	---	0.3	---	1.4	---
K5010	76.7	13.4	2.1	4.2	---	1.5	---	1.7	0.3
K5010	76.5	14.3	2.5	4.5	---	0.7	---	1.3	0.3
K5010	71.8	16.3	4.6	4.4	---	0.5	---	2.1	0.3
K5013	76.8	16.2	<1.3	4.7	---	0.4	---	1.3	0.5
K5013	77.3	15.2	---	4.4	---	0.9	---	1.9	0.3
K5013	78.1	14.8	---	4.4	---	0.5	---	1.6	0.5
K5026	78.4	11.9	---	4.0	---	1.3	---	3.7	0.3
K5026	75.4	12.0	---	3.7	---	1.9	---	5.3	0.9
K5026	72.7	11.0	2.3	3.4	---	2.4	---	6.2	1.0
K5033	74.2	15.7	---	4.1	---	1.6	---	3.7	0.7
K5033	73.9	14.6	---	3.6	---	1.6	---	5.2	1.1
K5033	76.3	14.3	---	4.4	---	1.3	---	3.2	0.5
A1215	66.8	20.2	4.5	5.0	---	0.8	1.7	0.4	---
A1215	73.7	13.5	2.8	4.9	---	0.2	---	4.4	0.5
A1215	66.3	20.0	5.6	5.3	---	0.8	1.6	0.4	---
A1216	66.5	19.8	4.4	5.0	---	2.3	0.5	1.0	---
A1216	65.6	16.7	4.1	4.8	---	5.3	0.7	0.8	---
A1216	63.9	20.7	5.9	5.1	---	5.1	2.5	0.4	---
A1268	71.3	13.2	---	3.3	---	2.5	---	7.0	1.5
A1268	76.8	13.5	---	3.7	---	1.1	---	4.1	0.8
A1268	66.1	11.6	3.9	1.5	---	3.7	---	11.5	1.0

TABLE 15 (continued)

<u>Sample</u>	<u>Wt. %</u>								
	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>MgO</u>	<u>CaO</u>	<u>BaO</u>	<u>FeO</u>	<u>TiO₂</u>
Al278	77.0	12.7	---	3.7	---	2.8	---	1.7	0.5
Al278	78.9	12.8	---	4.1	---	1.4	0.5	1.5	0.5
Al278	80.1	12.6	---	4.5	---	0.9	---	1.5	0.2
Al281	70.8	17.5	5.1	2.8	---	1.0	---	2.7	0.2
Al281	75.4	12.5	2.9	4.4	0.7	0.3	---	3.9	0.8
Al281	72.3	13.0	3.0	4.3	0.7	0.4	---	4.3	0.7

crystallization of pyroxenes and/or olivines. Silica values are often higher in the residual groundmass liquid.

Accessory Minerals

Several accessory apatites were analyzed, and the unit cell contents are reported in Table 16. All but one of the apatites contained magnesium and all contained iron. The second apatite analysis from sample A2056 is unusually high in iron. The OH, F and Cl were assumed to be present. The microprobe does not obtain results on these anions.

The analyses of several mineraloids from samples K5026 and Al268 are given in Table 17. Note that the FeO and TiO₂ contents are relatively high in both mineraloid samples, and are probably present as hydrous oxides. Although it was not possible to obtain x-ray diffraction patterns of these materials, it is highly probable that there would be little crystallization evident. It should also be noted that the MgO content was relatively low for both mineraloids.

The accessory minerals in sample K5013 were unusual. The presence of high manganese spots at 500X, apparently embedded in feldspar crystals, was confirmed by a microprobe chemical analysis given in Table 18. These were excellent analyses of rhodochrosite, a manganese carbonate. The analyses showed that the rhodochrosite also contained appreciable amounts of calcium, iron, barium and magnesium substituting for manganese. In addition, there were several small areas that were high in barium and sulfur. The analysis contained too much extraneous material to allow direct computations, but 35.4 wt% SO₄ and 24.8 wt% BaO were included. It very probably represents barite (BaSO₄) admixed with other impurities. It is rather surprising to find these normally hydrothermal type minerals included in a flow unit. Nothing like this occurrence has been seen in the other samples. They must have formed at a late stage in flow cooling, comparable to the hydrothermal environment in which they are normally found, filling already-available spaces. A relatively high CO₂ pressure would be required to form rhodochrosite at an earlier stage in flow crystallization. With flow units as fluid as these supposedly were, it stretches the imagination to see how a high CO₂ pressure could be maintained. Barite, on the other hand, melts at 1580°C, and could conceivably exist, once formed under the proper redox potential, in the melt. In contrast, the dissociation pressure of rhodochrosite reaches one atmosphere at 540°C. Frank and Moynihan⁷, in fact, have suggested a magmatic origin for crystals of barite occurring in vesicles in a rhyolite porphyry.

TABLE 16. DDH-3 And Type Section Apatite Analyses

Electron Microprobe Analyses of Accessory Apatites Based on the Molecule $(\text{Mg,CaFe})_{10} (\text{PO}_4)_6 (\text{OH,F,Cl})_2$.

<u>Sample</u>	<u>$\Sigma\text{Mg,Ca,Fe}$</u>	<u>PO_4</u>	<u>$\Sigma\text{OH,F,Cl}$</u>
A2046	9.944	6.422	2.000
A2046	10.335	6.266	2.000
A2056	10.137	6.345	2.000
A2056	9.964	6.414	2.000
A2060	10.402	6.239	2.000
A2061	9.605	6.558	2.000
A2123	10.008	6.397	2.000
A2123	10.576	6.170	2.000
A2050	9.930	6.000	2.000
A2050	9.620	6.000	2.000
A2059	9.810	6.000	2.000
A2067	10.420	6.000	2.000
A2089	9.480	6.000	2.000
A2098	9.530	6.000	2.000
A2128	10.040	6.000	2.000
A2128	10.410	6.000	2.000
K5008	10.740	5.710	2.000
K5008	9.408	6.208	2.000
K5013	10.100	5.951	2.000
A1215	9.130	6.312	2.000
A1215	9.159	6.300	2.000
A1216	9.874	6.033	2.000
A1216	9.873	6.034	2.000
A1278	10.230	5.901	2.000
A1281	9.333	6.236	2.000
A1281	9.463	6.188	2.000

TABLE 17. Type Section Mineraloid Analyses

Mineraloid Compositions from Electron
Microprobe Chemical Analysis.

<u>Sample</u>	<u>Wt%</u>										
	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>MgO</u>	<u>CaO</u>	<u>FeO</u>	<u>MnO</u>	<u>TiO₂</u>	<u>S</u>	<u>P₂O₅</u>
K5026	37.2	14.2	3.2	0.4	<0.3	4.5	17.3	0.2	23.0	<0.04	<0.2
K5026	58.3	10.1	2.5	1.5	---	2.6	12.8	<0.1	11.1	0.1	0.9
K5026	34.2	5.9	2.7	1.0	---	1.6	27.3	0.3	26.7	---	0.3
K5026	56.8	10.0	2.4	1.4	---	3.3	15.1	0.2	9.9	0.2	0.7
Al268	13.5	3.6	<1.3	0.3	3.0	2.5	45.6	0.3	30.5	---	0.6
Al268	27.7	3.5	---	1.1	1.9	3.3	36.7	0.3	25.5	---	---
Al268	26.0	6.3	---	0.7	5.0	3.1	27.8	0.3	29.5	---	1.4
Al268	33.7	4.4	---	1.1	5.3	1.8	34.6	0.3	18.9	---	---

TABLE 18. K5013 Rhodochrosite Analyses

Electron Microprobe Analyses of Manganese Mineral in K5013.
The molecule used was (Mn,Ca,Fe,Ba,Mg) (CO₃).

<u>Sample</u>	<u>Ca</u>	<u>Mn</u>	<u>Fe</u>	<u>Ba</u>	<u>Mg</u>	<u>Cation Sum</u>	<u>CO₃</u>	<u>Mineral</u>
K5013	0.0872	0.7646	0.0272	0.0238	0.0970	0.9998	1.0001	Rhodochrosite
K5013	0.0698	0.6915	0.1287	0.0220	0.1229	1.0349*	0.9824	Rhodochrosite

Several iron sulfides were found. This type of an iron to sulfur ratio looks more like the sulfide globules found in the vesicles of several lavas by Moore and Calk. The sulfide globules represented samples of an immiscible sulfide liquid deposited upon cooling in the vesicles. The sulfides shown in Table 19 may represent immiscible sulfide liquids rather than pyrrhotites.

TABLE 19. DDH-3 Sulfide Analyses

Electron Microprobe Analyses of Sulfur-Containing Metallics Based on the Iron to Sulfur Mole Ratio.

<u>Sample</u>	<u>Fe</u>	<u>S</u>
A2059	0.99	1.00
A2067	0.79	1.00
A2089	0.89	1.00
A2105	0.82	1.00
A2128	0.82	1.00

Optical Photomicrographs

A = Reflected Light, 80X B = Transmitted Polarized Light, 80X
(The reflected and transmitted light photos are not of the same area.)

A2044

The reflected light photo shows a long, bladed metallics crystal, white in color. Skeletal growth is apparent in the smaller metallics crystals. The pyroxenes are an intermediate gray and the feldspars a darker gray color. The black patches are groundmass or altered olivine. In the transmitted light

photo, many twinned feldspar and untwinned pyroxene crystals can be seen. The black areas are metallics and glassy groundmass.

A2050

The white metallics in the reflected light photo tend to be equidimensional. The intermediate gray shades are pyroxenes, the darker gray crystals are feldspars, and the darkest areas are groundmass. Two generations of feldspar crystals can be seen in the transmitted light photo along with a few pyroxene crystals. The black areas are glassy groundmass and metallics.

A2053

The metallics are seen as small, white feathery crystals in reflected light. The feldspars and pyroxenes are light and dark gray, respectively, and the altered glassy groundmass areas are black. Feldspar crystals and patches of pyroxene, metallics and groundmass are visible in transmitted light.

A2059

White metallics, light gray pyroxenes, dark gray feldspars, and some darkest gray groundmass are visible. The larger crystal size of this sample is seen in the transmitted light photo. Black metallics and dark gray groundmass can be seen, as well as the lighter feldspars and pyroxenes.

A2067

Several relatively large, white metallics crystals are visible in reflected light. The darker gray feldspars and lighter pyroxenes also are much in evidence. There is glassy groundmass that has been altered and began to microcrystallize in concentric rings. The transmitted light photo also shows evidence of microcrystallinity in altered groundmass.

A2079

This is one of two samples which showed the iron and titanium to be rather well-dispersed, mostly throughout the groundmass. There are very small, white metallics crystals apparently visible in the reflected light photo, dispersed throughout the groundmass. These tiny crystals, if they are metallics, still effectively disperse the iron and titanium as can be seen in the x-ray emission photomicrographs of this sample. Two feldspar generations can be seen in the transmitted light photo.

A2089

Besides the usual feldspars, pyroxenes and metallics, the glassy groundmass and olivine shows evidence in reflected light of alteration and crystallization. Little of this can be seen on the transmitted light photo.

A2098

There is evidence again of alteration and crystallization of the dark gray glass in reflected light. Some of these areas may represent former olivine crystals.

A2105

The white metallics present several unusual configurations in reflected light. The groundmass has begun to crystallize again. The large crystal near the center of the transmitted light photo is probably a pyroxene.

A2116

This sample shows dispersed iron and titanium. Many of what appear to be very tiny metallics crystals are dispersed through the sample. The largest of these crystals is about 5 microns in length and less than 0.1 micron in width. The x-ray emission photos show an excellent iron and titanium dispersion throughout this sample at 200X. The large feldspar crystal shown in the transmitted light photo is interesting because it is not only zoned but also has included crystals of something else on an old growth surface.

A2128

Dark areas of altered glass areas are visible in reflected light. There is more than one generation of feldspars seen in transmitted light.

X-Ray Emission Photomicrographs

In general, examination of iron and titanium x-ray emission photos locate the metallics; aluminum and calcium locate feldspar; magnesium, iron and calcium locate pyroxenes; and potassium the glassy groundmass or altered areas where clays predominate. The large pyroxene in the lower left corner, for example, is probably pigeonite or hypersthene, based on its relatively low calcium content. From examining the titanium x-ray emissions, it can be seen that most of the high iron

A

80X

B

80X

A2044

A

80X

B

80X

A2050

A

80X

B

80X

A2053

A

80X

B

80X

A2059

A

80X

B

80X

A2067

A

80X

B

80X

A2079

A 80X

B 80X

A2089

A 80X

B 80X

A2098

A

80X

B

80X

A2105

A

80X

B

80X

A2116

A

80 X

B

80 X

A 2128

areas are probably pyroxenes and not metallics. The accessory apatite can be located by examining the phosphorus and calcium x-ray emissions. Any sulfides present can be located by the sulfur x-ray emissions. Note that both apatite and sulfides occur in this sample.

A2050

This is a well-crystallized area of the sample. There is only a small area of glass seen in the middle of the left edge on the potassium x-ray emissions. There is also a small area of metallics in the upper right. The calcium and aluminum X-ray emissions delineate the large feldspar crystals, while the iron and magnesium show the pyroxene areas between and below the feldspar crystals. There are several apatite crystals outlined by the photos of calcium and phosphorus x-ray emissions.

A2053

X-ray emission photos were not taken due to an instrument problem at the time. They could be taken now, but nothing unusual was noted in the mineral analyses. It probably is not worth going back to recover these.

A2059

This area shows an interesting assemblage of pyroxenes composed of low iron, gray-colored material and high iron, white-colored material. The magnesium x-ray emissions show that this whole area is pyroxene, and the iron emissions delineate the high and low iron areas. The titanium x-ray emission photo shows a small area of metallics. The manganese is concentrated in the pyroxene. A long crystal of apatite is located by the phosphorus and calcium photos, as well as some sulfide spots in the sulfur emission photo. Some feldspar is seen in the aluminum photo, and glassy groundmass in the potassium photo.

A2067

Two white metallics crystals occur in the upper left of the electron scattering photo as well as light gray pyroxene crystals and darker gray feldspars and groundmass. The aluminum photo locates the feldspars and the potassium photo the groundmass. A relatively large number of apatite crystals can be located on the calcium and phosphorus emission photos.

A2079

This is an area of one of the two samples which contained dispersed iron and titanium. Compare the iron and titanium photos with the x-ray emission photo of potassium. There is a hint of the very tiny metallics crystals apparently visible in the reflected light photomicrographs of this sample in the titanium emission photo. However, with the exception of the iron located in the pyroxenes, the titanium and iron are widely disseminated throughout the groundmass. This sample or A2116 would probably not be too difficult to recognize.

A2089

This area of A2089 is full of metallics crystals. Note the section line drawn across the metallics crystal in the upper left corner of the electron scattering photo. This is the metallics crystal traversed by Harvey Tenney, and the results are given in Figure 34 in the metallics section. The higher titanium band shows clearly in the titanium emission photo. Note also that manganese is concentrated in the metallics in this case, which prompted including manganese in the metallics chemical analyses. There are a few darker gray pyroxenes that can be located in the magnesium emission photo. Most of the rest of the sample area is feldspar, with a little groundmass and a few apatite crystals.

A2098

This area is interesting because of the large, embayed apatite crystal that bisects it. It is medium gray in color and can be located on the calcium and phosphorus emission photos. The pyroxenes are numerous and can be delineated on the iron and magnesium emission photos. The white metallics are easily located by use of the titanium and iron emission photos.

A2105

This area of A2105 is smaller than those of the other samples. The magnification was increased to 500X. The light gray metallics and darker gray pyroxenes take up most of the area. Note that the manganese is concentrated in both the metallics and pyroxenes. There are four spots of sulfides, but little else of interest.

A2116

This is an area in the other sample in which iron and titanium were dispersed. Comparing the potassium, iron and titanium

FIGURE 34. Traverse of a Metallic Crystal in Sample A2089. This Crystal is Shown in the Electron Scattering Photomicrograph for A2089

ELECTRON SCATTERING

200X

Fe

Ti

Ca

A2044

Mg

Si

Al

K

A2044

P

S

A2044

ELECTRON SCATTERING
200X

Fe

Ti

Ca

A2050

Mg

Si

Al

P

A2050

K

A2050

ELECTRON SCATTERING
200X

Fe

Ti

Ca

A2059

Mg

Si

Al

K

A2059

P

S

Mn

A 2059

ELECTRON SCATTERING
200X

Fe

Ti

Ca

A2067

Mg

Si

Al

K

A2067

P

Mn

A2067

ELECTRON SCATTERING
200X

Fe

Ti

Ca

A2079

Mg

Si

Al

K

A2079

P

A2079

ELECTRON SCATTERING
200X

Fe

Ti

Ca

A2089

Mg

Si

Al

K

A2089

P

Mn

A2089

ELECTRON SCATTERING

Fe

Ti

Ca

A2098

P

Si

Al

Mg

A2098

K

A2098

ELECTRON SCATTERING
500X

Fe

Ti

Ca

A2105

Mg

Si

Al

K

A2105

Mn

S

A 2105

ELECTRON SCATTERING
200X

Fe

Ti

K

A2116

Mg

Si

Al

Ca

A2116

ELECTRON SCATTERING

200X

Fe

Ti

Ca

A2128

Mg

Si

Al

K

A2128

distributions, note that there is little difference between them. The iron and titanium are even more thoroughly dispersed than in A2079. The dark gray crystals are feldspars and the lighter gray patches are pyroxenes.

A2128

The white areas in the electron scattering photo are metallics, the medium gray areas are pyroxenes; and the darker gray areas are feldspars with a little glassy groundmass outlined by the x-ray emission of potassium.

SECONDARY MINERALIZATION

DDH-1 Core Well

Most of the minerals identified in the core samples were clay minerals. The clays were treated for identification in several steps as follows:

1. an oriented mount on a glass slide was made using a slurry from a dispersion of the as-received sample;
2. the clay was allowed to dry at room temperature;
3. a diffractogram was made and recorded of the sample slide;
4. d spacings shown on the diffractogram were labeled and identified;
5. the same slide was then contacted with ethylene glycol and warmed;
6. a diffractogram was taken of the glycolated slide (the montmorillonite group of clay minerals shows a strong peak at 17 Å);
7. d spacings shown on the diffractogram were labeled and identified;
8. if a montmorillonite family clay was identified in step 7, a small quantity was based with potassium ions;
9. a diffractogram of the potassium-based montmorillonite family clay slide was obtained;

10. d spacings shown on the diffractogram were labeled and identified.

In step 10, a normal montmorillonite does not show a potassium-based peak at a position much different from the 14 to 15 Å peak of the original as-received clay slide. Nontronite, on the other hand, collapses to 12 to 14 Å and does not move to 17 Å when glycolated as does a normal, potassium-based montmorillonite. With a little heating, the potassium-based nontronite collapses to the 10 Å illite spacing, and will not rehydrate or expand.⁹

The above sequence was that normally used to identify clays of the montmorillonite group. With the mixed-layer clays, the 17 Å peak is obtained upon glycolation if montmorillonite is a constituent. Special heat treatment is necessary to identify components other than montmorillonite in the mixed-layer clays. Mechanical mixtures of clay minerals are easier to identify than the mixed-layer clays because of all of the diagnostic d spacings of the reflection planes appear in their normal positions.

Calcite, quartz, and the zeolites, or other nonclay minerals, were identified from the positions of the reflecting planes of the as-received diffractogram.

Perhaps a short review of the mineralogy of the smectite group would help to orient the reader as to the reasoning behind the identification methods used here. First of all, the clays in the montmorillonite group are all three layer clays as shown in Table 20. Cation substitutions can occur both in the octahedral and tetrahedral layers. There are three

TABLE 20

Stacking Sequence of 3-Layer Clays.

Tetrahedral layer
Octahedral layer
Tetrahedral layer

Interlayer Cations + Water

Tetrahedral layer
Octahedral layer
Tetrahedral layer

Interlayer Cations + Water

end members within the smectite group, defined by their types of substitution, as shown in Table 21. Certain special cases occur such as Hectorite, under the end members. A so-called solid solution between any of the end members can occur. Montmorillonites are typical glass weathering products formed under conditions of poor drainage, an alkaline chemical environment and semi-arid climatic conditions. Zeolites may be formed under the same conditions depending upon alkaline environment, salinity and glass composition.

TABLE 21

Smectite Group Minerals

I. Montmorillonite

A) Al, Mg in octahedral positions

B) All Si in tetrahedral positions

1) Hectorite

a) Li, Mg in octahedral positions

b) All Si in tetrahedral positions

II. Beidellite

A) All Al in octahedral positions

B) Al, Si in tetrahedral positions (up to 25% Al)

III. Nontronite

A) Fe, Al in octahedral positions

B) Al, Si in tetrahedral positions (up to 25% Al)

1) Saponite

a) Al, Mg in octahedral positions

b) Al, Si in tetrahedral positions
(up to 25% Al)

Most montmorillonite group clays contain various amounts of interlayer water, leading to a variety of interspacings between the tetrahedral-octahedral-tetrahedral layers. The result on the as-received sample x-ray diffraction pattern is a broad basal reflection or peak from 10 to 20 Å in width. If the water is replaced by another polar molecule, ethylene glycol, a distinctive reflection occurs at 17.0 Å, indicative of a montmorillonite group mineral only.

Two factors are known to promote collapse in three-layer clays. These are a high degree of substitution in the tetrahedral layer and a high potassium ion interlayer population. If a nontronite is potassium-based, it collapses at room temperature almost immediately to a glycolated spacing of 12 to 14 Å. With a little heating, the nontronite will completely collapse to the 10 Å illite spacing, and will not rehydrate or expand. A beidellite also should show the same behavior, but beidellites are very rarely encountered, requiring a very magnesium and iron-deficient environment for their formation. Hence, any potassium-based montmorillonites from the cores that show room-temperature collapse are almost certainly nontronites.

Nontronite is known throughout the Columbia River region of Washington, Idaho and Oregon.¹⁰ It is formed chiefly from basaltic glass with minor amounts from augite and iddingsite. Palagonite formation (late stage hydration of basaltic glass by steam) is believed to be an intermediate step in nontronite formation but is not always a prerequisite. Weathering of the basaltic glass under alkaline conditions with poor drainage is considered essential for formation. Relatively large, lathe-like nontronite crystals are common, unlike most of the montmorillonites formed as weathering products. The color varies from yellow-green to dark green and is directly related to the iron content unless there has been iron adsorbed on the clay surfaces. The nontronite forms at the edges of pillows, within basalt fissures and cracks and on flow surfaces where unstable glass is present.

Nontronite occurs at Garfield, Washington, in large masses at vein intersections surrounding blocks of weathered basalt. At Manito, Washington, veins of yellow-green nontronite fill joint cracks and intersections in basalt. Nontronite is common in Spokane area weathered basalt, and is also known from Colfax and Excelsior, Washington. The iron contents vary from 25 to 40% ferric iron. Nontronites are usually calcium-based with sodium very low and very little, if any, potassium.

TABLE 22

Mineralogy of Core Samples From DDH-1 Well

Feet	Description	X-Ray Diffraction Fraction	
		As-received sample	K-based, glycolated sample
178.0 ft	Loose, white rock included in basalt flow	quartz	--
185.0 ft	Alteration on high angle fractures	broad basal peak	nontronite
189.0 ft	Basalt surface alteration	feldspar, broad basal peak	montmorillonite
192.5 ft	Basalt surface alteration	feldspar, illite, broad basal peak	montmorillonite
202.5 ft	Altered tuff	quartz, feldspar, broad basal peak	montmorillonite
214.0 ft	Sandy clay	quartz, feldspar, illite, broad basal peak	montmorillonite
236.0 ft	Clay	broad basal peak, illite	montmorillonite
237.0 ft	Sandy clay	broad basal peak, quartz	montmorillonite
242.5 ft	Clay	broad basal peak, quartz	montmorillonite
244.0 ft	Olive-gray sandstone	feldspar, broad basal peak, quartz, illite	montmorillonite
245.0 ft	Loose sand	feldspar, quartz, illite, broad basal peak	montmorillonite
248.0 ft	Light gray sandy clay	feldspar, quartz, illite, broad basal peak	montmorillonite
251.0 ft	Scoreaceous basalt filling	calcite, feldspar, broad basal peak	montmorillonite
254.0 ft	Altered basalt	broad basal peak, quartz, illite	montmorillonite
264.5 ft	Altered basalt with filled vesicles	feldspar, broad basal peak	montmorillonite
271.0 ft	Green basalt fracture filling	broad basal peak	nontronite
273.0 ft	Green basalt fracture filling	broad basal peak	nontronite
275.0 ft	Basalt vug filling	calcite	--
283.0 ft	Basalt vug filling	calcite	--
285.0 ft	Black, sooty material in basalt vugs	broad basal peak, calcite	montmorillonite
295.0 ft	Basalt vug filling	broad basal peak	montmorillonite
312.0 ft	Basalt fracture alteration	broad basal peak	nontronite
328.0 ft	Basalt fracture filling	broad basal peak	nontronite
356.0 ft	Altered upper basalt contact	broad basal peak, quartz, feldspar, illite	nontronite
442.0 ft	Altered upper basalt contact	broad basal peak, quartz, feldspar, illite	montmorillonite
450.0 ft	Gray clay	broad basal peak, quartz, illite	montmorillonite
454.0 ft	Light gray clay	broad basal peak, quartz, mica, feldspar	montmorillonite
457.0 ft	Gray sandy clay	broad basal peak, quartz, mica, feldspar	montmorillonite
460.0 ft	Gray clay	broad basal peak, quartz, feldspar	montmorillonite
464.0 ft	Breccia interclay	broad basal peak, quartz	montmorillonite
473.0 ft	Basalt vug filling	broad basal peak	nontronite
480.2 ft	Basalt fracture filling	broad basal peak	nontronite
488.0 ft	Basalt fracture filling	broad basal peak	nontronite
491.5 ft	Basalt vesicle filling, black	broad basal peak	nontronite
520.0 ft	Basalt fracture filling	broad basal peak	nontronite
560.0 ft	Basalt fracture filling	broad basal peak	nontronite
594.0 ft	Metallics in basalt vug	Pyrite, some feldspar	--
610.0 ft	Basalt fracture filling	broad basal peak, calcite	nontronite
635.0 ft	Basalt fracture filling	broad basal peak	nontronite
654.0 ft	Basalt fracture filling	broad basal peak, illite, chlorite, quartz	mixed-layer silicates
666.0 ft	Clay	broad basal peak, feldspar	montmorillonite
668.0 ft	Altered and mineralized basalt	broad basal peak, chlorite	montmorillonite
671.0 ft	Basalt fracture filling	broad basal peak	nontronite
677.0 ft	Basalt fracture filling	broad basal peak	nontronite

TABLE 22 (continued)

Feet	Description	X-Ray Diffraction	
		As-received sample	K-based, glycolated sample
709	Basalt fracture filling	montmorillonite	nontronite
718.2	Top of flow	montmorillonite, mica, feldspar	nontronite
764.5	Basalt fracture filling	montmorillonite	nontronite
797	Gray tuff	quartz, feldspar, mica, vermiculite	--
805	Pale green volcanic tuff	quartz, feldspar, mica, vermiculite	--
812	Dark green tuff	quartz, feldspar	--
833	Sandy clay	quartz, feldspar, illite-chlorite	--
850	Sandy clay	quartz, vermiculite-chlorite, feldspar	--
854	Vantage sand	quartz, feldspar, mica	--
872.5	White clay	vermiculite, quartz, feldspar	--
880.5	Sandy clay	quartz, vermiculite-chlorite, feldspar	--
887	White clay	quartz, vermiculite-montmorillonite	--
896	Green to brown clay	feldspar, vermiculite-montmorillonite	--
903	Green clay	vermiculite-montmorillonite, α -crystobalite	--
927	Fracture filling	vermiculite	--
935	Gray clay interbed	feldspar	--
956	Basalt fracture filling	montmorillonite	nontronite
959	Tuff interbed	quartz, chlorite-illite, feldspar	--
996	Basalt fracture filling	quartz, montmorillonite-vermiculite	--
1026	Basalt fracture cementing	quartz, montmorillonite-vermiculite	--
1064.5	Opaque white vug filling	α -crystaboliite	--
1064.5	Clear drusy crystals	calcite, pyrite	--
1064.5	Black altered basalt	feldspar, illite	--
1064.5	Vug filling	montmorillonite, vermiculite	nontronite
1067	Weathered basalt contact	montmorillonite, feldspar	nontronite
1112	Weathered flow breccia	montmorillonite, vermiculite, feldspar	nontronite
1163	Mineralized flow breccia	feldspar	--

It was deemed advisable, because of the known prevalence of nontronite in weathered Eastern Washington basalts, to check all smectite group clays in the cores for nontronite.

The most obvious trend in DDH-1 well samples is the prevalence of nontronite as a product of basaltic glass weathering on joint planes and fissures. The mineralogy changed as the sampling crossed into cores from the top of the Vantage formation at about 797 feet. At this point montmorillonite prevailed along with vermiculite and several mixed-layer clays. The siliceous nature of the tuffs also was obvious with abundant quartz in several beds. A single instance of a small amount of α -cristobalite was found at 903 feet. Cristobalite was also identified as filling vugs in a basalt at 1064.5 feet. Zeolites were not found in this second group of cores from DDH-1, although calcite vug filling was noted.

DH-2 Core Well

Comparing the results from DH-2 cores with previously reported results from DDH-1, several features are outstanding and may be summarized as follows:

1. weathering of the basalt along joints and fissures results in nontronite or nontronitic clay minerals,
2. due to leaching from the interbeds, silica was prevalent during basalt-interbed weathering,
3. weathering of interbeds resulted in formation of montmorillonites and mixed-layer silicates,
4. secondary minerals within basalt vugs were calcite, quartz, nontronite and pyrite.

Nontronite in the basalts was formed chiefly from basaltic glass with minor alteration of iddingsite and augite. Palagonite (hydrated, basaltic composition glass) is an intermediate step in the alteration of basalt to nontronite, and resulted when the lava gas quenched in a hydrous environment. Alkaline conditions with poor drainage complete the alteration of palagonite to nontronite.

During the course of this x-ray identification of core minerals, several samples containing relatively young silica precipitates that would be normally identified as opal or chert were found. Several of these samples were identified as α -cristobalite, the first phase encountered in the crystallization of a silica gel at room temperature to quartz. The

TABLE 23

Mineralogy of samples from DH-2 cores

Feet	Description	X-Ray Diffraction	
		As-received	Clay Minerals
51	tuff interbed	strong montmorillonite	montmorillonite
52	clay in vugs	montmorillonite	nontronite
52.5	crystals in vugs	calcite	
62	basalt fracture filling	montmorillonite	nontronite
72	basalt fracture filling	montmorillonite	nontronite
104	basalt fracture filling	montmorillonite	nontronite
169.5	fused tuff	glass	
170	baked tuff	feldspar, montmorillonite	montmorillonite
179	shiny clay vug filling	strong montmorillonite	nontronite
198	basalt fracture filling	montmorillonite	nontronite
225	basalt fracture filling	strong montmorillonite	nontronite
233	basalt fracture filling	montmorillonite	nontronite
356	basalt vein filling	quartz, calcite	
374	basalt vein filling	quartz, calcite	
404	altered tuff	montmorillonite, quartz	montmorillonite
409	tan to gray clay	montmorillonite-chlorite	
414	sandy tan clay	montmorillonite, feldspar, quartz	montmorillonite
425	sandy white clay	quartz, feldspar, mica	
435	silt-clay	quartz, feldspar, montmorillonite-illite-chlorite	
445.5	brown clay	strong montmorillonite	montmorillonite
459	gray clay	poorly crystallized montmorillonite	montmorillonite
464	green clay	montmorillonite, feldspar	montmorillonite
472	top of green clay	montmorillonite, feldspar	montmorillonite
481	white basal Mabton	montmorillonite	montmorillonite
481.1	top of basalt	poor α -cristobalite (opal)	
481.2	basalt fracture filling	strong montmorillonite	nontronite
531	basalt fracture filling	strong montmorillonite	nontronite

silica very likely originated during late stage flow cooling reactions.

Interbeds must have weathered under nearly the same alkaline, poor drainage conditions as the basalts because the resulting clay minerals were mostly montmorillonites. There were positive differences in the clay mineralogy of the interbed series in ARH-DC-1 from about 800 to 900 feet and the series in DH-2 from about 400 to 480 feet. The DH-2 series were characterized as predominantly montmorillonite with some montmorillonite-illite and montmorillonite-chlorite mixed layer silicates. The DDH-1 series, on the other hand, was chiefly montmorillonite-vermiculite mixed layer silicates. Nontronites did not occur in the interbed cores.

Secondary minerals within basalt vugs were chiefly calcite and secondary nontronite with some quartz and pyrite. No zeolites were identified in any of the cores. A study of side-wall cores from the original Rattlesnake Well identified several zeolites but chiefly below 2000 feet in depth.

DDH-3 Core Well

In choosing the DDH-3 samples, particular attention was paid to the late-stage mineralization of the basalts, weathering of the basalts and interbed mineralization due to weathering and resulting migration of ions. Alteration of one type or another was apparent throughout the section examined. Very thin alteration layers, chiefly of nontronite-beidellite, were identified even on joints and cracks of the fresh basalt. Two possibilities for the origin of these thin nontronite layers on fresh basalt joints are: 1) formation of the nontronite elsewhere in the section with migration into the joints and cracks of the fresh basalt; and 2) formation of nontronite in situ as a result of alteration of palagonite formed on fresh basalt surfaces during cooling. Alkaline solutions and poor drainage are required for nontronite formation in both cases.

The latter mode of formation of the nontronite is probable on the joints of fresh basalt examined. The thickness of the nontronite in a given area of jointing is approximately the same, and the color is always a very dark green to black which would typify a weathered, iron-bearing, poorly oxidized basaltic glass. The nontronites formed in a more oxidizing environment are lighter green to bluish in color as a function of the oxidation state of the admixed iron. There is obviously movement of nontronite as well, because the vesicular basalts often show nontronite as a vug filling associated with calcite

and quartz. In any case, the presence of nontronite, an iron montmorillonite with a cation exchange capacity of 70 to 100 milliequivalents per gram, on the joints and cracks of fresh basalt enhances the basalt use as a radioactive storage medium. Even if the stored radioactive wastes were able to migrate into cracks and joints of fresh basalt, the nontronite would act as a sealant and a cation exchanger. The sealing action would occur if sodium containing wastes came in contact with the normally calcium-based nontronite, causing the nontronite to exchange calcium for sodium and expand to effectively block the further flow of waste into the basalt joint or crack. It may be worthwhile to do some work on this aspect of waste migration through the fresh basalt to show that the above sealing action does occur, and obtain some measurements of the rates of migration of specific cations.

Quartz and alpha, or low-temperature, cristobalite occurs throughout the section. The α -cristobalite would be called "opal" in a field identification. In the past, opal was characterized as an amorphous silica gel. X-ray diffraction studies have shown, however, that opal is a submicro-crystalline aggregate of cristobalite containing nonessential water and other cations. The rate of conversion from a true silica gel to cristobalite is sensitive to the presence of alkalis and other cations in the wet gel. These ions are often held in the cristobalite structure, causing it to persist metastably for long periods of time rather than converting to quartz, its stable, low-temperature phase. The solubility of the cristobalite phase at room temperature in most surface waters is about 120 mg/l compared to 7 mg/l for quartz¹¹, accounting in part for the presence of this form of silica throughout the section represented by the well cores. Calcite, on the other hand, rapidly disappeared below 1000 feet in depth.

No zeolites were identified in the core samples to 1200 feet in depth. The zeolites begin to appear in the section at about 1300 feet and occurred through the section to the lowest depths sampled. Heulandite was the first zeolite identified. Heulandite, of course, belongs to the heulandite-clinoptilolite series which varies in silica/alumina ratio from about 5.4 to 10. Clinoptilolite and heulandite are difficult to distinguish in x-ray diffraction patterns. The relative intensities of the 9.0 Å and 4.0 Å peaks were used to distinguish between the two; clinoptilolite has the larger 4.0 Å peak and heulandite the larger 9.0 Å peak. This is not an infallible technique, but other methods such as cation exchange differences and chemical analyses are too expensive and time-consuming.

A single sample containing mordenite was found at 2894 feet and two samples containing gmelinite at 2426 and 2442 feet.

Besides montmorillonite and nontronite-beidellite, several illite and mixed-layer montmorillonite-illite containing samples were collected. The section is characteristically montmorillonite and nontronite for clay minerals, with the montmorillonite occurring in the interbeds and sometimes at basalt flow interfaces; and the nontronite resulting as a weathering product of palagonite. There was some movement of the latter into basalt vesicles from the joints and cracks where the palagonite formed originally. There are usually admixed iron and other oxides with the nontronite that give it a shiny, black to blue color rather than the usual light green. Only one chlorite, at 2373 feet, was identified. Despite the green color of many of the basalt alteration products, chlorites are quite rare. The clay minerals simply cannot be identified from a visual examination with any degree of certainty. The same may be true for the zeolites which can have several different crystal habits, or not even appear to be crystalline.

According to Raymond and Tillson¹², the Rattlesnake Hills No. 1 Well samples gave evidence of a zeolite zonal distribution with clinoptilolite-heulandite prevalent to the 8000 feet and laumontite the predominant zeolite below 8000 feet. Several other instances of zeolite zonal distribution with depth are given in the literature^{2,3}. Several types of deposits were involved, but the general sequence was clinoptilolite-heulandite-mordenite on the upper end of the section grading into analcime and then into a laumontite zone. There are some variations in this sequence as a function of original rock type, but the above general sequence seems to hold fairly well for any rock type. The primary cause of the zeolite zonal sequence is probably the temperature-pressure relationships as a function of depth since silica, alumina, the alkalies and alkaline earths are usually always produced as a result of late-stage activity of nearly any original rock type. The analcime is missing from the DDH-3 zonal sequence, probably because a much higher concentration of sodium cations than alkaline earth metal cations is required for analcime formation. The weathering environment of a basalt series is probably too high in Ca^{+2} and Mg^{+2} to be amenable to analcime formation. The rare gmelinite and phillipsite are not typical zeolites in the basalt sequence, and probably resulted from some unusual local variations in the chemical environment. The 3280 feet of cores from DDH-3 are still in the upper part of the zeolite zonal sequence for the Rattlesnake Hills No. 1 Well reported by Raymond and Tillson¹². Only the clinoptilolite-heulandite zone was penetrated by DDH-3 coring to 3280 feet.

TABLE 24

Results of Examination of the
Core Samples from DDH-3

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
233	Green alteration in vugs and on joints of basalt	Montmorillonite	Good Nontronite
261	Dark green joint alteration in fresh basalt	Montmorillonite	Nontronite
288	Thoroughly altered basalt	Montmorillonite	Good Nontronite
304	Vug filling in basalt	Calcite, little Montmorillonite	Nontronite
353	Alteration on steep joints of fresh basalt	Montmorillonite	Nontronite
355	Clay derived from altered basalt	Montmorillonite	Good Nontronite
368	White vug filling in fresh basalt	Calcite	----
383	Joint alteration in fresh, vuggy basalt	Calcite, some Montmorillonite	Nontronite
416	Joint alteration on fresh, steeply jointed basalt	Montmorillonite	Nontronite
457	Bottom of an altered basalt zone	Montmorillonite	Nontronite and Montmorillonite
460	Top of interbed clay, light gray	Montmorillonite, quartz	Montmorillonite
475	Dark gray clay	Montmorillonite, quartz	Good Montmorillonite
477	Variegated light and dark clay	Montmorillonite, calcite	Montmorillonite
480	Gray-green clay	Poor Montmorillonite	Montmorillonite
482	Light gray clay	Poor Montmorillonite	Montmorillonite
487	Greenish clay with basalt fragments	Poor Montmorillonite	Montmorillonite
506	Bluish vug filling in fresh basalt	Montmorillonite	Good Nontronite

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
596	Black joint alteration on fresh basalt	Montmorillonite	Good Nontronite
636	Vertical joint alteration on fresh basalt	Montmorillonite	Good Nontronite
645	Vertical joint alteration on fresh basalt	Montmorillonite	Good Nontronite
671	Light gray clay on top of interbed	Some Montmorillonite	Montmorillonite
677	Green clay from altered basalt	Montmorillonite	Nontronite
696	Clay mixed with altered basalt	Montmorillonite	Nontronite
707	Green clay admixed with basalt fragments	Some Montmorillonite	Nontronite
711	Alteration on basalt joints and fractures	Montmorillonite	Nontronite
723	Quartz or calcite mineralization on fresh basalt joints	Calcite	----
769	Light gray clay on top of interbed	Montmorillonite, Quartz	Montmorillonite
779	Light gray variegated clay interbed	Poor Montmorillonite, Montmorillonite Calcite	
796	Light gray clay interbed	Montmorillonite	Montmorillonite
806	Light green clay interbed	Montmorillonite	Good Montmorillonite
817	Tan clay mixed with basalt fragments	Montmorillonite	Good Montmorillonite
833	Dark green clay of interbed	Montmorillonite	Good Montmorillonite
842	White lenses in green clay interbed	Calcite, poor	Montmorillonite
842	Green clay interbed	Montmorillonite	Nontronite - Montmorillonite

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
858	Clay lenses in basalt	Montmorillonite	Montmorillonite- Nontronite
862	White clay filling in vugs in basalt	Montmorillonite	Montmorillonite
873	Quartz(?) fracture and vug filling in fresh basalt	Calcite	----
928	Vertical joint mineralization in fresh basalt	Montmorillonite	Nontronite
981	Quartz(?) fracture filling	Quartz, calcite	----
1096	Shiny black coating on fresh basalt joints	Poor Montmorillonite	Nontronite
1137	Light green clay bed	Quartz, minor mica and feldspar, mostly glass	----
1153	Green clay bed	Feldspar, minor montmorillonite, glass	Montmorillonite
1216	Black fissure coating on fresh basalt	Little crystalliza- tion, mostly palagonite	----
1298	Top of clay interbed	Montmorillonite	Montmorillonite
1300	Light gray clay	Good Montmorillonite	Montmorillonite
1309	Gray, sandy clay	Montmorillonite, illite	Montmorillonite, illite
1311	Black, micaceous sand	Good illite	Illite
1325	Altered flow breccia	Good Montmorillonite	Montmorillonite
1334	Altered basalt	Montmorillonite, Heulandite	Montmorillonite
1348	Crystals in vuggy basalt	Heulandite	----
1373	Mineralization in basalt	Quartz	----
1401	Fresh basalt joint coating	Montmorillonite	Nontronite
1428	Mineralization on fresh basalt fractures	Quartz, Montmorillonite	Nontronite

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
1437	Black coating on fresh basalt fractures	Quartz, Montmorillonite	Nontronite
1461	Fresh basalt fracture mineralization	Quartz, Montmorillonite	Nontronite
1477	Secondary mineralization in vuggy basalt	Good Montmorillonite, Heulandite	Nontronite
1486	Nodules in vuggy basalt	Quartz, α -cristobalite	----
1491	Silica in vuggy basalt	α -cristobalite	----
1540	Vug filling in basalt	Quartz	----
1580	Altered basalt flow breccia	Feldspar, no clays indicated	----
1608	Mineralized basalt flow breccia	Good Montmorillonite, minor Heulandite	Nontronite
1663	Shiny black on fresh basalt fractures	Good Montmorillonite	Nontronite
1692	Altered basalt flow breccia	Feldspar, minor Montmorillonite	Nontronite
1718	Black mineral in vugs of fresh basalt	Good Montmorillonite	Nontronite
1752	Altered, vuggy basalt flow breccia	Clinoptilolite, minor Montmorillonite	Montmorillonite
1773	Mineralization on fresh basalt joints	Heulandite	----
1799	Mineralized, vuggy basalt flow breccia	Montmorillonite, minor Mica	Montmorillonite
1809	Bluish vug filling in fresh basalt	Quartz, minor Montmorillonite	Nontronite
1831	Black vug filling in fresh basalt	Hydrated iron oxides, little crystallization	----
1858	Black alteration on joints of fresh basalt	Good Montmorillonite	Nontronite
1868	Alteration of joints of fresh basalt	Minor Montmorillonite, little crystallization	Nontronite
1917	Small gray crystals on black vug filling in basalt	Heulandite, minor Montmorillonite	Nontronite

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
1921	Large phenocryst in fresh basalt	Hypersthene(?) (closest match of pattern)	----
1935	Joint mineralization on fresh basalt	Quartz	----
1957	Crystals in vuggy basalt with a black mineral	Heulandite, Montmorillonite	Nontronite
1962	Vuggy basalt containing small crystals	Heulandite, minor Montmorillonite	Nontronite
1964	Blue clay in basalt vugs	Montmorillonite	Nontronite
1992	Small crystals in vuggy basalt	Heulandite	----
2009	Black vug filling in basalt	Little crystallization	---
2-26	Altered and mineralized basalt	Good Montmorillonite, minor Heulandite	Nontronite
2031	Medium-sized crystals in altered basalt vugs	Heulandite	----
2038	Altered basalt in a flow breccia zone	Montmorillonite	Montmorillonite
2048	Clay on heavily altered basalt joints	Montmorillonite	Nontronite
2074	Shiny black joint alteration on fresh basalt	Montmorillonite	Nontronite
2098	Black alteration on fresh basalt joints	Montmorillonite	Nontronite
2138	Black vug filling in fresh basalt	Good Montmorillonite	Nontronite
2166	Blue vug filling in fresh basalt	Illite	Illite
2183	Shiny black coating on fresh	Good Montmorillonite	Nontronite
2198	Mineralized flow breccia	Minor feldspar and quartz, little crystallization	----
2203	Bluish alteration at base of flow	Minor Montmorillonite	Nontronite
2224	Crystals in vuggy basalt	Heulandite	----
2230	Blue clay alteration on vuggy basalt fractures	Illite	Illite

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
2252	Green material in altered basalt	Clinoptilolite, minor illite-montmorillonite	Mixed layer clay
2252	Material associated with above	α -cristobalite, illite-montmorillonite	Mixed layer clay
2267	Minerals in fresh basalt vugs	α -cristobalite, Heulandite	----
2286	Green mineral on vuggy fresh basalt joints	α -cristobalite, minor Illite	Illite
2338	Green and white minerals on altered basalt joints	α -cristobalite, minor Heulandite	----
2373	Dull black mineral in	14 Å chlorite	----
2390	Silica in vugs of fresh	Quartz	----
2426	Soft, white mineral in vugs of fresh basalt	Gmelinite	----
2442	Hard, white vug filling in fresh basalt	Gmelinite	----
2578	Small crystals in basalt vugs	Heulandite	----
2592	Bluish crystals in fresh basalt vugs with pyrite	Heulandite, minor Montmorillonite	Nontronite
2606	Mineralized basalt flow breccia	Montmorillonite, minor Heulandite	Montmorillonite
2697	Joint mineralization on fresh basalt	Montmorillonite	Nontronite
2713	Alteration on joints of fresh basalt	Montmorillonite	Nontronite
2721	Joint alteration on fresh basalt	Montmorillonite	Nontronite
2768	Nodule in vug of fresh basalt	Quartz	----
2797	Honeycomb-like mineralization in basalt cavity	Quartz	----
2809	Altered basalt on top of flow	Feldspar, minor Montmorillonite	Montmorillonite
2828	Opal on joints of fresh basalt	α -cristobalite	----

TABLE 24 (continued)

<u>Feet</u>	<u>Description</u>	<u>X-ray Diffraction</u>	
		<u>As-received</u>	<u>Clay Minerals</u>
2858	Light blue crystals in basalt vugs	Heulandite	----
2866	White vug filling in horizontally jointed basalt	Clinoptilolite	----
2894	Fibrous, white vug filling associated with quartz	Mordenite	----
2932	Felty, crystalline vug filling in fresh basalt	Clinoptilolite	----
2943	Opal in vuggy fresh basalt	α -cristobalite	----
2977	Footy black vug filling in fresh basalt	Good Montmorillonite	Nontronite
2997	Chalky white vug filling with quartz	α -cristobalite	----
2997	Small crystals filling same	Heulandite	----
3007	Opal or quartz in vugs	α -cristobalite, minor Quartz	----
3013	Crystalline vug filling in fresh basalt	Heulandite	----
3071	Small crystals in vugs	Heulandite	----
3141	Altered basalt near flow base	Minor Feldspar, little crystallization	----

A total of four calcite samples were selected from DDH-3 well at 304 feet, 368 feet, 723 feet and 873 feet. These particular samples were selected both to determine the feasibility of using calcite to distinguish between hydrologically distinct calcite generations and because they were free of inclusions of foreign mineral matter that would invalidate the chemical analysis by electron microprobe. The trace elements used to identify the various calcite generations, or lack of them, must be present in the lattice of the calcite, and not as coatings or admixtures of other minerals.

To put the following trace element substitutions into perspective, some review on calcite substitutions is in order. Most calcite is relatively free of divalent cations other than calcium, although many other cations may partially replace calcium. Magnesium is one of the most common substitutes for calcium. Up to 9 molecular percent magnesium has been found to substitute for calcium in calcites associated with dolomites. Manganese is also a common substitute for calcium. Up to 42% manganese has been found substituting for calcium in natural calcites. Synthetic calcites have been made with a maximum of 15% manganese substituting for calcium.

The substitution of iron is also fairly common. Up to 10 molecular percent iron has been reported substituting for calcium in natural calcites. Other calcium substituting cations include strontium, barium, zinc, cobalt and lead.

Many studies have been made to find the relationships between calcite content of iron, copper, manganese, strontium, and magnesium and calcite color, all without success. Work with calcite fluorescence in ultraviolet light has shown an increasing pink intensity up to 3.3 molecular percent MnCO_3 . All of the four calcites from DDH-3 should give a pink fluorescence in ultraviolet light since they vary from 1.66 to 7.06 wt.% in manganese content.

The electron microprobe chemical analyses of the calcite samples are given in Table 25. These analyses are the same as those reported by the analyst; however, they have been recalculated to 100%. Recalculating entails obtaining a value for X in the equation $100/\text{total weight percent} = X$. If we multiply each constituent weight percent by X, the total weight percent is automatically corrected to 100% with the oxide constituents maintaining their same relationship as in the original analysis. Nothing is changed by this procedure but the total. If the original analysis was good, it remains good, while if the analysis is poor, it remains poor. The important factor in any analysis is not the weight percent total, but the molar

TABLE 25

Microprobe Chemical Analyses
Corrected to Total 100 Percent

<u>Oxides, Weight %</u>					
DDH-3 <u>Sample, ft.</u>	<u>CaO</u>	<u>MgO</u>	<u>MnO</u>	<u>FeO</u>	<u>CO₂</u>
304	46.36	2.79	7.06	<0.1	43.79
304	45.73	3.54	6.80	<0.1	43.94
304	48.61	2.74	4.66	<0.1	44.00
368	52.11	0.98	2.45	1.66	44.47
368	52.64	0.59	1.66	1.57	43.54
368	51.10	1.42	1.72	1.92	43.87
723	45.49	2.05	3.23	5.77	43.46
723	46.27	2.18	2.85	5.12	43.58
873	47.10	0.93	3.62	5.20	43.15
873	46.92	0.76	2.94	6.17	43.22
873	49.13	0.86	2.41	4.12	43.49

relationships between the oxide constituents. Changing the total weight percent by the above procedure in no way affects the molar relationship between the constituents.

More than a single analysis was run for a given calcite sample because the sample could not be expected to be absolutely uniform in chemical composition throughout. For the calcite to be absolutely uniform in composition, the solution depositing the calcite would also have to be uniform over an unknown length of time.

It is important, however, that the calcite compositional variations from sample to sample be larger than those from place to place within the sample. Otherwise the chemical data are of little value in accomplishing the original purpose of locating discrete and distinct calcite generations.

As can be seen from the data in Table 25, there is variation within the calcite samples. However, the changes in composition between samples can be seen to be considerably larger in magnitude. We are therefore justified in averaging the several values per sample to obtain composition characteristics of each sample.

To demonstrate the high quality of the calcite analyses, the chemical analyses were used to compute the "unit cell" contents on the basis of three oxygens, or $(\text{Ca}, \text{Mg}, \text{Mn}, \text{Fe})_{1.0} (\text{CO}_3)_{1.0}$. The "unit cell" contents for the various calcite analyses are given in Table 26. Note that the sum of $\text{Ca}+\text{Mg}+\text{Mn}+\text{Fe}$ in the "unit cell", as well as the amount of CO_3 , is always very close to the ideal 1.0. Some of this accuracy is reflective of the use of a gold-coated optical grade calcite standard to allow precise matrix corrections for calcium in calcite.

Note, too, that even the amount of cation substitutions for calcium in the various calcites changes. Iron substitution is below the analytical detection limit of 0.1 wt% at DDH-3, 304 feet. Magnesium substitution is relatively high at DDH-3, 304 feet and 723 feet. Manganese substitution is highest in DDH-3, 304 feet. It is apparent that there are real compositional differences between these calcite samples.

X-ray emission photomicrographs clearly showed that the distribution of magnesium, manganese and iron was uniform within the calcite, tending to support the basic premise that the above elements were in the calcite lattice rather than admixed with the calcite.

TABLE 26

Calcite Compositions Based on the Molecule
 $(\text{Ca}, \text{Mg}, \text{Mn}, \text{Fe})_{1.0} (\text{CO}_3)_{1.0}$ as Determined From
 the Microprobe Chemical Analyses

DDH-3 Sample -ft-	<u>Ca</u>	<u>Mg</u>	<u>Mn</u>	<u>Fe</u>	<u>$\Sigma \text{Ca, Mg, Mn, Fe}$</u>	<u>CO₃</u>
304	0.8304	0.0696	0.1000	--	1.0000	1.0000
304	0.8162	0.0880	0.0960	--	1.0002	0.9999
304	0.8665	0.0680	0.0658	--	1.0003	0.9999
368	0.9190	0.0240	0.0342	0.0228	1.0000	1.0000
368	0.9456	0.0146	0.0236	0.0220	1.0058	0.9971
368	0.9136	0.0354	0.0242	0.0268	1.0000	1.0000
723	0.8208	0.0516	0.0466	0.0810	1.0000	1.0000
723	0.8334	0.0546	0.0404	0.0718	1.0000	1.0002
873	0.8542	0.0234	0.0519	0.0727	1.0022	0.9986
873	0.8513	0.0194	0.0418	0.0876	1.0001	0.9999
873	0.8866	0.0212	0.0344	0.0576	0.9998	1.0000

The above evidence of uniform elemental distribution within the calcite plus the strong evidence of the excellent cation and anion balances within the calcite molecule make it very probable that we are actually measuring elements that are substituting for calcium in the calcite lattice.

The calcium substitution data are summarized in Table 27 for the several calcite samples analyzed. These are the weight percents of the respective elements substituting in the calcite unit cell for calcium, and not the weight percent oxides reported in Table 25. There are several interesting aspects of these calcite cation substitution data. For example, the magnesium to calcium ratio tends to follow the sum total of atomic substitutions for calcium in the calcite lattice. As the number of cations substituting for calcium tends to increase or decrease, the number of magnesium cations in relation to the number of remaining calcium ions tends to remain constant. In order for this to be true, the number of magnesium ions must change in relation to the total number of cations in a manner that parallels the changes in percent atomic substitutions for calcium as well as the magnesium to calcium ratio in the unit cell. As the magnesium to calcium ratio changes, the changes in atomic substitutions for calcium and the changes in magnesium unit cell content all tend to parallel one another. The unit cell iron contents do not change in a parallel manner. One would expect that the changes in amounts of iron and manganese in the unit cell would show a genetic relationship, but they do not.

The following is conjecture as to the source within the basalt for the magnesium and iron which could substitute for calcium in calcite. As was seen from the olivine analyses, many of the olivines are altered to the extent that magnesium and iron cations have migrated from them. A lesser percentage of the pyroxenes also shows evidence of magnesium, iron and calcium migration. The prevalence of nontronite suggests that much of the iron was tied up in this iron-rich clay mineral leaving the magnesium relatively free to continue its migration and be present during the formation of other secondary minerals such as calcite. The fact that changes in the amount of magnesium in the calcite unit cell tends to parallel changes in the total amount of cation substitutions for calcium in turn suggests that the calcium and magnesium were released and migrated together from the same altered source minerals without other intervening cation selective mineral reactions before the formation of the calcite that would tend to separate them or change the calcium to magnesium ratios. Iron, and probably manganese, have undergone selective processes, such as the formation of nontronite, before taking part in the

TABLE 27

Calcium Substitution Data for the
Several Calcite Molecules

DDH3 Sample -ft-	Wt. % Substitution for Calcium	Wt. % Fe	Wt. % Mn	Wt. % Mg	Mg/Ca Atom Ratio
304	8.48	<0.1	5.00	3.48	0.084
304	9.20	<0.1	4.80	4.40	0.108
304	6.69	<0.1	3.29	3.40	0.079
Average 304	8.12	<0.1	4.36	3.76	0.090
368	4.05	1.14	1.71	1.20	0.026
368	3.01	1.10	1.18	0.73	0.015
368	4.32	1.34	1.21	1.77	0.039
Average 368	3.79	1.19	1.37	1.23	0.027
723	8.96	4.05	2.33	2.58	0.063
723	8.34	3.59	2.02	2.73	0.066
Average 723	8.64	3.82	2.17	2.65	0.065
873	7.56	3.73	2.64	1.19	0.027
873	7.44	4.38	2.09	0.97	0.022
873	5.66	2.88	1.72	1.06	0.024
Average 873	6.88	3.66	2.15	1.07	0.024

TABLE 28

End-Members of the Montmorillonite or Smectite Group

<u>Diocahedral</u>				<u>X (Exchange Cations)</u>
	<u>Z</u>	<u>Y</u>		
Montmorillonite	Si _{4.00}	Al _{1.67} Mg _{0.33}		(1/2 Ca, Na, K) _{0.33}
Beidellite	Si _{3.67} Al _{0.33}	Al _{2.00}		(1/2 Ca, Na, K) _{0.33}
Nontronite	Si _{3.67} Al _{0.33}	Fe ³⁺ _{2.00}		(1/2 Ca, Na, K) _{0.33}
<u>Triocahedral</u>				
	<u>Z</u>	<u>Y</u>		
Saponite	Si _{3.67} Al _{0.33}	Mg _{3.00}		(1/2 Ca, Na, K) _{0.33}
Hectorite	Si _{4.00}	Mg _{2.67} Li _{0.33}		(1/2 Ca, Na, K) _{0.33}
Sauconite	Si _{3.35} Al _{0.65}	Zn _{2.00} (Mg, Fe ³⁺ , Al) _{1.00}		(1/2 Ca, Na, K) _{0.33}

formation of calcite, and after their migration from altered olivines and pyroxenes. The alteration of olivines and pyroxenes is very likely a late-stage hydrothermal effect during basalt cooling. However, migration of the various ions may have been over considerable distances and periods of time once the initial release of ions occurred. The calcite deposition (and clay and silica deposition) may have been due, then, to the combination late-stage hydrothermal and localized groundwater effects.

The name for the group of clay minerals referred to as the "Montmorillonite Group", including montmorillonite, beidellite, nontronite, saponite and hectorite, is somewhat confusing because a specific member of the group also is named montmorillonite. The name "Smectite" was recently revived to refer to the group as a whole, and is used here.

The smectite group is composed of two large divisions; the dioctahedral group of montmorillonite, beidellite and nontronite and the trioctahedral group of saponite, hectorite and sauconite. The two large divisions are on the basis of the manner of filling of the octahedral (Y) layer. There are three positions per "unit cell" in the octahedral layer with six negative charges to satisfy. The trioctahedral clays satisfy the charge requirements with three Mg^{+2} ions (saponite), Mg^{+2} - Li^{+} ions (hectorite) or Zn^{+2} ions (sauconite). The dioctahedral clays fill two-thirds, or slightly more, of the octahedral positions with Al^{+3} - Mg^{+2} (montmorillonite), Al^{+3} (beidellite) or Fe^{+3} (nontronite). There are so-called solid solution series between the above end-members within both divisions, but not between end-members from different divisions. That is, montmorillonite-beidellite-nontronite series members are common, but no montmorillonite-saponite series members have ever been found.

In addition to the ions of the tetrahedral layer (Z), the octahedral layer (Y) and the exchangeable cations (X) given in Table 28 for the smectite group end-members, there are 10 oxygens and two hydroxyl or fluorine ions per "unit cell". Oxygen, fluorine and hydroxyl ions are, of course, not included in the microprobe analysis. The elements down through sodium in weight are included in the analysis. These elements are reported as the oxides, which in effect include the oxygen associated with the cations. The method chosen for data treatment includes two hydroxyl or fluorine ions per unit cell so that it is not necessary to directly determine these. They fall out of the calculations in their proper relationship to the cations.

Well-crystallized clays were chosen for analysis from DDH-3 cores. It is not possible to be certain that there are no admixed oxides such as hematite or silica, but these would show up in the data treatment in any case, even if present only a few percent above the amounts required by the clay "unit cell".

The above discussion of smectite group structural chemistry provides the basis for calculation of mineral formulae. The most general formula for smectite group members is:

where the first bracketed group occupies the octahedral position, the second the tetrahedral position, the oxygen hydroxyl and fluorine anion positions and X represents the exchangeable cations, which average 0.33. The subscripts represent the proportions of cations in the formula.

A shortened formula:

contains all of the normally-encountered ions and will be used to illustrate the method of mineral formula calculation used here. This method was originated by Ross and Hendricks¹³ in 1945.

If the atomic proportions of $\text{Al} = A$, $\text{Fe}^{+3} = B$, $\text{Mg} = D$, $\text{Si} = Z$. Al in tetrahedral positions = Y and Oxygen = R ; then, the atomic proportions derived from the chemical analysis, with Al properly proportioned between octahedral and tetrahedral positions, must be interrelated as:

When the above is multiplied by a constant, K , it becomes:

Remember that the subscript to X is assumed to be 0.33, the average exchangeable cation value, and may not correspond to the particular analysis. Also, the negative valency of $\text{O}_{10} [\text{OH}]_2 = 22$, and the number of ions in tetrahedral

position must equal four. The first step in formula definition is to divide the weight percent oxides of the analysis by their respective mole weights to obtain the atomic proportions. There are three unknowns that must be determined from the analytical atomic proportions to obtain a formula. These include the number of ions in octahedral coordination (Σ), the constant by which the atomic proportions are multiplied (K) and the number of aluminum ions in tetrahedral coordination ($Y \cdot K$). These three unknowns can be defined by the following equations:

$$K [A(3) + B(3) + D(2) + Z(4)] + 0.33 = 22$$

or

$$K = \frac{22 - 0.33}{A(3) + B(3) + D(2) + Z(4)}$$

The above equation represents a balance of cation and anion charges, and uniquely defines K.

To determine Y, the relationship $[Z + Y]K = 4$, or $\frac{4}{K} - Z = Y$ is used. The condition $Si + Al = 4$ in tetrahedral coordination is expressed by the above. K was determined by the first equation.

The total number of ions in octahedral coordination is defined by the expression $\Sigma = K[A + B + D - Y]$. A, B, and D were derived directly from the analysis, and Y and K were determined above.

Throughout we have assumed the average value for exchangeable cations of 0.33. The actual value may be more or less than 0.33. This is usually the most difficult component of the formula to accurately determine. The values for X given in a group of 75 smectite group minerals by Ross and Hendricks¹² ranged from 0.06 to 0.70. The analyses given in Table 2 showed values for X ranging from 0.32 to 0.45, a relatively narrow range indicative of the good quality of these analyses. The average value of X, 0.33, was assumed in the calculations for the clays given in Table 29. The actual values of X, computed by summing the excess negative charges on the tetrahedral and octahedral cations, are given in Table 29. For example, for sample A2017, the negative charge on the octahedral sites is $6.00 - [(0.18)(3) + (1.62)(3) + (0.27)(2)]$, where 6.00 is the required number of cation charges to balance the negative charge on the octahedral layer, and the 0.18, 1.62 and 0.27 are the quantities of Al^{+3} , Fe^{+3} and Mg^{+2} , respectively, which are multiplied by their respective charges. Due to the substitution of Al^{+3} for Si^{+4} in the tetrahedral layer, there is a net charge deficit of 0.26. The sum of both charges is 0.32 which equals X, the equivalent

TABLE 29. Composition of Several Clay Minerals Found
in DDH-3 Well Core Samples

<u>Sample</u>	<u>Al</u>	<u>Octahedral</u>		<u>Σ</u>	<u>Tetrahedral</u>	
		<u>Fe</u>	<u>Mg</u>		<u>Al</u>	<u>Si</u>
A2017	0.180	1.620	0.270	2.070	0.260	3.730
A2045	0.316	1.432	0.385	2.133	0.345	3.655
A2045	0.357	1.459	0.314	2.130	0.406	3.594
A2045	0.599	1.115	0.353	2.067	0.178	3.822
A2064	0.267	1.441	0.529	2.237	0.512	3.488
A2064	0.300	1.094	0.906	2.300	0.326	3.674
A2072	0.844	0.863	0.352	2.059	0.155	3.845
A2072	0.916	0.840	0.315	2.071	0.231	3.769
A2072	0.447	1.224	0.385	2.056	0.116	3.884
A2083	0.072	1.112	1.318	2.502*	0.518	3.482
A2083	0.019	1.104	1.424	2.547*	0.548	3.452
A2083	0.002	1.072	1.505	2.579*	0.561	3.439
A2092	0.591	0.909	0.651	2.151	0.132	3.868
A2092	0.541	0.937	0.666	2.144	0.098	3.902
A2123	0.118	1.272	0.890	2.280	0.282	3.718
Standard Nontronite	0.090	1.950	--	2.040	0.445	3.555

*Excess iron oxides

charge on the exchangeable cations. There is some K^+ in the exchangeable cations, but the predominant exchangeable cation is Ca^{+2} .

The results of the treatment of DDH-3 clay analyses are given in Table 29. The sum of the cations in the octahedral position always exceeds 2.0, ranging up to 2.3 for dioctahedral smectites. The reason for exceeding the theoretical limit of 2.0 for dioctahedral smectites is found in the partial substitution of Mg^{+2} in the $Al^{+3} - Fe^{+3}$ octahedral sites. There are three octahedral sites available per "unit cell" associated with six negative charges. The six negative charges can be satisfied by filling all three sites with plus two cations that fit, usually Mg^{+2} , to give a trioctahedral clay, or by filling two of the three sites with plus three cations, usually Al^{+3} or Fe^{+3} , to give a dioctahedral clay. What usually occurs with dioctahedral clays is that a few plus two cations also fill part of the remaining one-third of the octahedral sites, resulting in an octahedral cation sum that fractionally exceeds 2.0.

Trioctahedral series clays, however, always give an octahedral cation sum equal to three. The value cannot be less than three for a trioctahedral clay, or more than three because there are no more than three octahedral sites available.

Hence, the clays of Table 29 are dioctahedral clays, or members of the montmorillonite-beidellite-nontronite series. There are no saponites, or trioctahedral series members, among them.

The precise nomenclature of the dioctahedral clays is difficult in terms of the end-members given in Table 28. They are in part nontronite, as shown by their high Fe^{+3} content, but substitution of Mg^{+2} in the octahedral position also requires them to be called montmorillonites. Apparently, these clays are somewhat variable in composition because an occasional area showing no aluminum substitution for silicon in the tetrahedral position is seen. In terms of the end-members, these areas could be called montmorillonite-nontronite to indicate the large amount of Fe^{+3} in the octahedral position and fit in with no Al^{+3} substitution in the tetrahedral position. The clay sample A2017 is very close to the nontronite end-member.

DH-4 Core Well

The most prevalent minerals found in core vugs and joints of DH-4 were quartz, zeolites and members of the smectite or

montmorillonite group of clay minerals. These last minerals were at least partially collapsible when potassium-based or heat-treated, and were dioctahedral clays with substantial contents of nontronite-beidellite. Silica occurred throughout the section, both as quartz and opal. The zeolites were mainly heulandite with a few instances of clinoptilolite. Chabazite occurred in two samples, erionite in one.

Clinoptilolite has an x-ray diffraction pattern very similar to that of heulandite, but can be distinguished from the latter by the presence of much higher 4Å peak relative to the 9Å peak. With heulandite, the 9Å peak is the higher one.

Two occurrences of fibrous mordenite were also noted. The clinoptilolite and mordenite are typical of highly siliceous environments during formation. The prevalence of accompanying quartz testifies to the siliceous nature of the environment at the time of zeolite formation. A single chabazite occurrence at 3415 feet was identified.

In addition to smectite group clay minerals, two occurrences of chlorites were found, and several illite occurrences. The latter was usually present as vug filling, and had the appearance of a blue clay. Not all blue clays in the section were illites, however. Many of the alteration products that looked like clays were often not crystalline.

Calcite has not been found in the other well cores much below 1000 feet. Four calcite occurrences were located in this series of cores. One was at 3267 feet as basalt joint coating, and three more calcites, as breccia cements, were located at 4383 feet, 4583 feet and 4701 feet, respectively. The breccia cements, especially, are very well-crystallized calcites, up to half an inch in thickness, colorless and transparent. The physical character of these calcites is hardly that which is associated with the caliche type of calcite that is formed in the sedimentary cycle by lime-bearing carbonated waters at low temperatures. The sedimentary calcites are normally white to colored, opaque and fine-grained. The breccia-cementing calcites are clear and cleave much like optical calcite. In other words, the breccia cements are almost certainly hydrothermal calcites, formed during late-stage cooling of the basalt. The joint coating calcite is admixed with clay minerals, and may or may not be hydrothermal in origin. It is not a clearcut case of hydrothermal calcite, as the other three cases appear to be.

On checking into the chemical constitution of the water samples taken from ARH-DC-1¹⁴, some of the waters were in equilibrium with calcite and some were not. This was not due to a high

calcium content. In fact, the calcium content was very low for a basalt groundwater. The calcite near-equilibrium condition of some of the groundwater samples was due, rather, to the high bicarbonate-carbonate content in conjunction with high pH. Some of the samples showed pH values of greater than 10 where essentially only carbonate (CO_3^{2-}) is present. Whereas calcite is soluble in waters containing bicarbonate (HCO_3^-), the opposite is true of waters high in carbonate. Since there are both equilibrium and nonequilibrium conditions in the ARH-DC-1 wellwater samples, we can say very little about the conditions prevailing in the deep calcite zones in DH4. It would be necessary to collect and analyze groundwater samples from each zone before any firm conclusions could be reached.

The prevalence of montmorillonite group clay minerals indicates conditions of poor drainage of stagnant, alkaline solutions. Any extensive leaching leads to the formation of kaolinite, resulting partly from the neutral to slightly acid conditions formed as a consequence of the increased leaching rate. The implication of montmorillonite clay mineral prevalence is that the interchange and flow through and between basalt hydrological units have been limited. There has been no extensive leaching or interchange such as would be required by the presence of kaolinite.

The above evidence for limited hydrological interchanges between basalt units, plus the evidence shown by the trace element substitutions for calcium in calcite, make it seem less and less likely that water moved through the basalt series by overhead percolation from surface waters.

The x-ray diffraction data on secondary mineralization found in DH-4 well cores are listed in Table 30.

Complete so-called "solid solution" series exist between all three end-members of the dioctahedral smectite group. Ross and Hendricks¹³, for example, list 13 nontronite analyses. Of the 13 analyses, only four showed no magnesium substituting in the octahedral position for Fe^{+3} , as does the standard nontronite from Wards given in Table 29. The nontronite end-member has no substitution for Fe^{+3} . Hence, nine of the 13 analyses are actually intermediate between montmorillonite and nontronite. It is unusual to find a smectite that corresponds to one of the three end-member compositions given in Table 28. The vast majority of smectites range between the end-members in composition.

Collapse of the montmorillonite group with potassium exchange is confined to nontronite and beidellite. Montmorillonite

TABLE 30. X-ray Diffraction Data from Mineral
Alteration Found in the DH-4 Cores

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
20.5	volcanic ash interbed	some calcite, glass	---
33	alteration in vugs in fine-grained basalt	calcite, montmorillonite	nontronite
42	greenish-white vug filling in altered basalt	montmorillonite	nontronite
53	black vug filling in fresh basalt	strong montmorillonite	nontronite
68	crystalline joint alteration on fresh basalt	calcite, little montmorillonite	nontronite
82	black joint alteration with pyrite	strong montmorillonite some illite	nontronite
92	tan vug filling in altered basalt	montmorillonite	montmorillonite
107	black, altered basalt with pyrite	poor feldspar, some montmorillonite	montmorillonite
148	black joint alteration on fresh basalt	strong montmorillonite	nontronite
163	crystals on joints of fine-grained basalt	calcite	---
172	weathered top of flow, tan clay	strong montmorillonite	montmorillonite
177	alteration along fresh basalt joints	calcite, some montmorillonite	nontronite
182	blue clay vug filling in fresh basalt	strong montmorillonite	nontronite
192	black joint alteration on fresh, compact basalt	montmorillonite	nontronite
212	blue vug filling in fresh basalt	strong montmorillonite	nontronite

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
233	bluish-green clay on fresh basalt joints	strong montmorillonite	nontronite
277	black joint alteration on fresh basalt	montmorillonite	nontronite
337	black joint alteration on fresh basalt	montmorillonite	nontronite
356	wedge-shaped crystals in basalt vug	calcite	---
406	tan caly, interbed	montmorillonite, quartz	montmorillonite
411	gray clay, interbed	illite- montmorillonite mixed layer, some montmorillonite	montmorillonite
417	tan clay, interbed	montmorillonite	montmorillonite
422	brown clay, interbed base	strong montmorillonite	montmorillonite
422.5	altered basalt breccia at top of clay-basalt contact	montmorillonite	montmorillonite
465	black joint alteration on fresh basalt	strong montmorillonite	nontronite
496	black alteration on top of basalt flow	some calcite, little other crystallization	---
508	gray, altered basalt	strong montmorillonite	montmorillonite
539	brown clay on basalt joints	montmorillonite	montmorillonite
546	brown clay on basalt joints	little crystallization	---
563	white vug filling in fresh basalt	calcite	---

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
622	altered, fine-grained basalt at flow top	alpha-cristobalite, montmorillonite	montmorillonite
637	black joint alteration on fresh basalt	montmorillonite	nontronite
690.5	black fracture filling in fresh basalt	some montmorillonite, little crystallization	some nontronite
768	light blue clay alteration in fresh, vuggy basalt	strong montmorillonite	nontronite
815	black alteration in fresh basalt	montmorillonite	nontronite
837	gray clay in large of fresh basalt	some montmorillonite	montmorillonite
845.5	white mineralization on fresh basalt joints	quartz	---
878	black joint alteration on fresh basalt	quartz, montmorillonite	nontronite
891	blue clay alteration of basalt	strong montmorillonite	nontronite
929	blue to black large vug filling in fresh basalt	montmorillonite	nontronite
985.5	black clay in altered basalt	strong montmorillonite	nontronite
1033	small crystals in vuggy basalt	montmorillonite, heulandite	nontronite
1075.5	blue alteration in basalt vugs	montmorillonite	nontronite
1100	black joint alteration on fresh basalt	strong montmorillonite	nontronite

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
1131	blue vug filling in fresh basalt	some montmorillonite, little other	nontronite
1160.3	white vug filling in fresh basalt	alpha-cristobalite	---
1208	small crystals in vuggy basalt	heulandite, some montmorillonite	nontronite
1236	nodules filling vugs in fresh basalt	quartz	---
1243	small crystals in vuggy basalt	strong heulandite, montmorillonite	nontronite
1265	small, white crystals on basalt joints	strong montmorillonite, heulandite	nontronite
1288	Small crystals in vuggy, fresh basalt	strong montmorillonite, heulandite	nontronite
1290.5	Shiny, black joint alteration on fresh basalt	montmorillonite	nontronite
1322	Dull black alteration in fresh basalt	montmorillonite	nontronite
1351	Small, gray crystals on altered basalt	strong montmorillonite, heulandite	---
1381	Medium sized crystals fresh basalt vugs	quartz	---
1407	Quartz(?) crystals in fresh basalt vugs	quartz	---
1469	Same as 1432 feet		
1481	Sandy interbed	quartz, feldspar, mica, 14 A chlorite	---

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
1488	Black clay bed 1.5 cm wide in basalt	little crystallization	
1496	Small crystals in vuggy, fresh basalt	strong heulandite, montmorillonite	nontronite
1508	Altered basalt at flow top	heulandite, some montmorillonite	---
1517	Black clay in basalt flow breccia	some montmorillonite, little crystallization	---
1532	White coating on flow breccia	some vermiculite, little crystallization	---
1550.5	Vug filling in fresh basalt with pyrite	montmorillonite, heulandite	nontronite
1598	Black clay and small crystals in basalt vugs	strong heulandite, some montmorillonite	nontronite
1601	Blue crystalline vug filling in basalt	heulandite, a little montmorillonite	---
1643	White filling, small crystals in vugs	heulandite, opal (alpha-cristobalite)	---
1673	Green clay in vuggy basalt	some heulandite, little other crystallization	---
1692	White filling, black clay and crystals in vugs	strong heulandite, montmorillonite	nontronite
1711	Brown crystals, white and blue clay in vugs	heulandite, little other crystallization	---
1722	Bluish crystals in large basalt vugs	heulandite	---
1773	Medium size crystals in basalt vugs	strong heulandite	---
1845.5	Small crystals and black coating in vugs	heulandite	---
1916	Joint alteration on fresh, compact basalt	montmorillonite	nontronite

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
1933	Small crystal stringers in large basalt vug	strong heulandite, montmorillonite	nontronite
2068	Black joint alteration on fresh basalt	montmorillonite	nontronite
2098	Small crystals in basalt vugs	heulandite, montmorillonite	nontronite
2111	Bluish clay and small crystals in basalt vugs	strong heulandite little other crystallization	---
2118	White vug filling in fresh basalt	opal	---
2130.5	Brown crystal strings, black clay and pyrite in vugs	opal, strong heulandite montmorillonite	nontronite
2145	White, medium size crystals on black clay in vugs	montmorillonite, chabazite	nontronite
2153	Black clay and brown crystals in large vug	montmorillonite, chabazite	nontronite
2168	Black joint alteration on fresh basalt	montmorillonite	nontronite
2216	Black joint alteration on basalt	montmorillonite, some 14 Å chlorite	nontronite
2236	Filoform crystals in vuggy basalt	strong heulandite	---
2261	Black joint alteration on dense basalt	little crystallization	---
2333	Clay vug coating in altered, vuggy basalt	montmorillonite, opal, heulandite	nontronite
2354	Joint alteration on fresh, dense basalt	strong montmorillonite	nontronite
2437	Small crystals and blue clay in vugs	heulandite, little other crystallization	---

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
2440	Clay and white vug filling in basalt	montmorillonite, opal, heulandite	nontronite
2457	Small crystals lining vugs in basalt	strong heulandite, opal	---
2479	Clay and small crystals lining basalt vugs	some heulandite, little other crystallization	---
2482	Small crystals lining basalt vugs	strong heulandite, opal	---
2509	White, felty crystals lining basalt vugs	strong heulandite	---
2550.5	Crystal vug filling in basalt	opal, quartz	---
2572	Black clay and white crystals in vugs	heulandite, little other crystallization	---
2599	Crystals lining large vug	quartz	---
2620	Crystalline, white vug filling	quartz	---
2923	White, felty crystals and clay filling vugs	heulandite, montmorillonite	nontronite
2941	Hard, white joint coating in basalt	strong heulandite, quartz	---
2977	Hard, white crystals and vug coating in basalt	quartz	---
2988	Greenish-black clay zone in basalt	montmorillonite, poorly crystallized erionite	nontronite
2997	Hard, white vug filling and black clay in basalt	montmorillonite, quartz	nontronite
3001.5	Altered basalt zone clay and white material	little crystallization	---

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD, Clays</u>
3043	White vug filling and crystals in basalt breccia	Strong heulandite quartz	-----
3048	Gray-green clay layer in basalt breccia	Quartz, heulandite montmorillonite	Some nontronite-beidellite
3056	Black clay layer in basalt breccia	Some montmorillonite, little crystallization	-----
3077	Brown clay layer in vuggy basalt	Quartz, clinoptilolite	-----
3098	Gray, altered basalt	Montmorillonite, feldspar, heulandite	Nontronite-beidellite
3117	White stringers in gray, altered basalt	Feldspar, heulandite montmorillonite	Some nontronite-beidellite
3138	Gray, powdery altered basalt	Montmorillonite, feldspar, quartz	Nontronite-beidellite
3143	Gray filiform crystals in large vug	Quartz, montmorillonite	Some nontronite-beidellite
3191	Black joint alteration on fresh basalt	Montmorillonite	Nontronite-beidellite
3203	Altered, gray basalt	Feldspar, montmorillonite	Some nontronite-beidellite
3208	Powdery, white vug filling	Clinoptilolite, quartz	-----
3253	Quartz crystals in vuggy basalt	Quartz	-----
3267	White coating on basalt joints	Heulandite, calcite	-----
3276	Crystals in vuggy basalt	Strong heulandite	-----

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD, Clays</u>
3278	Altered rim around broken material	Feldspar, montmorillonite	Some nontronite-beidellite
3296	Hard crust on basalt breccia	Quartz, montmorillonite	Some nontronite-beidellite
3302	Small crystals lining basalt vugs	Strong heulandite	-----
3392	Black clay filling vugs	Montmorillonite	Nontronite-beidellite
3396	Nodule filling vug in fresh basalt	Quartz	-----
3415	Blue clay alteration and vug filling	Some chabazite	-----
3427	White joint alteration	Heulandite	-----
3428	White vug filling	Opal	-----
3507	Gray crystals in basalt vugs	Strong heulandite, quartz	-----
3508	Soft, white and hard, white vug filling	Quartz, clinoptilolite	-----
3528	Powdery, white vug filling	Quartz	-----
3558	Small crystals in basalt vugs	Strong heulandite, montmorillonite, quartz	Some nontronite-beidellite
3560	White vug filling in basalt	Quartz, heulandite	-----
3585	Blue clay on basalt	Heulandite	-----
3635	Black clay and crystals in vugs	Quartz, heulandite	-----
3641	White filling in large vug	Quartz, heulandite	-----

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD, Clays</u>
3657	Filoform crystals in large vug	Quartz	-----
3668	Blue clay and crystals in vugs	Heulandite, little other crystallization	-----
3703	Black clay and crystals in vugs	Montmorillonite, heulandite, quartz	Some nontronite-beidellite
3705	Soft, white vug filling in basalt	Heulandite	-----
3735.5	Crystals in basalt vug	Quartz	-----
3768	Blue and black clay on basalt joint	Quartz, montmorillonite heulandite	Some nontronite-
3796	Blue clay on basalt flow tops	Quartz, heulandite, illite	-----
3803	Blue clay and crystals in vugs	Quartz, heulandite, illite	-----
3824	White joint alteration with blue clay	Quartz, heulandite	-----
3871	White joint coating	Quartz	-----
3897	Small, black crystals in vugs	Quartz montmorillonite	-----
3918	Blue clay and white vug filling	Heulandite, illite	-----
3918	Fibrous white vug filling	Mordenite	-----
3963	Fibrous white vug filling	Mordenite	-----
3967	Brown crystals and blue clay vug filling	Heulandite, illite	-----
3993	White crystals on basalt joints	Quartz	-----
4111	Black clay and quartz? on flow base	Quartz	-----

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD, Clays</u>
4123	Black clay and crystals in vugs	Heulandite, montmorillonite	Some nontronite-beidellite
4131	Small, white crystals in vugs	Quartz	-----
4134	Black clay and crystals in vugs	Heulandite, montmorillonite	Some nontronite-beidellite
4149	White vug filling in basalt	Clinoptilolite, quartz	-----
4157	Felty, white vug filling	Heulandite, quartz, opal	-----
4160	White vug filling	Opal, quartz	-----
4198	White stringers in basalt	Quartz, opal	-----
4207	Black clay and white vug filling	Opal, little other crystallization	-----
4233	Black clay alteration	Little crystallization	-----
4246	Blue clay and white stringers in basalt	Heulandite, little other crystallization	-----
4297	Brown crystals in basalt vug	Quartz	-----
4302	Felty, white crystals lining vugs	Quartz, heulandite, montmorillonite	Some nontronite-beidellite
4325	White vug coatings	Quartz	-----
4345	Breccia coating	Quartz	-----
4372	Basalt breccia cement, black	Little crystallization	-----
4383	Basalt breccia cement, clear white	Calcite	-----
4402	Greenish crystals in basalt vugs	Quartz	-----

TABLE 30 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD, Clays</u>
4422	Black crystals in basalt vugs	Quartz	-----
4540	Felty, brown crystals in vugs	Heulandite, quartz montmorillonite	Some nontronite- beidellite
4541	White vug filling	Quartz	-----
4556	Greenish alteration	Quartz	-----
4574	Small, white crystals on oxidized basalt	Quartz, chlorite	-----
4583	Shiny, white crystalline material in breccia	Calcite	-----
4628	Black clay in basalt breccia	Little crystallization	-----
4642	Gray crystals on basalt	Quartz, montmorillonite	Some nontronite- beidellite
4676	Black clay on basalt joints	Chlorite, montmorillonite	Some nontronite- beidellite
4687	Hard, white vug filling	Quartz	-----
4701	Clear, crystalline breccia cement	Calcite, a little quartz	-----
4769	White vug filling in basalt	Poor opal and heulandite	-----

does not collapse with potassium basing unless it was derived from the weathering of a mica, certainly not the case with the montmorillonites in the basalt. Hence, two conditions are required for collapse; substitution of Al^{+3} in the tetrahedral position and trivalent ions (Al^{+3} , Fe^{+3}) in the octahedral position. All of the clays in Table 31 collapsed with potassium treatment, some more than others depending upon the above two conditions of nontronite (Fe^{+3}) and beidellite (Al^{+3}) content. The samples vary from 55 to 87% nontronite-beidellite, as shown in Table 32. It is uncertain whether even 55% of a clay structure can be collapsed without leaving little of the original basal spacing intact. The practice of referring to the collapsed clays in the core alteration reports as nontronite is justified, but nontronite-beidellite would be a more precise terminology. It is very difficult to identify the 10 to 45% montmorillonite component remaining after collapse. The appearance is that of total collapse due to the relatively small montmorillonite component content.

The clay mineral identification in terms of the percent nontronite, beidellite, and montmorillonite in the clay is given in Table 32. It is not implied that these clays are physical mixtures of the three components, any more than a plagioclase is a physical mixture of albite and anorthite when expressed as percent Ab and An. They are single clays of intermediate composition. The percent nontronite, beidellite and montmorillonite was derived from the amount of Fe^{+3} , Al^{+3} and Mg^{+2} , respectively, in octahedral positions.

Heulandite has been distinguished from clinoptilolite on the basis of x-ray diffraction peak heights. Some mounts of heulandite from DH-4 were fabricated and electron microprobe analyses made. These analyses are presented in Table 33.

In determining the unit cell from the chemical analysis, the relationship between Al, exchangeable cations and Si, is important. The charge on the exchangeable cations should equal the charge (negative) on the framework due to substitution of $(\text{AlO}_4)^{-5}$ groups for $(\text{SiO}_4)^{-4}$ groups. Since these values are interdependent and flexible, the molecule can be written as $(\text{Ca}, \text{Na}, \text{K})_x \text{Al}_x \text{Si}_{36-x} \text{O}_{72} \cdot 24\text{H}_2\text{O}$. The sum of Al + Si should ideally equal 36, while "x" can have any value depending upon the amount of Al substituting for Si. Note in Table 33 that the plus charges on the exchangeable cations do not exactly equal the Al in the unit cell except for the DH-4-2236 feet sample analysis. However, these values are very difficult to match. The analyses given in standard texts are not much better than those given in Table 33 in this respect. The Si plus Al values given in Table 33 are very close to the ideal 36. The ideal composition of

TABLE 31

Composition of Several Clays Found
in the Cores from DH3 and DH4

<u>Sample</u>	<u>Octahedral</u>				<u>Tetrahedral</u>		
	<u>Al</u>	<u>Fe</u>	<u>Mg</u>	<u>Σ</u>	<u>Al</u>	<u>Si</u>	<u>X</u>
*DH4 768 feet	0.25	1.38	0.33	1.96	----	4.00	0.45
DH4 768 feet	0.15	1.11	0.98	2.24	0.18	3.82	0.34
DH4 891 feet	0.60	0.60	1.00	2.20	----	4.00	0.40
DH4 891 feet	0.64	0.60	1.00	2.24	0.06	3.94	0.34
DH4 985.5 feet	0.31	0.98	1.00	2.29	0.21	3.79	0.34
Standard Nontronite	0.09	1.95	----	2.04	0.44	3.56	0.32

*may contain excess silica; Σ should exceed 2.00

TABLE 32

Clay Mineral Identification

<u>Sample</u>	<u>Percent</u>		
	<u>Nontronite</u>	<u>Beidellite</u>	<u>Montmorillonite</u>
DH4 768 feet	70.4	12.8	16.8
DH4 768 feet	49.6	6.6	43.8
DH4 891 feet	27.3	27.2	45.5
DH4 891 feet	26.8	28.6	44.6
DH4 985 feet	42.8	13.5	43.7
DH3 723 feet	78.3	8.7	13.0

TABLE 33

Heulandite Microprobe Analyses Referred to
a Molecule of $(\text{Ca}, \text{K}, \text{Na})_x \text{Al}_x \text{Si}_{36-x} \text{O}_{72} \cdot 24\text{H}_2\text{O}$

<u>Sample</u>	<u>Heulandite Framework</u>			<u>Exchangeable Cations</u>		
	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>K</u>	<u>Ca</u>	<u>Σ Plus Charges</u>
DH4-1933 feet	30.541	5.712	36.253	4.389	0.156	4.701
DH4-1550 feet	29.955	6.280	36.253	3.867	0.738	5.353
DH4-1550 feet	29.668	6.526	36.194	3.587	1.082	5.751
DH4-2236 feet	29.568	6.417	35.985	5.750	0.364	6.478
DH4-2437 feet	30.164	6.266	36.430	3.875	0.335	4.545
DH4-2437 feet	29.718	6.024	35.742	6.254	0.400	7.054

heulandite is $(\text{Ca}, \text{Na}_2, \text{K}_2)_4 \text{Al}_8 \text{Si}_{28} \text{O}_{72} \cdot 24\text{H}_2\text{O}$. The water was not determined for any of the heulandites since it is not an integral part of the structure.

The heulandite of Table 33 could be termed siliceous, or higher in Si than the ideal heulandite, but they are not clinoptilolites which vary from 32 to 40 Si.

One unusual aspect of the heulandites is the large amount of K in the exchangeable cations, and the absence of Na. The portion of the basalt that is highest in K is the glass. This suggests that the glass constituted the source material for these zeolites, which were probably hydrothermally synthesized from solubilized glass constituents.

DH-5 Core Well

The most prevalent minerals in the DH-5 cores were members of the smectite or montmorillonite group. Those members occurring as alteration on basalt joint surfaces, or lining basalt vugs

TABLE 34

X-Ray Diffraction Data from Mineral Alteration
Identified in the DH-5 Cores.

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
237	Greenish-yellow clay in vuggy basalt	Montmorillonite	Nontronite- beidellite
242	Brown clay in altered basalt	Montmorillonite	Nontronite- beidellite
267	White to tan clay in altered basalt	Montmorillonite	Mostly mont- morillonite
286	Green clay vug filling	Montmorillonite	Nontronite- beidellite
302	Cream-colored clay from interbed top	Quartz, opal, montmorillonite	Montmorillonite
318	Greenish-tan clay from interbed	Some montmorillonite, Quartz	Montmorillonite
324	Sandy clay from basalt- interbed contact	Montmorillonite	Montmorillonite
363	Bluish clay on basalt joints	Montmorillonite	Nontronite- beidellite
403	Bluish clay on basalt joints	Some montmorillonite, little crystallization	Some nontronite- beidellite
448	Black and white joint alteration	Montmorillonite, calcite	Nontronite- beidellite
460	Top or sandy interbed	Quartz, calcite, feldspar	-----
470	White layer in tan interbed	Some montmorillonite, little crystallization	Montmorillonite
480	Pink clay in interbed	Montmorillonite, opal	Mostly mont- morillonite
493	Light gray clay in interbed	Montmorillonite, quartz, opal	Mostly mont- morillonite

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
516	Dark gray, sandy interbed	Illite, 7 Å chlorite, quartz, feldspar	---
532	Basalt with many white phenocrysts	Feldspar	----
573	Light to dark clay in basalt	Montmorillonite	Nontronite- beidellite
588	Pitch black alteration in basalt	Some montmorillonite little crystallization	Some nontronite- beidellite
604	Light to dark clay at basalt flow base	Some montmorillonite, little crystallization	Mostly mont- morillonite
611	Green clay near top of interbed	Some montmorillonite, little crystallization	Some nontronite- beidellite
627	Sandy interbed	Quartz, feldspar	----
646	Very sandy portion of interbed	Quartz, feldspar	----
658	Fine-grained portion of interbed	Some montmorillonite, quartz	Mostly mont- morillonite
679	Fine-grained white clay from interbed	Some montmorillonite, quartz	Mostly mont- morillonite
689	Green clay on top of basalt contact	Montmorillonite	Nontronite- beidellite
721	Black joint alteration on fresh basalt	Montmorillonite	Nontronite- beidellite
747	Black and white basalt alteration	Quartz, calcite, some montmorillonite	Some nontronite- beidellite
774	Black joint alteration on fresh basalt	Some montmorillonite, little crystallization	Some nontronite- beidellite
786	Black joint alteration on fresh basalt	Little crystallization	----
813	2" wide black and white joint alteration	Montmorillonite	Nontronite- beidellite
894	Mineralized area in basalt containing sulfides	Pyrite, little other crystallization	----

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
904	Black alteration on basalt joints	Little crystallization	----
935	Filoform crystals and bluish clay in vugs	Montmorillonite, quartz	Nontronite-beidellite
973	Black alteration in vuggy basalt	Montmorillonite	Nontronite-beidellite
992	Bluish clay in basalt vugs	Montmorillonite	Nontronite-beidellite
1046	Clay in basalt vugs	Little crystallization	----
1049	Intensely altered basalt zone	Montmorillonite	Some nontronite-beidellite
1073	Black clay in basalt vugs	Montmorillonite	Nontronite-beidellite
1097	Gray to black clay in basalt vugs	Montmorillonite	Nontronite-beidellite
1101	Brown to black clay in basalt vugs	Montmorillonite	Nontronite-beidellite
1158	White mineral on basalt joints	Calcite	----
1181	White mineral on vertical basalt joints	Quartz	----
1206	Shiny black alteration on vertical basalt joints	Montmorillonite	Nontronite-beidellite
1242	Joint alteration on basalt	Montmorillonite	Nontronite-beidellite
1282	Black mineral on basalt joints	Montmorillonite	Nontronite-beidellite
1307	Blue clay vug filling	Montmorillonite	Nontronite-beidellite

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
1351	Black alteration on vertical basalt joints	Montmorillonite	Nontronite-beidellite
1374	Altered zone at basalt flow top	Feldspar	----
1387	Black stringers in basalt vugs	Some montmorillonite, little crystallization	Some nontronite-beidellite
1417	Sooty black altered basalt zone	Feldspar, opal, montmorillonite	Some nontronite-beidellite
1419	Small crystals on basalt joint	Montmorillonite, Harmotome	Nontronite-beidellite
1458	Clay and quartz vug filling	Quartz, montmorillonite	Nontronite-beidellite
1476	Black and white vug filling	Opal, montmorillonite	Nontronite-beidellite
1488	Crystals and clay in basalt vugs	Montmorillonite, quartz	Nontronite-beidellite
1516	Blue to black clay in basalt vugs	Montmorillonite	Nontronite-beidellite
1530	White mineral on basalt joint	Quartz	----
1556	Black joint alteration on basalt	Montmorillonite	Nontronite-beidellite
1571	Black and white basalt coating	Montmorillonite, quartz	Nontronite-beidellite
1581	Basalt joint coating	Montmorillonite, quartz	Nontronite-beidellite

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
1671	Black joint alteration on fresh basalt	Little crystallization	---
1689	Highly altered basalt	Some montmorillonite, heulandite	Montmorillonite
1690	Gray interbed	Montmorillonite, quartz	Montmorillonite
1695	Light green interbed	Montmorillonite, quartz, illite	Montmorillonite
1698	Black veins in interbed	Quartz, chlorite, illite	---
1701	Sandy, gray interbed	Quartz, illite, chlorite	---
1710	Sand-clay interbed	Quartz, montmorillonite, chlorite, illite, feldspar	Montmorillonite
1722	Crystals and white vug filling	Heulandite	---
1773	Small white crystals on basalt joints	Heulandite	---
1778	Sulfide crystals on basalt joints	Pyrite	---
1811	Gray crystals on basalt breccia	Heulandite	---
1834	Brown, altered basalt	Quartz, feldspar montmorillonite	Montmorillonite
1849	Small sulfide crystals in vugs	Pyrite	---
1928	Blue alteration on basalt joints	Montmorillonite	Nontronite- beidellite
1938	Sulfide on basalt joints	Pyrite	---

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As Received XRD</u>	<u>K-Based XRD</u>
1952	Three inch, brown alteration vein	Quartz, poor feldspar montmorillonite	Nontronite- beidellite
1968	Small crystals and white vug filling	Heulandite, opal	---
1978	Four inch alteration vein or surface	Quartz, chlorite, montmorillonite	Montmorillonite
2012	Small crystals in vugs	Heulandite	---
2023	Soft and hard white vug filling	Heulandite, opal	---
2150	Medium sized, light blue crystals in vugs	Chabazite	---
2237	Black joint alteration on basalt	Little crystallization	---
2242	Sulfides on basalt joints	Pyrite	---
2243	Black joint alteration	Pyrite	---
2274	Small, gray crystals in basalt vugs	Heulandite	---
2291	Small gray crystals in basalt vugs	Chabazite	---
2316	Small, white crystals in vugs	Heulandite	---
2323	Brown and light blue crystals in vugs	Heulandite, chabazite	---
2357	Small crystals in basalt vugs	Heulandite, opal	---
2365	Small gray crystals in vugs	Heulandite	---
2433	Crystals and clay in vugs	Heulandite, montmorillonite	Nontronite- beidellite

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As Received XRD</u>	<u>K-Based XRD</u>
2442	Small crystals in vuggy basalt	Heulandite	---
2494	White vug filling in fresh basalt	Opal, heulandite	---
2521	Small crystals in vugs	Heulandite	---
2617	Gray crystals in breccia	Heulandite	---
2631	White coating in open breccia	Opal, heulandite	---
2642	Small crystals in breccia	Heulandite	---
2833	White vug filling	Quartz, heulandite	---
2891	Black clay in basalt breccia	Montmorillonite	---
2897	Agate vug filling	Opal, heulandite	
2913	One inch layer of black clay	Little crystallization	---
2927	White and green joint alteration	Opal	---
2941	Agate vug filling	Quartz	---
2951	White vug filling	Opal	---
2961	Black clay vein, 1/4 inch wide	Little crystallization	---
2986	Green and black clay alteration	Opal	---
3016	Small crystals on basalt joint	Heulandite	---

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As Received XRD</u>	<u>K-Based XRD</u>
3025.5	Green clay vein, 1/2 inch wide	Little crystallization	---
3158	White joint coating	Opal, heulandite	---
3158	Small crystals filling vugs	Heulandite	---
3174	White vug filling	Quartz	---
3183	Bluish vug filling	Quartz, opal, illite	---
3295.5	White vug filling	Calcite, quartz	---
3305	White vug filling	Opal	---
3335	Small crystals and agate filling vugs	Heulandite, quartz	---
3341	Hard, white vug filling	Opal	---
3375	Crystals in basalt vugs	Quartz, opal, heulandite	---
3528	Black joint alteration	Little crystallization	---
3542	Black joint alteration	Montmorillonite	Nontronite- beidellite
3588	Medium crystals in basalt vugs	Heulandite	---
3599	Crystals in basalt vugs	Heulandite	---
3599	White vug filling	Opal, heulandite	---
3601	Brown and white vug filling	Quartz, calcite	---
3607	Light gray crystals on basalt joints	Heulandite, quartz, Montmorillonite	Nontronite- beidellite
3610	Calcite(?) in vugs	Calcite	---
3622	Crystals in basalt vugs	Calcite, heulandite	---
3655	Hard, white vug filling	Opal, quartz, heulandite	---
3663	Clay in bottom of vugs	Opal, little other crystallization	---

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
3665	Hard, white vug filling	Quartz	---
3756	Clay and hard, white vug filling	Opal, quartz, little other crystallization	---
3774	Small crystals in vugs	Heulandite	---
3786	White vug filling	Opal, quartz	---
3825	Hard, white vug filling	Quartz, heulandite, opal	---
3836	Clay filling basalt vugs	Montmorillonite, heulandite quartz	Nontronite-beidellite
3854	Soft, white vug filling	Opal, quartz	---
3857	Small crystals in vugs	Quartz	---
3889	Hard, agate vug filling	Quartz	---
3914	Hard, green and felty, white vug filling	Montmorillonite-illite, opal, mordenite	---
3947	Small, black crystals in vugs	Heulandite, quartz, montmorillonite	Nontronite-beidellite
3947	Pyrite on crystals in vugs	Quartz, pyrite	---
3947	Calcite(?) in vugs	Calcite	---
3972	Blue crystals in vugs	Heulandite, opal	---
4010	Hard, white joint coating	Quartz	---
4047	White crystals in vugs	Quartz	---
4062	White joint mineralization	Quartz, heulandite	---
4109	Black clay in vugs	Heulandite, little other crystallization	---
4128	Black clay in veins	Quartz, little other crystallization	---

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
4152	Black clay and white joint coating	Opal, heulandite, little other crystallization	---
4166	Crystals in large vugs	Quartz, heulandite, opal	---
4182	Soft, white vug filling	Opal, quartz, heulandite	---
4218	Hard, white vug filling	Quartz	---
4231	Small green crystals in vugs	Heulandite	---
4232	White joint mineralization	Opal	---
4242	Hard, green vug filling	Quartz, little other crystallization	---
4314	Small, greenish crystals in vugs	Heulandite, quartz	---
4332	Black joint alteration	Little crystallization	---
4346	White vug filling	Calcite	---
4365	White vug filling	Quartz, opal	---
4385	White vug coating	Heulandite, quartz, opal	---
4465	White vug filling	Heulandite	---
4551	White vug filling	Opal, quartz, heulandite	---
4576	Black clay vug filling	Heulandite, little other crystallization	---
4588	White vug filling	Opal	---
4617	Small crystals in vugs	Quartz	---
4696	Soft, white, fibrous mineral in breccia	Mordenite	---
4701	Crystals on gray clay in vugs	Quartz, heulandite	---
4893	Black joint alteration	Heulandite, little other crystallization	---

TABLE 34 (continued)

<u>Feet</u>	<u>Physical Description</u>	<u>As-Received XRD</u>	<u>K-Based XRD</u>
4910	White vug filling	Quartz, heulandite	---
4932	Soft, white vug filling	Mordenite, quartz	---
4957	Hard, white vug filling	Opal, quartz	---
4998	Clay and crystals lining vugs	Quartz, montmorillonite	Nontronite- beidellite
5001	Clay and crystals lining vugs	Quartz, montmorillonite, heulandite	Nontronite- beidellite

with or without associated minerals, were at least partially collapsible when potassium-based and heat-treated, or were dioctahedral clays with substantial contents of nontronite-beidellite. The interbed smectites tended much more toward the montmorillonite end of the solid solution series.

Beidellite was added to the collapsible clays description because both it and nontronite collapse under the same conditions. It was not apparent that there was a variable, but often sizeable, component of beidellite in the smectite group clays until chemical analyses were obtained and reported. It is not possible to determine from the x-ray diffraction patterns whether nontronite or beidellite, or both, are causing the collapse. Neither is it possible to accurately determine the amount of uncollapsed montmorillonite component remaining. Therefore, nontronite-beidellite was reported where collapse occurred without attempting to also report the amount of montmorillonite component remaining. It should be emphasized again that these smectite group clays represent single clay minerals in the montmorillonite-beidellite-nontronite series, not admixtures of the above three end-member clays.

The DH-5 core mineralization differs somewhat from the mineralization found in previous well cores in that calcite is rather scarce above 1000 feet in depth, and heulandite was not found below 1000 feet in depth, at least to 1581 feet. Heulandite was identified in DDH-3 cores at 1300 feet and in DH-4 cores at 1200 feet. DDH-1 and DH-2 did not penetrate the zeolite zone.

A single zeolite, harmotome, was located at 1419 feet in depth in DH-5. Harmotome, ideally, is $\text{BaAl}_2\text{Si}_6\text{O}_{16} \cdot 6\text{H}_2\text{O}$ in composition, but there can be replacement of Si by Al with alkalies in the Ba position to preserve the charge balance. Na and K are the usual alkalies found in the Ba position. Calcium is sometimes present substituting for barium but usually in amounts less than 2% CaO. Harmotome is usually found in basalt cavities associated with calcite, barite, or hematite.

As to any other clay minerals, illite and a 7 angstrom chlorite were identified in an interbed sample from 516 feet. No other types of clay minerals were found, but several samples with the appearance of clays showed little crystallization on x-ray diffraction patterns. Probably "mineraloid" is as good a name as any for these areas. Enough metallic sulfide was separated from a mineraloid sample at 894 feet to definitely identify it as pyrite.

The zeolites were the most prevalent secondary minerals in the lower half of the well. Heulandite was the most common zeolite, with an occasional instance of chabazite.

It is difficult not to assume that the apparent zeolite zone below 1000 feet postdates emplacement of the basalt series. Any mineralization of this nature requires a source of heat, with the lavas supplying the cavities and chemical raw materials including water. If we assume that the zeolites are formed as a result of late-stage hydrothermal activity on the part of each flow unit, we must explain, in view of the missing zeolites, what happened in the top 1000 feet of basalt that was different from that below 1000 feet in depth. Walker³ has shown that zeolite zoning has occurred in the Iceland basalts as a result of heat furnished by intrusion of dikes into a succession of lava flows. The heat source for zeolitization of the Hanford basalts is not readily apparent. The source could have been the basalts themselves if the succession of flows was initially rapid with increasingly longer elapsed time between flows toward the end of the flow series. Enough heat could have been retained in the initial rapid flow sequence to furnish a heat source for zeolitization of part of the basalt sequence.

There were several sulfide occurrences in these cores in amounts large enough to obtain a good sample for x-ray diffraction. All of these sulfides gave good x-ray diffraction patterns for pyrite (FeS_2). These are thus at least two sulfides present in the cores. The primary sulfide probably represents an immiscible sulfide phase that approaches pyrrhotite (Fe_7S_8) in composition. This primary sulfide is the likely source of sulfur for the late-stage pyrite found in the cores.

The x-ray diffraction results for secondary mineralization in DH-5 well cores is given in Table 34.

Four clean samples of calcite were selected from DH-4 cores, and three samples from DH-5 cores, for microprobe analysis. Areas of these samples were free of clays and other admixed mineral matter, allowing a good chemical analysis by electron microprobe. The trace elements typical of the various calcite samples must be present in the lattice of the calcite, not as coatings or admixtures of other minerals.

Several analyses were taken on each calcite sample to show the range in chemical composition. Very few minerals maintain the same absolute amounts of trace elements throughout their period of crystal growth. The growth solution is bound to change with time, although the shorter the length

of time involved in crystal growth, the less the composition changes. In any case, the changes between calcite sample trace elements have to be larger than changes within each calcite sample if the trace element contents are to be of any use in distinguishing between calcite samples. Otherwise the original premise that the calcites in the various flow units represent late-stage flow cooling activity, and are discrete and distinct for each flow cooling history, cannot be substantiated with trace element studies. The alternative to the above premise is that the calcite resulted from a flow unit weathering process. Meteoric waters bearing calcium and carbonate species could have percolated down through the flow units and deposited calcite under the right conditions.

There are two possible ways in which the calcite could have been deposited under weathering conditions. The first is that of water percolating through many flow units while depositing calcite. Under these conditions, the calcites in the various units would tend toward a uniform trace element content, or a trace element content that rose or fell in a uniform manner from the top of the weathered rock column to the bottom.

The second manner of calcite deposition by percolating waters would be that of successive individual weathering of each flow unit. The trace element content of calcites in this case would tend to reflect the individual weathering conditions prevailing for each flow. The changes in trace element contents could be more abrupt between flows, and would be more difficult to distinguish from late-stage cooling calcites on this basis. However, trace element changes within each calcite sample would tend to be very small because the weathering conditions for each flow unit could be rather uniform.

Keeping in mind the above criteria for trace element content changes in calcite, it should be possible to apply them to the actual results following and for DDH-3 calcites and reach a fairly firm conclusion as to the origin of the calcites found in the drill hole cores.

The analytical results are given in terms of the calcite unit cell, $(\text{Ca}, \text{Mg}, \text{Mn}, \text{Fe}) (\text{CO}_3)$, in Table 35. Note, first of all, the high quality of these analyses. The third analysis of DH-4-163 feet calcite shows the largest error at plus 1.3%. The majority of the remainder of the analyses vary less than $\pm 1\%$ from the ideal 1.000 total for CO_3 and the sum of the cations. The probability that these trace elements are actually in the calcite crystal lattice is very high. Three-fourths of the DH-4 calcites were below the detection

TABLE 35

Calcite Compositions Based on the Molecule
(Ca,Mf,Mn,Fe)(CO₃) as Determined from the
Microprobe Chemical Analyses.

<u>Sample</u>	<u>Ca</u>	<u>Mg</u>	<u>Mn</u>	<u>Fe</u>	<u>ΣCa,Mg, Mn,Fe</u>	<u>CO₃</u>
DH4, 68 feet	0.961	0.031	0.009	---	1.001	1.000
DH4, 68 feet	0.968	0.015	0.015	---	0.998	1.001
DH4, 68 feet	0.968	0.015	0.016	---	0.999	1.000
DH4, 163 feet	0.968	0.032	---	---	1.000	1.000
DH4, 163 feet	0.968	0.032	---	---	1.000	1.000
DH4, 163 feet	0.981	0.032	---	---	1.013	0.993
DH4, 356 feet	0.968	0.031	---	---	0.999	1.000
DH4, 356 feet	0.976	0.024	---	---	1.000	1.000
DH4, 356 feet	0.976	0.024	---	---	1.000	1.000
DH4, 563 feet	0.774	0.037	0.129	0.047	0.987	1.006
DH4, 563 feet	0.786	0.034	0.133	0.045	0.998	1.000
DH4, 563 feet	0.791	0.034	0.128	0.046	0.999	1.000
DH5, 448 feet	0.957	0.033	0.006	0.007	1.003	0.999
DH5, 448 feet	0.957	0.034	0.003	0.004	0.998	1.000
DH5, 448 feet	0.960	0.033	0.003	0.006	1.002	0.999
DH5, 747 feet	0.933	---	0.043	0.024	1.000	1.000
DH5, 747 feet	0.891	0.034	0.045	0.032	1.002	0.999
DH5, 747 feet	0.912	0.020	0.046	0.023	1.001	1.000
DH5, 1158 feet	0.875	0.023	0.081	0.018	0.997	1.001
DH5, 1158 feet	0.888	0.028	0.059	0.023	0.998	1.001
DH5, 1158 feet	0.872	0.014	0.095	0.020	1.001	1.000

limit for FeO (<0.1 wt%) and half were below the MnO detection limit (<0.1 wt%). The amounts of Mg, Mn, and Fe substituting for Ca were fairly uniform, as they were in DH-3, but there appears to be enough variation within samples to rule out individual flow weathering as a calcite emplacement mechanism. Likewise, there is enough random variation in trace element contents between calcite samples to rule out contemporaneous weathering of many flow units as a calcite source. That leaves late-stage hydrothermal cooling processes as the most likely cause of calcite deposition.

Considerable random variation in trace element contents of these calcites is apparent. Since the locating of several calcite occurrences in the DH-4 well below 1000 feet in depth it becomes much easier to attribute these calcites to hydrothermal late-stage cooling processes. It would have been difficult to explain why only the top 1000 feet of flow units produced calcite during their cooling cycles, while the 4000 feet of underlying flow units did not produce calcite.

The compositions of the clays from DH-4 and DH-5 well cores are given in Table 36. The first aspect of these data to note are the sums of the octahedral cations. All of these clays are members of the dioctahedral division with approximately two-thirds of the three octahedral locations filled. Note also that negative charges (or the cation exchange capacities) arise from substitutions in both the tetrahedral and octahedral layers of the clay structures. This means that the clays do not exactly correspond to any of the dioctahedral end-members, but are a single clay structure containing elements of all of the end-member structures. For example, all contain magnesium in dioctahedral positions, characteristic of the montmorillonite end-member. The substitution of aluminum for silicon in the tetrahedral position is characteristic of beidellite and nontronite end-members, and the iron content in the octahedral position is characteristic of the nontronite end-member again.

For the most part, these clay samples were chosen from those indicating a smectite group clay mineral on the x-ray diffraction patterns. Most of them would probably be called "mineraloids" during a microscopic examination. In fact, nearly twice as many clay analyses were reported by the analyst than is given in Table 36. The rejected analyses indicated excess silica or hydrated oxides such as DH-5, 573 in Table 36. Only those clay analyses from samples that were free of admixed mineral matter are given in Table 36. These are high-quality analyses, and would take many man-months to duplicate using wet chemical analytical methods.

TABLE 36

Composition of Several Clays in the
Cores from DH-4 and DH-5 Wells

<u>Sample</u>	<u>Octahedral</u>				<u>Tetrahedral</u>	
	<u>Al</u>	<u>Fe</u>	<u>Mg</u>	<u>Σ</u>	<u>Al</u>	<u>Si</u>
DH4, 68 feet	0.189	1.206	0.887	2.282	0.287	3.713
DH4, 68 feet	0.619	0.884	0.624	2.127	0.088	3.912
DH4, 68 feet	0.583	0.899	0.665	2.147	0.104	3.896
DH4, 163 feet	0.113	1.526	0.412	2.051	0.070	3.930
DH4, 356 feet	0.334	0.958	0.960	2.252	0.126	3.874
DH4, 356 feet	0.337	0.892	1.074	2.253	0.064	3.936
DH4, 2153 feet	0.392	1.112	0.759	2.263	0.361	3.639
DH4, 2153 feet	0.307	1.236	0.725	2.268	0.408	3.592
DH4, 2153 feet	0.722	0.941	0.421	2.084	0.163	3.837
DH4, 2236 feet	0.029	1.706	0.370	2.105	0.274	3.726
DH4, 2236 feet	0.022	1.679	0.419	2.120	0.272	3.728
DH4, 2437 feet	0.575	0.984	0.513	2.072	0.034	3.966
DH5, 267 feet	0.836	0.664	0.624	2.124	0.078	3.922
DH5, 267 feet	0.986	0.505	0.660	2.151	0.124	3.876
DH5, 267 feet	0.826	0.715	0.643	2.184	0.237	3.763
DH5, 448 feet	0.056	1.727	0.302	2.085	0.283	3.717
DH5, 448 feet	0.015	1.690	0.403	2.108	0.252	3.748
DH5, 573 feet	0.461	0.540	1.501	2.502*	0.334	3.666
DH5, 573 feet	0.642	0.470	1.326	2.438*	0.320	3.680
DH5, 573 feet	0.632	0.435	1.420	2.487*	0.371	3.629
DH5, 689 feet	1.032	0.827	0.169	2.028	0.245	3.755
DH5, 689 feet	0.952	0.901	0.221	2.074	0.333	3.667
DH5, 689 feet	0.955	0.952	0.182	2.089	0.416	3.584
DH5, 813 feet	0.098	1.415	0.690	2.203	0.249	3.751

*Σ too high; probably contains excess iron oxides.

WELLWATER CARBONATE EQUILIBRIA

In order to undertake the mineral equilibria work on storage of radioactive waste materials in a natural environment such as basalt caverns beneath Hanford, certain information must be furnished. Included in this information is a detailed knowledge of the chemical constitution of the groundwaters underlying Hanford which may contact the stored wastes. A preliminary report¹³ is already available on the chemical constitution of ARH-DC-1 wellwaters. Part of these data are reproduced in Table 46 over the well depth intervals in feet from which the water samples were taken. In order to check the quality of the carbonate data given in Table 37, the question was posed as to whether or not the above well waters were in equilibrium with calcite (CaCO_3). This is a valid question to ask because these waters should be in contact with calcite over this depth zone according to the x-ray diffraction work on the well cores. To be more precise, what should the equilibrium calcium molality be at the ionic strength and pH of each solution, assuming that the solutions are in equilibrium with atmospheric CO_2 . The equilibrium assumption is open to some question, but this will be assumed to see what carbonate values fall out of the calculations. During these calculations the quality of the carbonate species values (CO_3 , HCO_3) and pH values given in the analysis also will become apparent. At a given pH, the ratio HCO_3/CO_3 is fixed in the solution because the pH is the negative log of the hydrogen ion activity, and the hydrogen ion activity directly determines the HCO_3/CO_3 ratio. This relationship is shown in Figure 35 where the fractions of CO_3 , HCO_3 and H_2CO_3 in solution were plotted versus pH. The HCO_3/CO_3 ratio is 1.0, for example, at about pH 10.4, and only at that pH.

There are five reactions that describe a calcite-carbonate system. These are:

1. $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$
2. $\text{H}_2\text{CO}_3 = \text{HCO}_3^- + \text{H}^+$
3. $\text{HCO}_3^- = \text{CO}_3^{--} + \text{H}^+$
4. $\text{H}_2\text{O} = \text{H}^+ + \text{OH}^-$
5. $\text{CaCO}_3 = \text{Ca}^{++} + \text{CO}_3^{--}$

All of the above are equilibrium reactions, i.e., the product of the activities of the reaction products divided by the

FIGURE 35. Distribution Diagram for Carbonate Species

product of the activities of the reactants is a constant at a given pressure and temperature.

At one atmosphere and 25°C:

$$1. \quad \frac{[\text{H}_2\text{CO}_3]}{P_{\text{CO}_2}} = k_{\text{CO}_2} = 10^{-1.5}$$

$$2. \quad \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} = k_{\text{H}_2\text{CO}_3} = 10^{-6.4}$$

$$3. \quad \frac{[\text{H}^+][\text{CO}_3^{--}]}{[\text{HCO}_3^-]} = k_{\text{HCO}_3} = 10^{-10.3}$$

$$4. \quad [\text{H}^+][\text{OH}^-] = k_{\text{H}_2\text{O}} = 10^{-14.0}$$

$$5. \quad [\text{Ca}^{++}][\text{CO}_3^{--}] = k_{\text{CaCO}_3} = 10^{-8.3}$$

where the brackets denote thermodynamic concentration or activities. By definition, the activities of solids and pure liquids are 1.0, so that the activities for H_2O and CaCO_3 drop out of expressions 4 and 5. The activity of hydrogen ions is given by the pH measurement. This is the only activity value that is available. All of the other values given in Table 37 are concentrations, not activities. In the calculations to determine if the groundwaters are in equilibrium with calcite and if the groundwaters are in equilibrium with atmospheric CO_2 , only the activity of hydrogen (a_{H^+}) as measured will be used. However, the basic equilibria (1-5) will have to be rearranged into a more useful form.

To relate the molality of the species (m_s) to the activity (a_s), the relationship $m_s = \gamma_s a_s$ was used, where γ_s is the activity coefficient of the species at the ionic strength of the solution in which it occurs. Ionic strength was determined from the analysis of each wellwater given in Table 37. Ionic strength = $\mu = 1/2 \sum C_i Z_i^2$, where C_i is the concentration (molality) of a given ion and Z_i its charge. The ionic strength of a 1 molal CaCl_2 solution, for example, would be: $\mu = 1/2 [(1)(2)^2 + (2)(1)^2] = 3$. The ionic strength of each wellwater solution is given in Table 38. After obtaining

TABLE 37

Chemical Analysis of Water Samples
from ARH-DC-1 Well

Interval <u>ARH-DC-1</u>	<u>Mg/L</u>										
	<u>pH</u>	<u>Ca</u>	<u>Mg</u>	<u>Na</u>	<u>K</u>	<u>HCO₃</u>	<u>CO₃</u>	<u>SO₄</u>	<u>Cl</u>	<u>F</u>	<u>SiO₂</u>
540-620	8.6	2.1	0.3	79	7.8	199	10	---	4.2	1.0	46
636-726	8.9	1.7	0.4	90	9.9	205	14	---	13	1.7	55
720-810	9.3	1.7	0.4	114	14	134	43	1.6	49	7.5	57
980-1120	9.5	0.9	0.4	164	10	55	67	2	120	16	89

TABLE 38

Ionic Strengths of the Wellwaters

<u>Interval</u> <u>ARH-DC-1</u>	<u>μ</u>
540-620	0.00553
636-726	0.0064
720-810	0.0081
980-1120	0.0115

μ values, the activity coefficients can be determined using the Debye-Huckel method where:

$$\text{the activity coefficient} = -\log \gamma_i = \frac{A Z_i^2 \sqrt{\mu}}{1 + a_i^0 B \sqrt{\mu}}$$

A and B are constants characteristic of water and of the temperature and pressure, Z_i is the charge of the ion, μ is the ionic strength and a_i^0 is a value dependent on the "effective diameter" of the ion in solution. All of these above values are known for most ions and conditions, and are tabulated in several texts. The computed activity coefficients are given in Table 39. These values are given in powers of ten because they are much easier to use in this form.

The equations given in 1 through 5 can now be rewritten into a more useful form for these calculations in terms of activity coefficients and molalities (at these low concentrations, molality closely approximates molarity). Substituting molalities and activity coefficients, and rearranging 1 through 5:

$$6. \quad m_{\text{H}_2\text{CO}_3} = 10^{-1.5} P_{\text{CO}_2} \quad (\gamma_{\text{H}_2\text{CO}_3} \text{ very nearly} = 1.0)$$

$$7. \quad \frac{(a_{\text{H}^+}) (m_{\text{HCO}_3^-}) (\gamma_{\text{HCO}_3^-})}{(m_{\text{H}_2\text{CO}_3})} = 10^{-6.4}$$

$$8. \quad \frac{(a_{\text{H}^+}) (m_{\text{CO}_3^{--}}) (\gamma_{\text{CO}_3^{--}})}{(m_{\text{HCO}_3^-}) (\gamma_{\text{HCO}_3^-})} = 10^{-10.3}$$

$$9. \quad (a_{\text{H}^+}) (m_{\text{OH}^-}) (\gamma_{\text{OH}^-}) = 10^{-14.0}$$

$$10. \quad (m_{\text{Ca}^{++}}) (\gamma_{\text{Ca}^{++}}) (m_{\text{CO}_3^{--}}) (\gamma_{\text{CO}_3^{--}}) = 10^{-8.3}$$

One of the calculations will be given as an example. The calculations for the water from the 540 to 620 foot interval is as follows. Given are the measured pH of 8.6 ($a_{H^+} = 10^{-8.6}$), an atmospheric CO₂ pressure (P_{CO2}) of $10^{-3.5}$, and the activity coefficients in Table 39.

Using 10:

$$(m_{Ca^{++}}) (m_{CO_3^{--}}) = \frac{10^{-8.3}}{(\gamma_{Ca^{++}}) (\gamma_{CO_3^{--}})} = \frac{10^{-8.3}}{(10^{-0.1314}) (10^{-0.1357})} = 10^{-8.033}$$

for 8,

$$\frac{(a_{H^+}) (m_{CO_3^{--}})}{(m_{HCO_3^-})} = \frac{(10^{-10.3}) (\gamma_{HCO_3^-})}{(\gamma_{CO_3^{--}})} = \frac{(10^{-10.3}) (10^{-0.0343})}{(10^{-0.1357})} = 10^{-10.199}$$

for 7,

$$\frac{(a_{H^+}) (m_{HCO_3^-})}{(m_{H_2CO_3})} = \frac{10^{-6.4}}{\gamma_{HCO_3^-}} = \frac{10^{-6.4}}{10^{-0.0343}} = 10^{-6.366}$$

for 9,

$$(a_{H^+}) (m_{OH^-}) = \frac{10^{-14.0}}{\gamma_{OH^-}} = \frac{10^{-14.0}}{10^{-0.0347}} = 10^{-13.965}$$

and $(a_{H^+}) = 10^{-8.6}$

and for 6,

$$m_{H_2CO_3} = 10^{-1.5} P_{CO_2} = (10^{-1.5}) (10^{-3.5}) = 10^{-5.0}$$

Substituting the above value for $m_{H_2CO_3}$ back into modified expression 7:

$$\frac{(10^{-8.6}) (m_{HCO_3^-})}{(10^{-5.0})} = 10^{-6.366}$$

$$(m_{HCO_3^-}) = 10^{-2.766} = 0.00171 \text{ molal} = 104.3 \text{ mg/l}$$

TABLE 39

Activity Coefficients for the Various Ions
of Interest at 25°C

Interval ARH-DC-1	$\gamma_{\text{Ca}^{++}}$	$\gamma_{\text{CO}_3^{--}}$	$\gamma_{\text{HCO}_3^-}$	γ_{OH^-}
540-620	$10^{-0.1314}$	$10^{-0.1357}$	$10^{-0.0343}$	$10^{-0.0347}$
636-726	$10^{-0.1406}$	$10^{-0.1378}$	$10^{-0.0368}$	$10^{-0.0373}$
720-810	$10^{-0.1555}$	$10^{-0.1616}$	$10^{-0.0409}$	$10^{-0.0415}$
980-1120	$10^{-0.1798}$	$10^{-0.1879}$	$10^{-0.0477}$	$10^{-0.0485}$

Using this value for $m_{\text{HCO}_3^-}$ - in modified expression 8:

$$\frac{(10^{-8.6}) (m_{\text{CO}_3^{--}})}{(10^{-2.766})} = 10^{-10.199}$$

$$(m_{\text{CO}_3^{--}}) = 10^{-4.365} = 0.0000432 \text{ molal} = 2.6 \text{ mg/l}$$

Substituting the above $m_{\text{CO}_3^{--}}$ value into the modified expression 10,

$$(m_{\text{Ca}^{++}}) (10^{-4.365}) = 10^{-8.033}$$

$$(m_{\text{Ca}^{++}}) = 10^{-3.668} = 0.000215 \text{ molal} = 8.6 \text{ mg/l}$$

A tabulation of the computed and measured Ca, CO_3 and HCO_3 values are presented in Table 40. The discrepancy between computed and measured values of CO_3 and HCO_3 is pronounced in the lower samples. What this discrepancy means is that the P_{CO_2} in the lower level of these wellwaters is much less than $10^{-3.5}$, or in other words, the waters are not in equilibrium with atmospheric CO_2 below 720 feet in depth. In fact, the P_{CO_2} gets progressively lower below 720 feet with increasing depth. The computed value for P_{CO_2} is 10^{-5} at the 980 to 1120 foot interval. The measured and computed CO_3 and HCO_3 values at the 636 to 726 foot interval agree as well as can be expected.

To find out whether or not the measured Ca and CO_3 values represent calcite equilibrium, we may utilize modified expression 10, substitute the measured values for $m_{\text{Ca}^{++}}$ and $m_{\text{CO}_3^{--}}$ into it, and compare the computed values equilibrium k with the measured values k . For example, with 540 to 620 foot interval water:

$$(m_{\text{Ca}^{++}}) (m_{\text{CO}_3^{--}}) = 10^{-8.033} = 9.27 \times 10^{-9} = \text{computed values } k$$

$$(10^{-4.284}) (10^{-3.777}) = 10^{-8.061} = 8.70 \times 10^{-9} = \text{measured values } k$$

TABLE 40

Comparison of Computed and Measured
Ca, CO₃ and HCO₃ Values in mg/l

<u>Interval</u> <u>ARH-DC-1</u>	<u>Measured</u>			<u>Computed</u>		
	<u>Ca</u>	<u>CO₃</u>	<u>HCO₃</u>	<u>Ca</u>	<u>CO₃</u>	<u>HCO₃</u>
540-620	2.1	10	199	8.6	2.6	104.3
636-726	1.7	14	205	2.2	10.4	209.8
720-810	1.7	43	134	0.4	69.0	532.5
980-1120	0.9	67	55	0.15	184.2	860.1

This water is probably at equilibrium with calcite, within the experimental error. The measured values k and computed values k are compared for each of the four sampling intervals in Table 41. It is highly probable that, within the measuring and computational errors, all of the wellwaters in Table 41 are in equilibrium with calcite.

There is one more exercise that might be performed on these data. There were some field pH measurements on the water samples that gave consistently higher pH values than those taken later in the laboratory. Note also that the measured HCO_3/CO_3 ratios are consistently higher than those of the computed HCO_3/CO_3 ratios. These two facts strongly suggest that the measured laboratory pH values given in Reference 14 are too low. It is easy to find out what the pH values should be, using the measured values for $m_{\text{CO}_3^{--}}$ and $m_{\text{HCO}_3^-}$. For the interval 540 to 620 feet, for example, the measured carbonate and bicarbonate molalities are substituted into modified expression 8 again:

$$\frac{(a_{\text{H}^+}) (m_{\text{CO}_3^{--}})}{(m_{\text{HCO}_3^-})} = \frac{(10^{-10.3}) (\gamma_{\text{HCO}_3^-})}{(\gamma_{\text{CO}_3^{--}})}$$

$$\frac{(a_{\text{H}^+}) (10^{-3.777})}{(10^{-2.487})} = \frac{(10^{-10.3}) (10^{-0.0343})}{(10^{-0.1357})}$$

$$(a_{\text{H}^+}) (10^{-3.913}) = 10^{-12.821}$$

$$(a_{\text{H}^+}) = 10^{-8.91}, \text{ pH} = 8.91$$

The measured pH values are compared with the pH values computed from the laboratory measured CO_3 and HCO_3 values in Table 42. If the CO_3 and HCO_3 values measured in the laboratory were correct, then the laboratory measured pH values are consistently too low. Unless special precautions were taken in sample collection, sealing, shipment and pH measurement to exclude atmospheric CO_2 , the lab measured pH values probably are too low. The computed pH values are probably closer to the actual pH values of in situ wellwater.

TABLE 41
Measured Values k Compared to Computed
Values k for Wellwater Samples

<u>Interval</u> <u>ARH-DC-1</u>	<u>Computed</u> <u>Values k</u>	<u>Measured</u> <u>Values k</u>
540-620	9.27×10^{-9}	8.70×10^{-9}
636-726	9.51×10^{-9}	9.77×10^{-9}
720-810	1.14×10^{-8}	3.00×10^{-8}
980-1120	1.17×10^{-8}	2.46×10^{-8}

To summarize:

- 1) the wellwaters below 720 feet in depth are not in equilibrium with CO₂ in the atmosphere ($P_{CO_2} = 10^{-5.45}$ at 980 to 1120 foot interval),
- 2) all the wellwaters are very likely in equilibrium with calcite,
- 3) the pH values measured in the laboratory are very likely consistently lower than the actual pH values of in situ water.

It will be noted that the pH values given in Table 42 are relatively high. The pH of water + calcite at $P_{CO_2} = 10^{-3.5}$ is 8.4 and at $P_{CO_2} = 0$ is 9.9. The pH of wellwaters is probably controlled by the glassy portion of the flows and interbeds that they contact. The glassy portion would be more soluble than crystalline constituents of the flows. The analyses in Table 1 show relatively high concentrations of silica, alkalies, and chlorine and fluorine. The glassy groundmass is high in silica, and would be expected to contain most of the fluorine and chlorine in the flow because these do not fit well into any of the main stage flow minerals. Alkalies prefer the aqueous environment, and could be expected to leach with relative ease from the glassy groundmass.

TABLE 42

Comparison of Computed and Laboratory Measured
pH Values for the Wellwater Samples

<u>Interval</u>	<u>Laboratory</u> <u>Measured pH</u>	<u>Computed</u> <u>pH</u>
ARH-DC-1		
540-620	8.6	8.91
636-726	8.9	9.04
720-810	9.3	9.69
980-1120	9.5	10.26

SPECIFIC BASALT FLOW MINERALOGY

POMONA MEMBER

Feldspars

The contents of 56 feldspar molecules from Pomona core samples, as determined from the microprobe chemical analyses, are given in Table 43. Four of the 56 analyses were substandard. These analyses are from samples of the Pomona flow from DH-3, DH-4 and DH-5, and were identified by work on the basalts. The molecular percentages of albite, anorthite and orthoclase and the crystal sizes are given in Table 44. Of the remaining 52 analyses, nine are andesines, one is a bytownite, and the rest are labradorites. As a group, these feldspars are considerably more calcic than the average feldspar from DDH-3. The feldspar compositions clearly show the higher than average calcium content of the Pomona flow feldspars. Thirty-four of the 70 feldspars (48.6%) in an average flow unit were labradorites, while 43 of the 52 analyses (82.7%) from the Pomona were labradorites plus one bytownite. The bytownite is the first one identified in the many feldspar analyses made to date. The clear indication is that the Pomona feldspar is considerably more calcic than that of the average flow unit in the series. The usual trend of more sodic feldspar crystals being smaller in size is still apparent, though.

Linear changes apparently do occur between wells. DDH-3 samples, represented by the 2000 series, are more calcic than the feldspars from DH-4 and DH-5 Pomona samples. No andesines occur in the DDH-3 samples. The whole rock analyses also show that the Pomona in DDH-3 is more siliceous than the Pomona in DH-4 and DH-5.

Pyroxenes

The compositions of 58 pyroxene molecules from the Pomona samples are given in Table 45. One of these 58 analyses was substandard. Of the 57 good analyses, 43 were augites; three were subcalcic augites; seven were magnesium pigeonites; and four were intermediate pigeonites as shown in Table 46. There was no correlation between the type of pyroxene and crystal size. This is probably due to the small size of the electron beam area ($\sim 1\mu\text{m}^2$) from which the analysis is obtained, and the

TABLE 43. Pomona Feldspar Analyses

Contents of 56 feldspar molecules as computed from the microprobe chemical analyses. The four analyses marked with asterisks are substandard. All feldspars contained less than 0.2 wt% BaO.

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K, Na,Fe</u>
A2011	9.632	6.271	15.903	2.500	0.067	0.980	0.073	3.620
A2011	9.814	5.980	15.794	2.434	0.045	1.244	0.087	3.810
A2011	9.725	6.122	15.847	2.339	0.044	1.399	0.072	3.854
A2011	9.359	6.522	15.881	2.405	0.042	1.493	0.082	4.022
A2012	10.094	5.286	15.380	2.476	0.067	1.448	0.378	4.369
A2012	9.427	6.409	15.836	2.491	0.043	1.405	0.071	4.010
A2012	10.440	5.306	15.746	1.917	0.151	1.669	0.113	3.850
A2012	9.555	6.251	15.806	2.277	0.063	1.642	0.139	4.121
A2013	9.452	6.277	15.729	2.579	0.044	1.500	0.072	4.195
A2013	9.023	6.719	15.742	2.896	0.022	1.251	0.073	4.242
A2013	10.013	5.909	15.922	1.929	0.061	1.652	0.108	3.750
A2013	9.632	6.198	15.830	2.276	0.043	1.634	0.085	4.038
A2014	9.630	6.117	15.747	2.397	0.045	1.559	0.117	4.118
A2014	9.693	6.240	15.933	2.145	0.043	1.553	0.084	3.825
A2014	9.609	6.172	15.781	2.439	0.045	1.426	0.102	4.012
A2014	9.990	5.779	15.769	2.083	0.086	1.787	0.098	4.054
A4007	9.957	5.697	15.654	2.207	0.046	1.412	0.356	4.021
A4007	9.974	5.822	15.796	2.072	0.073	1.841	0.073	4.030
A4007	10.158	5.662	15.820	1.801	0.065	2.042	0.113	4.021
A4007	10.367	5.527	15.894	1.599	0.108	1.974	0.127	3.808
A4008	9.746	5.977	15.723	2.357	0.047	1.613	0.154	4.171
A4008	9.752	5.908	15.660	2.272	0.070	1.843	0.153	4.338
A4008	9.540	6.277	15.817	2.352	0.045	1.567	0.102	4.066
A4008	10.494	5.299	15.793	1.493	0.146	2.320	0.124	4.083
A4008	10.078	5.677	15.755	1.996	0.087	1.856	0.128	4.067
A4008	9.648	6.125	15.773	2.420	0.045	1.483	0.087	4.035
A4009	9.475	6.323	15.798	2.312	0.068	1.646	0.148	4.174
A4009	9.769	6.117	15.886	2.118	0.064	1.592	0.112	3.886
A4009	9.364	6.469	15.833	2.469	0.044	1.456	0.100	4.069
A4009	10.069	5.610	15.679	2.002	0.104	2.002	0.151	4.259
A5006	10.034	5.835	15.869	1.748	0.110	1.965	0.172	3.995
A5006	9.480	6.399	15.879	2.255	0.087	1.493	0.157	3.992
A5006	9.905	5.880	15.785	1.843	0.088	2.088	0.204	4.223
*A5006	9.504	6.079	15.583	2.371	0.094	2.003	0.185	4.653
A5006	9.478	6.340	15.818	2.425	0.045	1.327	0.176	3.973

TABLE 43 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K, Na,Fe</u>
A5007	10.148	5.516	15.664	2.153	0.043	1.674	---	3.870
A5007	9.990	5.930	15.920	1.787	0.110	1.900	0.115	3.912
A5007	9.548	6.327	15.875	2.447	0.045	1.295	0.059	3.846
A5007	9.693	6.113	15.806	2.152	0.044	1.830	0.114	4.140
A5008	9.559	6.335	15.894	2.451	0.045	1.194	0.073	3.763
*A5008	9.477	6.158	15.635	2.235	0.044	2.056	0.258	4.593
A5008	9.844	5.999	15.843	2.002	0.067	1.862	0.117	4.048
A5008	10.562	5.321	15.883	1.542	0.133	1.849	0.159	3.683
A5009	9.404	6.322	15.726	2.662	0.022	1.435	0.059	4.178
A5009	10.925	4.969	15.894	1.286	0.194	1.998	0.127	3.605
A5009	9.711	5.982	15.693	2.547	0.046	1.386	0.089	4.068
A5009	9.945	5.903	15.848	2.281	0.044	1.275	0.087	3.687
A5010	9.805	6.092	15.897	2.308	0.042	1.253	0.069	3.672
A5010	10.069	5.841	15.910	2.008	0.088	1.867	0.115	4.078
A5010	9.872	5.902	15.774	2.359	0.070	1.835	0.091	4.355
*A5010	9.493	6.184	15.677	2.666	0.069	1.805	0.135	4.675
A5011	9.826	6.006	15.832	2.282	0.124	1.765	0.113	4.284
A5011	9.643	6.254	15.897	2.269	0.099	1.770	0.130	4.260
A5011	11.692	4.125	15.817	1.055	0.238	2.338	0.085	3.716
A5011	9.684	6.211	15.895	2.565	0.051	1.315	0.067	3.998
*A5011	9.412	6.290	15.702	2.770	0.052	1.618	0.136	4.576

TABLE 44. Pomona Feldspar Compositions

Feldspar compositions as determined from the micro-probe chemical analyses. The listing is in the same order as that of Table 52, except the four substandard analyses were deleted. Ab = albite An = anorthite Or = orthoclase

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
A2011	27.6	70.5	1.9	Bytownite	225x440
A2011	33.4	65.4	1.2	Labradorite	15x100
A2011	37.0	61.8	1.2	Labradorite	100x275
A2011	37.9	61.0	1.1	Labradorite	20x100
A2012	36.3	62.0	1.7	Labradorite	75x200
A2012	35.7	63.2	1.1	Labradorite	200x250
A2012	44.7	51.3	4.0	Labradorite	20x55
A2012	41.2	57.2	1.6	Labradorite	25x75
A2013	36.4	62.6	1.1	Labradorite	100x500
A2013	30.0	69.5	0.5	Labradorite	90x300
A2013	45.4	53.0	1.7	Labradorite	5x50
A2013	41.3	57.6	1.1	Labradorite	10x70
A2014	39.0	59.9	1.1	Labradorite	85x350
A2014	41.5	57.3	1.1	Labradorite	10x50
A2014	36.5	62.4	1.1	Labradorite	40x75
A2014	45.2	52.7	2.2	Labradorite	25x50
A4007	38.5	60.2	1.2	Labradorite	40x150
A4007	46.5	52.4	1.1	Labradorite	25x175
A4007	52.2	46.1	1.7	Andesine	10x50
A4007	53.6	43.4	2.9	Andesine	10x40
A4008	40.2	58.7	1.2	Labradorite	40x300
A4008	44.0	54.3	1.7	Labradorite	10x40
A4008	39.5	59.3	1.1	Labradorite	60x150
A4008	58.6	37.7	3.7	Andesine	20x50
A4008	47.1	50.7	2.2	Labradorite	50x400
A4008	37.6	61.3	1.1	Labradorite	25x150
A4009	40.9	57.4	1.7	Labradorite	50x175
A4009	42.2	56.1	1.7	Labradorite	25x75
A4009	36.7	62.2	1.1	Labradorite	125x275
A4009	48.7	48.7	2.5	Labradorite	10x40

TABLE 44 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
A5006	51.4	45.7	2.9	Andesine	25x175
A5006	38.9	58.8	2.3	Labradorite	75x200
A5006	52.0	45.8	2.2	Andesine	15x100
A5006	34.9	63.9	1.2	Labradorite	30x175
A5007	43.3	55.6	1.1	Labradorite	25x110
A5007	50.0	47.1	2.9	Andesine	10x125
A5007	34.2	64.6	1.2	Labradorite	400x400
A5007	45.5	53.4	1.1	Labradorite	15x75
A5008	32.4	66.4	1.2	Labradorite	175x500
A5008	47.4	50.9	1.7	Labradorite	25x125
A5008	52.5	43.8	3.8	Andesine	5x50
A5009	34.8	64.6	0.5	Labradorite	450x900
A5009	57.5	37.0	5.6	Andesine	10x75
A5009	34.8	64.0	1.1	Labradorite	60x225
A5009	35.4	63.4	1.2	Labradorite	25x75
A5010	34.8	64.1	1.2	Labradorite	75x350
A5010	47.1	50.7	2.2	Labradorite	12x50
A5010	43.0	55.3	1.6	Labradorite	40x100
A5011	42.3	54.7	3.0	Labradorite	12x125
A5011	42.8	54.8	2.4	Labradorite	12x125
A5011	64.4	29.1	6.6	Andesine	100x125
A5011	33.5	65.2	1.3	Labradorite	100x250

TABLE 45. Pomona Pyroxene Analyses

Pyroxene compositions, based on the molecule (Mg, Fe,Ca,Ti,K,Mn,Cr,Al)₂ (Al,Si)₂O₆, as determined from the microprobe chemical analyses. * = substandard analysis

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Cr	Al	Σ
A2011	1.943	0.057	2.000	0.921	0.276	0.707	0.020	---	0.003	0.002	0.048	1.977
A2011	1.981	0.019	2.000	1.001	0.311	0.628	0.012	---	0.007	0.002	0.022	1.983
A2011	2.008	---	2.008	0.951	0.216	0.691	0.011	---	---	0.004	0.061	1.934
A2011	2.008	---	2.008	1.009	0.414	0.443	0.012	---	0.007	0.002	0.055	1.942
A2012	1.967	0.033	2.000	0.857	0.382	0.595	0.028	---	0.006	---	0.078	1.946
A2012	2.002	---	2.002	0.885	0.278	0.617	0.019	---	0.003	0.002	0.113	1.917
A2012	1.962	0.038	2.000	0.807	0.316	0.730	0.028	---	0.006	---	0.069	1.956
A2012	1.986	0.014	2.000	1.009	0.476	0.387	0.012	---	0.010	---	0.068	1.962
A2013	1.981	0.019	2.000	0.850	0.206	0.809	0.014	---	---	0.005	0.067	1.951
A2013	1.958	0.042	2.000	0.834	0.310	0.724	0.023	0.005	0.003	---	0.067	1.966
A2013	1.989	0.011	2.000	0.924	0.525	0.460	0.021	---	0.007	0.002	0.027	1.966
A2013	2.045	---	2.045	0.799	0.761	0.252	0.012	---	0.013	---	0.041	1.878
A2014	2.040	---	2.040	0.833	0.353	0.587	0.022	---	0.006	---	0.065	1.886
A2014	2.039	---	2.039	1.123	0.523	0.190	0.011	---	0.010	---	0.031	1.897
A2014	1.965	0.035	2.000	0.926	0.383	0.602	0.024	---	0.007	---	0.035	1.977
A2014	1.951	0.049	2.000	0.731	0.426	0.683	0.032	---	0.010	---	0.074	1.956
A4007	1.927	0.073	2.000	0.796	0.307	0.754	0.024	---	0.003	0.002	0.081	1.967
A4007	1.971	0.029	2.000	0.913	0.224	0.713	0.009	0.004	---	0.009	0.078	1.950
A4007	1.972	0.028	2.000	1.047	0.372	0.552	0.009	---	0.007	0.002	0.009	1.996
A4007	1.975	0.025	2.000	0.833	0.254	0.743	0.023	---	0.003	0.005	0.080	1.941
A4008	2.118	---	2.118	0.815	0.563	0.286	0.012	---	0.010	---	0.044	1.730
A4008	2.035	---	2.035	0.874	0.386	0.620	0.015	---	0.007	---	0.009	1.911
A4008	2.022	---	2.022	1.081	0.562	0.194	0.011	---	0.010	0.002	0.053	1.913
A4008	2.045	---	2.045	1.073	0.608	0.168	0.009	---	0.010	0.002	0.018	1.888
A4008	1.949	0.051	2.000	0.860	0.263	0.757	0.011	---	0.003	0.009	0.061	1.964
A4008	2.096	---	2.096	0.911	0.666	0.169	0.009	---	0.010	0.002	0.019	1.786

TABLE 45 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Cr	Al	Σ
A4009	2.017	---	2.017	0.800	0.244	0.797	0.008	---	0.003	0.002	0.065	1.919
A4009	1.990	0.010	2.000	0.918	0.290	0.680	0.014	---	0.006	0.004	0.047	1.959
A4009	2.011	---	2.011	0.856	0.505	0.486	0.014	---	0.010	0.002	0.058	1.931
A4009	2.042	---	2.042	0.969	0.631	0.209	0.011	---	0.010	0.002	0.044	1.876
A5006	1.978	0.022	2.000	0.922	0.250	0.744	0.014	---	---	0.002	0.041	1.973
A5006	1.999	0.001	2.000	0.861	0.375	0.640	0.015	---	0.007	0.002	0.054	1.954
A5006	2.107	---	2.107	1.019	0.531	0.150	0.008	---	0.009	0.002	0.035	1.754
A5006	2.080	---	2.080	0.944	0.645	0.165	0.009	---	0.010	0.005	0.028	1.806
A5006	2.065	---	2.065	0.865	0.712	0.186	0.012	---	0.007	0.005	0.042	1.829
A5007	1.958	0.042	2.000	0.956	0.307	0.687	0.015	---	0.003	---	0.025	1.993
A5007	2.094	---	2.094	1.041	0.487	0.220	0.006	---	---	---	0.035	1.789
A5007	1.994	0.006	2.000	0.855	0.303	0.734	0.015	0.004	0.003	---	0.050	1.964
A5007	2.088	---	2.088	0.960	0.615	0.189	0.012	---	0.010	---	0.018	1.804
A5007	1.979	0.021	2.000	0.882	0.202	0.798	0.012	---	---	0.007	0.056	1.957
A5007	2.001	---	2.001	0.925	0.394	0.585	0.012	---	0.007	---	0.042	1.965
A5008	1.997	0.003	2.000	0.852	0.237	0.769	0.012	---	0.003	0.005	0.069	1.947
A5008	1.992	0.008	2.000	0.850	0.230	0.791	0.012	---	---	0.005	0.064	1.952
A5008	1.954	0.046	2.000	0.731	0.601	0.534	0.034	---	0.011	0.002	0.047	1.960
A5008	1.990	0.010	2.000	0.819	0.407	0.588	0.024	---	0.007	---	0.092	1.937
A5008	2.016	---	2.016	0.823	0.246	0.747	0.011	---	0.003	0.007	0.070	1.907
A5009	1.970	0.030	2.000	0.914	0.311	0.640	0.021	---	0.007	0.002	0.063	1.958
A5009	1.977	0.003	2.000	0.859	0.201	0.793	0.012	---	0.003	0.002	0.052	1.958
A5009	1.857	0.049	1.906	0.774	0.535	0.845	0.019	0.005	0.011	0.002	---	2.191
A5009	2.021	---	2.021	0.839	0.256	0.720	0.015	---	0.003	0.005	0.064	1.902
A5010	1.987	0.013	2.000	0.815	0.217	0.817	0.012	---	---	0.007	0.075	1.943
*A5010	2.248	---	2.248	0.739	0.185	0.521	0.011	---	0.010	---	0.018	1.484
A5010	1.987	0.013	2.000	0.897	0.195	0.808	0.008	---	0.003	0.004	0.050	1.965
A5010	1.963	0.037	2.000	0.919	0.230	0.765	0.014	---	0.003	0.007	0.036	1.974
A5011	1.998	0.002	2.000	0.797	0.428	0.684	0.017	---	0.007	0.002	0.030	1.965
A5011	1.951	0.042	1.993	0.916	0.336	0.738	0.018	---	0.003	0.002	---	2.013
A5011	2.008	---	2.008	0.862	0.201	0.818	---	---	---	---	0.070	1.951
A5011	2.012	---	2.012	0.928	0.244	0.735	0.009	---	0.003	0.005	0.023	1.947

TABLE 46. Pomona Pyroxene Compositions

Percentages of Magnesium, Iron and Calcium
Silicate "Molecules" Comprising the
Pyroxenes of Table 45.

<u>Sample</u>	<u>Crystal Size, μm</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
		<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A2011	12x50	48.4	14.5	37.2	Augite
A2011	40x75	51.6	16.1	32.4	Augite
A2011	40x40	51.2	11.6	37.2	Augite
A2011	25x40	54.1	22.2	23.8	Subcalcic Augite
A2012	25x40	46.7	20.8	32.5	Augite
A2012	40x50	49.7	15.6	34.7	Augite
A2012	25x40	43.5	17.1	39.4	Augite
A2012	15x15	53.9	25.4	20.7	Subcalcic Augite
A2013	25x150	45.6	11.1	43.4	Augite
A2013	30x100	44.7	16.6	38.7	Augite
A2013	30x50	48.4	27.5	24.1	Subcalcic Augite
A2013	50x75	44.1	42.0	13.9	Intermediate Pigeonite
A2014	40x50	47.0	19.9	33.1	Augite
A2014	15x40	60.9	28.8	10.3	Magnesium Pigeonite
A2014	40x50	48.5	20.0	31.5	Augite
A2014	30x40	39.7	23.2	37.1	Augite
A4007	50x100	42.8	16.6	40.6	Augite
A4007	400x400	49.3	12.1	38.5	Augite
A4007	50x75	53.1	18.9	28.0	Augite
A4007	20x35	45.5	13.9	40.6	Augite
A4008	25x25	49.0	17.2	33.9	Augite
A4008	50x100	46.5	20.5	33.0	Augite
A4008	50x100	58.8	30.6	10.6	Magnesium Pigeonite
A4008	30x40	58.0	32.9	9.1	Magnesium Pigeonite
A4008	75x75	45.8	14.0	40.2	Augite
A4008	25x40	52.2	38.1	9.7	Intermediate Pigeonite
A4009	25x50	43.4	13.3	43.3	Augite
A4009	25x50	48.6	15.4	36.0	Augite
A4009	25x75	46.3	27.4	26.3	Augite
A4009	10x25	53.5	34.9	11.6	Magnesium Pigeonite

TABLE 46 (continued)

<u>Sample</u>	<u>Crystal Size, μm</u>	<u>Mole Percent</u>			<u>Pyroxene Identification</u>
		<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A5006	50x80	48.1	13.1	38.8	Augite
A5006	75x125	45.9	20.0	34.1	Augite
A5006	30x180	59.9	31.2	8.8	Magnesium Pigeonite
A5006	30x60	53.8	36.8	9.4	Intermediate Pigeonite
A5006	20x150	49.0	40.4	10.5	Intermediate Pigeonite
A5007	50x75	49.0	15.7	35.2	Augite
A5007	25x40	59.6	27.8	12.6	Magnesium Pigeonite
A5007	30x75	45.2	16.0	38.8	Augite
A5007	30x50	54.4	34.9	10.7	Magnesium Pigeonite
A5007	40x70	46.8	10.7	42.4	Augite
A5007	25x40	48.6	20.7	30.7	Augite
A5008	40x50	45.9	12.8	41.4	Augite
A5008	20x25	45.4	12.3	42.3	Augite
A5008	25x70	39.2	32.2	28.6	Augite
A5008	40x50	45.1	22.4	32.4	Augite
A5008	25x50	45.3	13.6	41.1	Augite
A5009	50x60	49.0	16.7	34.3	Augite
A5009	50x55	47.4	10.6	42.0	Augite
A5009	10x25	35.9	24.8	39.2	Augite
A5009	35x50	46.2	14.2	39.6	Augite
A5010	40x160	44.1	11.7	44.2	Augite
A5010	25x60	47.2	10.3	42.5	Augite
A5010	75x75	48.0	12.0	40.0	Augite
A5011	75x75	41.8	22.4	35.8	Augite
A5011	40x50	46.0	16.9	37.1	Augite
A5011	25x40	45.8	10.7	43.5	Augite
A5011	25x35	48.7	12.8	38.5	Augite

zoning of the Pomona pyroxene crystals. The latter will be discussed in detail later. There is an indication of a high calcium - low calcium grouping of the pyroxenes or pigeonite-augite grouping. Pigeonite normally inverts to an orthorhombic pyroxene, and its occurrence is restricted to lavas where it is a product of rapid crystallization and cooling of the flow. In plutonic rocks, inverted pigeonites can be identified by augite lamellae along the (001) planes of the original pigeonite in an orthorhombic pyroxene. The pigeonite in the Pomona exists at room temperature today because cooling was too rapid to allow inversion to augite-orthorhombic pyroxene. The later pigeonites usually become progressively iron-enriched.

The normal course of pyroxene crystallization usually proceeds from the initial two pyroxene (augite-pigeonite) to the one pyroxene (augite) field. Thus, the Pomona was "frozen", or rapidly cooled, not progressing past the initial two pyroxene condition for main stage mineral crystallization.

Scans of specific pyroxene crystals from DH-5 well samples for magnesium, calcium and iron content are given in Figures 36 through 41. Pyroxenes from all three well samples were not scanned because of the extra expenses involved. More than two hours of instrument time is required for each scan. Several normal whole pyroxene analyses can be accomplished in the time required for one scan. The number of scans was purposely limited to one Pomona well section (DH-5) in order to conserve time and money.

The most important constituent of these scans from a mineralogical viewpoint is the wt% CaO. In general <6 wt% CaO indicates pigeonite, 6 to 11 wt% CaO indicates a subcalcic augite, and >11 wt% CaO indicates an augite. The wt% FeO and MgO also change, but usually CaO exerts the greatest control on mineralogy. Note that all of the pyroxene compositions of Figure 2 are less than 50% FeSiO₃, indicating again a relatively early and short period of pyroxene crystallization.

The zoning in these pyroxenes is rather unusual. An individual pyroxene crystal in each case was scanned lengthwise and across the crystal. Thus, the scan lines are 90° to each other. The classical zoning sequence would result in a pigeonite core with an augite composition rim, or vice versa. As can be seen from Figure 36 (A5006), for example, the crystal is actually zoned in a peculiar manner. In this 60 by 100 μm pyroxene, the lengthwise scan from 0 to almost 40 μm is a pigeonite (probably ferropigeonite), from almost 40 μm to a little past 40 μm is a subcalcic augite area, and from there to 100 μm is a normal augite, grading once again into a small area of subcalcic augite near 100 μm. The crosswise scan shows subcalcic

FIGURE 36. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 60 by 100 μm Pyroxene Crystal Contained in Sample A5006

FIGURE 37. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 25 by 40 μm Pyroxene Crystal Contained in Sample A5007

FIGURE 38. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 70 by 70 μm Pyroxene Crystal Contained in Sample A5008

FIGURE 39. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 50 by 55 μm Pyroxene Crystal Contained in Sample A5009

FIGURE 40. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 35 by 60 μm Pyroxene Crystal Contained in Sample A5010

FIGURE 41. Electron Microprobe Scans of Magnesium, Calcium and Iron Content of a 30 by 40 μm Pyroxene Crystal Contained in Sample A5011

augite on both ends of the 0 to 60 μm distance, but no pyroxene of pigeonitic composition. This pyroxene crystal, then, has a pigeonite composition on one end up to nearly 40% of the crystal length, and an augite core with rims of subcalcic augite around the other end and both sides. The pyroxene CaO wt% scan in Figure 4 (A5007) shows an augite crystal grading into subcalcic augite-pigeonite along one side only. A single side grading into pigeonite from augite also is shown in pyroxene crystal scans given in Figures 38 (A5008) and 41 (A5011). A resemblance to normal pyroxene crystal zoning can be seen in Figures 39 (A5009) and 40 (A5010) where the CaO wt% tends to decrease on both sides of the crystal in the crosswise scans. Such peculiar zoning probably results from growth of the two pyroxenes in a restricted or limited media. Otherwise, the pyroxene crystal would have a core of either augite or pigeonite (both can occur as cores) surrounded by a rim of augite or pigeonite. Growth has apparently taken place only on one crystal face in many instances. Another possible cause of pyroxene zoning could be variations in the availability of calcium in the crystallization media because of the proximity of growing feldspar crystals. The feldspars are higher in calcium than is usual in the rest of the flow sequence. The transition from pigeonite to augite is not abrupt, so that these pyroxene crystals probably represent continuous, rather than intermittent, crystal growth.

In any case, the pyroxenes in the Pomona are zoned, and in a rather unusual and easily recognizable manner. In addition, the feldspars are distinctively higher in calcium, as a group, than the feldspars from the other flow units. More useful information may be generated by this type of an intensive study of a few selected flow units than can be generated by a cursory examination of the whole flow series.

Metallics

The compositions of the Pomona metallics, referred to an ilmenite molecule, are given in Table 47. Many of the metallics were in small, feathery crystals in the groundmass, and included areas of silicates within the crystals. The resulting metallics analyses were contaminated by the silicate inclusions in several instances, as noted in Table 47. The remaining metallics analyses were predominantly ilmenites. Of the 27 analyses, 19 were ilmenites (70%).

TABLE 47. Pomona Metallics Analyses

Microprobe Chemical Analyses of Metallics
 Referred to a Molecule of $(\text{Fe}, \text{Mg}, \text{Mn}, \text{Cr})_2$
 $(\text{Ti})_2\text{O}_6$.

<u>Sample</u>	<u>Ti</u>	<u>Mg</u>	<u>Fe</u>	<u>Mn</u>	<u>Cr</u>	<u>ΣMg,Fe Mn,Cr</u>	<u>Crystal Size, μm</u>	<u>Mineral</u>
A2011	(metallics small and contaminated with silicates)							
A2012	(metallics small and contaminated with silicates)							
A2013	1.696	0.189	2.375	0.020	0.007	2.591	5x50	Ilmenite-magnetite
A2013	1.982	0.217	1.782	0.018	0.006	2.023	10x15	Ilmenite
A2013	1.960	0.160	1.878	0.020	0.007	2.065	10x50	Ilmenite
A2013	1.979	0.180	1.824	0.019	0.007	2.030	25x30	Ilmenite
A2014	(metallics small and contaminated with silicates)							
A4007	(metallics small and contaminated with silicates)							
A4008	1.972	0.180	1.845	0.013	0.006	2.044	20x40	Ilmenite
A4008	1.940	0.186	1.897	0.018	0.007	2.108	15x35	Ilmenite
A4008	1.115	0.144	3.576	0.027	0.008	3.755	40x50	Magnetite-ilmenite
A4008	1.075	0.211	3.591	0.023	0.008	3.833	5x5	Magnetite-ilmenite
A4008	1.070	0.190	3.612	0.026	0.011	3.839	10x10	Magnetite-ilmenite
A4008	1.925	0.198	1.908	0.017	0.009	2.132	40x125	Ilmenite
A4009	1.846	0.190	2.084	0.014	0.007	2.295	25x30	Mostly ilmenite
A4009	1.112	0.212	3.486	0.017	0.020	3.735	50x50	Magnetite-ilmenite
A4009	1.837	0.175	2.102	0.019	0.010	2.306	30x100	Mostly ilmenite
A4009	1.874	0.157	2.048	0.015	0.011	2.231	40x50	Mostly ilmenite
A5006	1.931	0.124	1.979	0.014	0.007	2.124	15x60	Ilmenite
A5006	1.913	0.230	1.912	0.014	0.006	2.162	7x15	Ilmenite
A5006	1.926	0.203	1.904	0.013	0.009	2.129	20x100	Ilmenite
A5006	1.127	0.228	3.473	0.018	0.009	3.728	10x12	Magnetite-ilmenite
A5006	1.901	0.206	1.940	0.023	0.010	2.179	30x125	Ilmenite
A5007	(metallics small and contaminated with silicates)							
A5008	(metallics small and contaminated with silicates)							
A5009	(metallics small and contaminated with silicates)							
A5010	1.106	0.191	3.531	0.032	0.012	3.766	40x60	Magnetite-ilmenite
A5010	1.891	0.134	2.043	0.022	0.006	2.205	15x40	Mostly ilmenite
A5010	1.917	0.146	1.987	0.017	0.006	2.156	10x40	Ilmenite
A5010	1.913	0.149	1.954	0.017	0.006	2.126	7x25	Ilmenite
A5011	1.946	0.161	1.900	0.018	0.010	2.089	25x125	Ilmenite
A5011	1.959	0.089	1.969	0.014	0.003	2.075	10x25	Ilmenite
A5011	1.962	0.089	1.957	0.018	0.003	2.067	12x100	Ilmenite
A5011	1.703	0.102	2.443	0.016	0.011	2.572	30x100	Ilmenite-magnetite

Groundmass Compositions

The groundmass compositions and whole rock analyses are presented in Table 48. The whole rock analyses were obtained from ARHCO well logs.

All of the analyses of the groundmasses, representing residual liquid samples of the melt composition near the end of the crystallization sequence, were enriched in silica and potassium. In some cases (A2011, A4007, A4009, and A5007), samples near the outer edges of the flow units showed an enrichment in sodium. Some enrichment in iron and titanium also was apparent, especially when the metallics crystallized as part of the groundmass. Depletion usually resulted for magnesium, calcium, sodium, iron and titanium, while the alumina content remained nearly the same throughout the differentiation and distribution process.

Elemental Distributions

The distribution of manganese and chromium between the whole rock, pyroxenes and metallics for several samples is given in Table 49. Manganese and chromium are given in parts per million (ppm). The weight percents were arithmetically averaged for each sample from the pyroxene and metallics analyses. The whole rock manganese and chromium analyses are given where available on the well logs.

According to Prinz¹⁵ (in Hess and Poldervaart, p. 302), the arithmetic mean of chromium in basalts is 162 to 168 ppm chromium. The chromium content of these samples ranges from 104 to 130 ppm, considerably less than Prinz's mean value. Thus, the chromium content of the pyroxenes and metallics is not due to an unusually high chromium content in the initial melt. The chromium, rather, is concentrated in the pyroxenes and metallics for crystallographic reasons.

The chrome spinels (chromite and picotite) are the first chromium minerals to crystallize, and usually are found as inclusions in olivine crystals. Pyroxenes also are known to remove considerable amounts of the available chromium. McDougall and Lovering¹⁶ reported that augite contained more chromium than coexisting pigeonite. An examination of the pyroxene analyses in Table 3 shows this same trend here, with the highest chromium values in the augites rather than in the pigeonites. The metallics, though, contain up to three times as much chromium in Table 49. According to Prinz, however, ilmenite contains little or no chromium. The major

TABLE 48. Pomona Groundmass and Whole Rock Analyses

Groundmass Compositions from Electron Microprobe
Chemical Analyses. "W" analyses are whole rock
analyses.

Sample	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	FeO	TiO ₂	Total Wt. %
A2011	64.0	10.3	<1.3	5.0	<0.3	2.7	6.3	0.6	89.7
A2011	65.6	13.1	2.4	2.8	---	3.8	7.6	0.6	96.4
A2011	64.5	13.6	2.4	4.4	---	2.9	6.2	2.5	97.2
A2011	70.4	14.1	---	7.0	---	1.1	3.7	0.4	96.7
A2011W	55.0	13.5	2.1	0.4	7.2	10.2	11.3	1.70	101.4
A2012	58.6	8.1	---	4.7	---	3.9	12.7	4.9	92.9
A2012	64.7	10.6	---	3.3	---	3.4	9.9	1.2	94.1
A2012	68.0	11.2	---	5.8	---	3.3	8.8	0.3	98.1
A2012	63.0	9.2	---	3.6	---	5.0	13.6	2.2	97.5
A2012W	57.1	13.8	2.3	0.6	7.3	9.1	11.4	1.65	103.25
A2013	69.8	11.8	---	7.5	---	1.3	3.0	0.4	94.1
A2013	67.0	10.7	---	7.0	0.9	3.2	2.7	0.3	93.2
A2013	69.5	10.9	---	5.9	---	1.2	3.1	0.3	90.8
A2013	75.5	11.1	---	8.3	---	0.8	2.8	0.4	98.9
A2013W	56.9	14.1	2.4	0.5	7.5	9.4	11.3	1.70	103.8
A2014	64.9	9.9	---	5.2	---	3.0	9.2	1.6	94.1
A2014	66.0	10.5	---	5.7	---	2.6	9.1	1.6	96.4
A2014	64.9	10.5	---	2.2	---	4.1	10.0	1.3	93.9
A2014	60.5	10.5	---	4.9	---	2.8	12.1	3.2	95.1
A2014W	58.0	14.0	2.4	0.6	7.6	9.1	11.1	1.76	104.56
A4007	63.6	10.4	---	5.6	---	3.9	11.5	1.3	97.8
A4007	63.1	18.0	2.9	1.9	---	6.0	3.1	0.2	95.2
A4007	63.0	14.3	3.1	4.1	---	4.2	7.3	0.4	97.0
A4007	60.6	14.6	4.1	2.6	---	5.9	3.8	0.4	92.0
A4007W	51.0	13.5	2.3	0.2	7.3	10.1	10.9	1.60	96.9
A4008	73.8	12.6	---	8.3	---	0.4	2.1	0.4	97.6
A4008	75.7	11.8	---	9.7	---	0.5	2.2	0.4	100.3
A4008	73.9	11.8	2.4	8.5	0.5	0.9	2.8	0.5	101.3
A4008	62.6	9.3	---	7.4	0.9	6.0	3.2	0.3	95.6
A4008W	51.0	13.5	2.3	0.3	7.6	10.2	10.9	1.60	97.4
A4009	72.1	14.7	4.3	9.9	---	0.4	0.5	<0.2	101.9
A4009	56.7	14.9	4.7	6.9	---	1.4	3.4	---	88.0
A4009	65.0	14.7	4.0	8.3	---	1.3	1.1	---	94.4
A4009	59.5	19.5	6.7	4.5	---	4.0	1.0	---	95.2
A4009W	51.0	13.3	2.4	0.3	7.4	10.2	10.8	1.70	97.1

TABLE 48 (continued)

<u>Sample</u>	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>MgO</u>	<u>CaO</u>	<u>FeO</u>	<u>TiO₂</u>	<u>Total Wt. %</u>
A5006	75.6	12.4	---	8.0	---	0.6	2.8	0.4	99.8
A5006	71.5	12.1	---	7.5	---	2.4	3.2	0.4	97.8
A5006	73.4	11.4	---	6.8	---	2.0	3.0	0.8	94.4
A5006	70.3	11.0	---	7.3	0.9	2.5	2.6	0.4	95.8
A5006W	53.0	14.0	2.4	0.3	7.1	9.7	10.8	1.60	98.9
A5007	64.0	12.3	4.4	4.4	---	2.8	6.1	0.6	95.2
A5007	58.5	8.9	---	6.1	0.7	4.8	13.4	1.2	94.6
A5007	71.5	10.1	---	7.5	---	1.6	3.9	0.6	95.5
A5007	68.1	14.1	4.3	3.3	---	2.2	4.2	0.6	97.4
A5007W	53.0	13.9	2.2	0.3	7.4	9.7	10.8	1.70	99.0
A5008	70.1	12.4	---	6.2	---	3.3	4.2	----	96.7
A5008	59.1	9.6	---	4.4	0.8	3.9	9.0	1.2	89.6
A5008	70.4	12.3	---	7.4	---	1.5	3.8	0.6	96.6
A5008	65.0	12.3	---	3.9	1.1	2.8	8.9	1.3	95.7
A5008W	52.0	14.2	2.4	0.7	7.6	8.6	11.0	1.60	98.1
A5009	75.1	11.2	---	8.1	---	0.8	2.7	0.3	98.2
A5009	72.9	10.6	---	7.4	---	1.0	1.9	0.3	94.4
A5009	64.6	9.5	---	6.5	---	3.3	6.9	0.7	92.4
A5009	69.9	10.8	---	7.6	---	2.2	4.9	0.4	96.1
A5009W	52.0	14.2	2.4	0.7	7.7	9.6	11.4	1.60	99.6
A5010	74.5	11.5	---	9.6	---	1.1	1.7	0.4	98.9
A5010	77.5	13.0	---	9.6	---	0.6	1.5	0.4	102.6
A5010	72.6	10.7	---	9.3	---	0.6	1.7	----	94.9
A5010	75.1	13.4	---	9.3	---	0.6	1.5	0.4	100.3
A5010W	52.0	14.2	2.4	0.5	7.8	9.5	11.0	1.60	99.0
A5011	69.4	9.9	---	7.0	---	3.7	0.9	0.5	94.3
A5011	67.2	12.6	2.7	9.3	---	1.2	0.7	0.2	94.3
A5011	71.1	12.0	---	8.8	---	0.3	0.9	----	93.1
A5011	74.8	9.6	---	7.2	---	0.8	1.0	0.4	94.3
A5011W	51.0	13.8	2.4	0.6	7.4	9.4	10.6	1.60	96.8

TABLE 49. Pomona Manganese and Chromium Distribution

Distribution of Manganese and Chromium During
Crystallization of the Basalt.

<u>Sample</u>	<u>Element Location</u>	<u>Ave. Mn Wt. %</u>	<u>Ave. Cr Wt. %</u>	<u>Mn, ppm</u>	<u>Cr, ppm</u>
A2013	Metallics	0.3485	0.1170	3485	1170
	Pyroxenes	0.1810	0.0412	1402	412
	Whole Rock	-----	0.0130	-----	130
A4008	Metallics	0.3454	0.1290	3454	1290
	Pyroxenes	0.2051	0.0629	2051	629
	Whole Rock	0.1900	0.0133	1900	133
A4009	Metallics	0.2819	0.1914	2819	1914
	Pyroxenes	0.1762	0.0655	1762	655
	Whole Rock	0.1700	0.0120	1700	120
A5006	Metallics	0.2890	0.1366	2890	1366
	Pyroxenes	0.1626	0.0765	1626	765
	Whole Rock	-----	-----	-----	-----
A5010	Metallics	0.3798	0.1205	3798	1205
	Pyroxenes	0.0990	0.1058	990	1058
	Whole Rock	0.1900	0.0105	1900	105
A5011	Metallics	0.2982	0.1160	2982	1160
	Pyroxenes	0.0813	0.0553	813	553
	Whole Rock	0.1700	0.0104	1700	104

chromium values, then, must be in a spinel-type structure associated with the ilmenites, either as small amounts of chromite or in magnetite which also is a spinel-type structure. Gjelsvik¹⁷ studied the magnetites and ilmenites from the Norwegian titaniferous ores and reported that chromium was strongly concentrated in the magnetite portion of the ore. Manganese substitution also is common in pyroxenes.

It should also be mentioned that the highest chromium values in the pyroxenes are usually found in the high magnesium, or earlier-formed pyroxenes. Much above 15 wt% FeO, the chromium content is low because these are the later-formed pyroxenes. An examination of Table 45 shows an apparent inverse relationship between chromium and iron pyroxene content, i.e., the lower iron pyroxenes tend to contain more chromium.

Optical Photomicrographs

All photomicrographs are 80X magnification. They were taken with reflected light (A) and polarized, transmitted light (B).

Two generations of feldspar crystals are identifiable in these photos, a very large size feldspar generation and a smaller, and probably later, generation of feldspars. The large feldspar phenocrysts are contaminated by many smaller crystals of metallics and pyroxenes, and by areas of groundmass.

The metallics vary from medium size crystals to small, dendritic growths in the groundmass. The larger metallics crystals show no evidence in the reflected light photos for more than a single mineral phase.

The pyroxenes in these photos usually are seen by their very irregular crystal outlines to have occupied spaces available after feldspar crystallization. The metallics crystallized at nearly the same time as the pyroxenes, as the metallics are sometimes partially surrounded by the pyroxenes (A4009A). The crystallization of most of the dendritic metallics was probably somewhat later than pyroxene crystallization. Relatively rapid cooling of the flow often leads to overlapping or telescoping of the normal crystallization sequence.

There are also microcrystalline groundmass areas (A4007B) and other areas where the groundmass has altered to a mineraloid with the approximate composition of high iron, dioctahedral smectite.

A

80X

B

80X

A2011

A

80X

B

80X

A2012

A

80X

B

80X

A2012

A

80X

A

80X

A2013

B **80X**
A2013

A **80X**
A2014

B **80X**
A2014

A **80X**
A4007

B **80X**
A4007

A **80X**
A4008

B **80X**
A4008

A **80X**
A4009

B
A4009

80X

A
A5006

80X

A

80X

B

80X

A5007

A

80X

B

80X

A5008

A

80X

B

80X

A5009

A

80X

B

80X

A5010

A

80X

B

80X

A5011

X-Ray Emission Photomicrographs

The following x-ray emission and electron scattering photos were selected from the Pomona samples. The normal metallics, feldspars, pyroxenes and altered groundmasses are illustrated by these samples and can be easily discerned in them by comparison of elemental x-ray emission photos. In addition, manganese and chromium photos are given to show that very limited information as to mineral chromium and manganese content can be obtained from them. The emission photos are useful in a qualitative examination, but are not necessarily adequate for a study of elemental distribution by themselves. Chemical analyses by the microprobe were required to locate manganese and chromium accumulating minerals.

The photos have other uses, though, such as confirming the existence of mineral zoning in some cases. For example, A2013 shows a pyroxene crystal on the right-hand side of the electron scattering photo and a little more than halfway up the photo (circled on photo). In the iron emission photo, the concentration of iron diminishes in moving from left to right on this crystal. Conversely, the magnesium concentration on the magnesium emission photo is seen to increase in moving in the same direction across the crystal. The calcium emission photo was not included because little is shown due to the proximity of so much high calcium feldspar. Other instances of pyroxene zoning can be seen in the other figures, especially in the iron emission photos. The pyroxenes in all of the three well samples are zoned. The zoning was subsequently confirmed by scans of the pyroxenes in samples from one of the wells (DH-5).

HIGH CHROMIUM BASALT FLOW

A flow unit in DH-4 was chosen for detailed study. The samples and their locations in the basalt section are given in Figure 42. This particular flow unit was chosen for study for several reasons.

First, this unit was lumped with the Pomona flow unit above it. The unit was not classified as belonging to the Pomona, and there is a reasonable doubt as to whether or not it belongs with the Pomona on the basis of K_2O/MgO correlations. Secondly, how well can a flow contact be identified on mineralogical evidence alone?

A third reason for looking at this particular unit in detail was the high, whole rock chromium content of A4013 (432 ppm).

ELECTRON SCATTERING
200X

Fe

Ti

Al

A 2013

Mg

K

Mn

Cr

A 2013

ELECTRON SCATTERING
200X

Fe

Ti

Al

A4008

Mg

K

Mn

Cr

A4008

ELECTRON SCATTERING

200X

Fe

Ti

Al

A4009

Mg

K

Mn

Cr

A4009

ELECTRON SCATTERING

200X

Fe

Ti

Al

A5006

Mg

K

Mn

Cr

A5006

ELECTRON SCATTERING
200X

Fe

Ti

Al

A5010

Mg

K

Mn

Cr

A5010

ELECTRON SCATTERING

200X

Fe

Ti

Al

-A5011

Mg

K

Mn

Cr

A5011

Where is this high chromium content located? Is it dispersed throughout the rock in several minerals, or concentrated in one mineral?

With these questions in mind, the examination of the samples shown in Figure 42 was undertaken.

Feldspars

The contents of the feldspars, as computed from the microprobe analyses, are given in Table 50. Sample 4009 is from the bottom of the Pomona. Several mineral analyses from A4009 were given previously. All of the feldspars analyzed at that time were labradorites. The new analyses show that one of the large, main-stage feldspars was bytownite, as seen in Table 51. Analytical data on the flow unit represented by samples A4010 through A4015 show that many of the main-stage large feldspars of this flow were bytownites. This circumstance suggests that the feldspars were crystallized very early, probably before and during flow extrusion. Note the relatively sharp break in feldspar compositions (bytownite to labradorite) over the lower contact, or between A4015 and A4016. Bytownite is not at all unusual in a basalt, but it is rather unusual in the case of this flow unit to see so much of it. The upper contact is somewhat less distinct than the basal contact, but, in general, the presence of such relatively large amounts of bytownite in this flow unit helps to differentiate it from those units immediately above and below.

The presence of iron in these feldspars in nearly uniform amounts would indicate that the iron is probably located in the feldspar lattice. A feldspar crystal scan will be presented later to show just how uniform the iron distribution was across a feldspar crystal.

The electron scattering photos of the feldspars shown in the following three pages of photos indicate the scanning direction and distance with an arrow across the plagioclase crystal. The crystal size can be obtained from the scan distances given in Figures 43 through 49. All of the crystal scans show minor, or normal, plagioclase zoning. Oscillatory zoning in plagioclases, due to recurrent supersaturation of the melt in anorthite, is apparently a part of normal crystallization sequence.¹⁸ Note on the scans that all of these plagioclases are high in calcium content. There were no high potassium feldspars as there were in the high barium flow.

FIGURE 42. Location of Samples in DH-4 Well Basalt Column

FIGURE 43. Scan Across a Feldspar Crystal (A) in A4009

FIGURE 44. Scan Across a Feldspar Crystal (B) in A4009

FIGURE 45. Scan Across a Feldspar Crystal in A4010

FIGURE 46. Scan Across a Feldspar Crystal in A4011

FIGURE 47. Scan Across a Feldspar in A4014

FIGURE 48. Scan Across a Feldspar Crystal in A4015

FIGURE 49. Scan Across a Feldspar Crystal in A4016

TABLE 50. DH-4 High Chromium Basalt Feldspar Analyses
Contents of 26 Feldspar Molecules as Computed from the
Microprobe Chemical Analyses and Referred to 32 Oxygens.

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>ΣCa,K, Na,Fe</u>
A4009	9.616	6.226	15.842	2.779	0.046	1.094	0.121	4.040
A4009	9.935	5.937	15.862	2.216	0.068	1.912	0.117	4.223
A4010	9.678	6.136	15.814	2.581	0.090	1.363	0.132	4.166
A4010	9.784	6.075	15.859	2.426	0.033	1.480	0.102	4.041
A4011	9.880	5.883	15.763	2.453	0.069	1.461	0.104	4.087
A4011	9.550	6.515	16.065	2.556	0.045	1.271	0.135	4.007
A4012	9.528	6.321	15.849	2.909	0.044	0.945	0.130	4.028
A4012	9.784	5.911	15.695	2.639	0.069	1.020	0.239	3.967
A4012	9.625	6.413	16.038	2.518	0.045	0.978	0.225	3.766
A4012	10.692	4.687	15.379	1.144	0.281	2.516	0.327	4.268
A4013	9.420	6.496	15.916	3.043	0.048	0.790	0.097	3.978
A4013	9.463	6.565	16.028	2.972	0.012	0.664	0.083	3.731
A4013	10.028	5.812	15.840	2.081	0.099	1.869	0.097	4.146
A4013	9.371	7.008	16.379	2.572	0.050	0.964	0.116	3.702
A4013	9.921	5.782	15.703	2.586	0.050	1.306	0.098	4.040
A4014	9.831	6.178	16.009	2.350	0.070	1.327	0.122	3.869
A4014	9.813	6.187	16.000	2.375	0.069	1.431	0.089	3.964
A4014	9.447	6.479	15.926	2.910	0.049	1.049	0.082	4.090
A4015	9.830	6.112	15.942	2.435	0.048	1.327	0.079	3.889
A4015	9.776	6.157	15.933	2.516	0.094	1.170	0.094	3.873
A4016	9.915	6.108	16.023	2.193	0.091	1.545	0.105	3.934
A4016	9.872	6.124	15.996	2.237	0.069	1.686	0.090	4.082
A4016	9.849	6.003	15.852	2.389	0.069	1.541	0.105	4.104
A4016	9.963	5.848	15.811	2.314	0.069	1.623	0.103	4.109
A4016	9.996	5.898	15.894	2.167	0.092	1.763	0.090	4.112
A4016	9.990	5.895	15.885	2.189	0.091	1.694	0.105	4.079

TABLE 51. DH-4 High Chromium Basalt Feldspar Compositions

Feldspar Compositions as Determined from the Data of Table 1.
 Ab = albite, An = Anorthite, Or = Orthoclase.

Sample	Molecular %			Feldspar	Crystal Size, μm
	Ab	An	Or		
A4009	27.9	70.9	1.2	Bytownite	100x200
A4009	46.5	51.8	1.7	Labradorite	50x125
A4010	33.8	64.0	2.2	Labradorite	25x150
A4010	37.6	61.6	0.8	Labradorite	100x100
A4011	36.7	61.6	1.7	Labradorite	150x250
A4011	32.8	66.0	1.2	Labradorite	25x40
A4012	24.3	74.6	1.1	Bytownite	50x300
A4012	27.4	70.8	1.8	Bytownite	25x100
A4012	27.6	71.1	1.3	Bytownite	75x525
A4012	63.8	29.1	7.1	Andesine	10x25
A4013	20.4	78.4	1.2	Bytownite	32x125
A4013	18.2	81.5	0.3	Bytownite	225x525
A4013	46.2	51.4	2.4	Labradorite	25x125
A4013	26.9	71.7	1.4	Bytownite	22x200
A4013	33.1	65.6	1.3	Labradorite	25x125
A4014	35.4	62.7	1.9	Labradorite	35x50
A4014	36.9	61.3	1.8	Labradorite	240x550
A4014	26.2	72.6	1.2	Bytownite	230x625
A4015	35.8	63.9	1.3	Labradorite	225x475
A4015	30.9	66.6	2.5	Labradorite	30x150
A4016	40.3	57.3	2.4	Labradorite	40x150
A4016	42.2	56.1	1.7	Labradorite	110x750
A4016	38.5	59.8	1.7	Labradorite	30x50
A4016	40.5	57.8	1.7	Labradorite	25x150
A4016	43.8	53.9	2.3	Labradorite	125x275
A4016	42.6	55.1	2.3	Labradorite	15x25

Pyroxenes

The pyroxene compositions computed from the microprobe analyses are given in Table 52. The pyroxene minerals are identified in Table 53. As a group, all of the pyroxenes in the flow unit are high in magnesium content and low in iron content. Like the feldspars, this would suggest that the pyroxenes here crystallized early in the cooling sequence. The late pyroxenes are characteristically high in iron content. Though the augites below (in A4016) the flow contact tend to be somewhat higher in iron content, the difference is not marked. The pyroxenes are not of much help in delineating flow contacts, at least not in this case.

The chromium content of all of these augites was below the chromium detection limit.

Pyroxene Scans

The following pages show electron scattering photos of the scanned pyroxene crystals of Figures 50 through 56. The arrows indicate the direction and length of the scan. The bulk of the scans are of high magnesium augites. However, B in A4009 (Figure 51) is a pigeonite and A in Figure 54 is an altered or zoned olivine. The iron in this olivine is quite unevenly distributed, as the iron x-ray emission photo shows. Note that there are several other olivine crystals in the same area as the scanned olivine. There is some zoning in these pyroxene constituents. The highest magnesium values should occur in the earliest formed part of the crystal, or toward the middle. The highest magnesium areas generally are toward the middle section of these crystals.

Metallics

The elemental content of the metallic oxides, based on the microprobe analyses, is given in Table 54. Note that analyses of metal oxides from A4010, A4011 and A4016 are not represented. These are missing because the iron and titanium were dispersed through the groundmass as a result of rapid cooling of the flow units at their tops. Samples A4010 and A4011 are near the top of a flow unit, as is A4016. The size and distribution of metallics crystals is a very good indication of where in the flow unit they are located. Those at the top of the flow tend to be very small and evenly distributed due to rapid cooling rates. The metallics near the center of the flow may be largest in size, those near the base, which also lost heat relatively

FIGURE 50. Scan Across a Pyroxene Crystal (A) in A4009

FIGURE 51. Scan Across a Pyroxene Crystal (B) in A4009

FIGURE 52. Scan Across a Pyroxene Crystal in A4010

FIGURE 53. Scans Across Pyroxene Crystals (A and B) in A4011

FIGURE 54. Scans Across Pyroxene Crystals (C and A) in A4014

FIGURE 55. Scan Across a Pyroxene Crystal in A4015

FIGURE 56. Scan Across a Pyroxene Crystal in A4016

TABLE 52. DH-4 Chromium Basalt Pyroxene Analyses

Pyroxene Compositions, Based on the Molecule $(\text{Mg}, \text{Fe}^{+2}, \text{Ca}, \text{Ti}, \text{K}, \text{Mn}, \text{Al})_2(\text{Al}, \text{Si})_2\text{O}_6$ as Determined from the Microprobe Chemical Analyses.

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	Σ	Crystal Size, μm
A4009	1.935	0.070	2.005	1.093	0.229	0.680	0.008	0.004	0.006	--	2.020	85x160
A4009	1.981	0.019	2.000	1.116	0.655	0.199	0.008	0.003	0.012	0.006	1.999	35x45
A4010	1.926	0.096	1.996	0.918	0.311	0.713	0.021	0.027	0.006	--	2.022	100x200
A4010	1.965	0.046	2.011	1.120	0.245	0.595	0.011	0.041	0.003	--	2.015	50x75
A4011	1.922	0.078	2.000	1.027	0.246	0.688	0.016	0.004	0.003	0.027	2.011	40x100
A4011	1.887	0.113	2.000	0.994	0.238	0.730	0.019	0.004	--	0.036	2.021	55x120
A4012	1.924	0.030	1.954	1.012	0.441	0.593	0.028	--	0.006	--	2.080	30x50
A4012	1.971	0.029	2.000	0.929	0.394	0.600	0.027	--	0.006	0.021	1.977	75x100
A4012	1.927	0.073	2.000	0.860	0.441	0.645	0.027	0.004	0.006	0.006	1.989	20x70
A4012	1.926	0.038	1.964	0.928	0.435	0.652	0.036	--	0.009	--	2.060	100x125
A4013	1.905	0.064	1.969	0.700	0.543	0.737	0.051	0.005	0.010	--	2.046	25x50
A4013	1.873	0.041	1.914	0.909	0.396	0.800	0.038	--	0.007	--	2.150	50x60
A4013	1.917	0.061	1.978	0.890	0.353	0.765	0.030	0.010	--	--	2.048	50x75
A4013	1.835	0.111	1.946	0.856	0.389	0.823	0.047	--	--	--	2.115	30x50
A4014	1.899	0.119	2.018	0.894	0.378	0.689	0.040	0.004	0.009	--	2.014	60x125
A4014	1.939	0.061	2.000	0.819	0.414	0.721	0.019	0.003	0.006	0.020	2.002	45x75
A4015	1.879	0.103	1.982	0.954	0.373	0.686	0.023	--	0.006	--	2.042	65x110
A4015	1.920	0.086	2.006	0.955	0.284	0.752	0.017	0.004	0.003	--	2.015	140x225
A4016	1.855	0.152	2.007	0.877	0.320	0.796	0.030	0.003	0.006	--	2.032	50x125
A4016	1.885	0.115	2.000	0.767	0.476	0.594	0.035	0.004	0.006	0.094	1.976	15x25
A4016	1.899	0.101	2.000	0.820	0.600	0.502	0.053	0.005	0.002	--	1.982	20x40
A4016	1.904	0.096	2.000	0.923	0.354	0.680	0.020	0.004	0.006	0.011	1.998	25x35
A4016	1.954	0.051	2.005	1.061	0.484	0.433	0.014	0.004	0.009	--	2.005	8x12

TABLE 53. DH-4 High Chromium Basalt Pyroxene Compositions

Percentages of Magnesium, Iron and Calcium Silicates
Comprising the Pyroxenes of Table 52.

<u>Sample</u>	<u>Molecular %</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
A4009	54.6	11.4	34.0	Augite
A4009	56.6	33.3	10.1	Magnesium Pigeonite
A4010	47.3	16.0	36.7	Augite
A4010	57.1	12.5	30.4	Augite
A4011	52.4	12.5	35.1	Augite
A4011	50.7	12.1	37.2	Augite
A4012	49.5	21.5	29.0	Augite
A4012	48.3	20.5	31.2	Augite
A4012	44.2	22.7	33.1	Augite
A4012	46.0	21.6	32.4	Augite
A4013	35.4	27.4	37.2	Augite
A4013	43.2	18.8	38.0	Augite
A4013	44.3	17.6	38.1	Augite
A4013	41.4	18.8	39.8	Augite
A4014	45.6	19.3	35.1	Augite
A4014	41.9	21.2	36.9	Augite
A4015	47.4	18.5	34.1	Augite
A4015	48.0	14.2	37.8	Augite
A4016	44.0	16.1	39.9	Augite
A4016	41.8	25.9	32.3	Augite
A4016	42.7	31.2	26.1	Augite
A4016	47.2	18.1	34.7	Augite
A4016	53.6	24.5	21.9	Subcalcic Augite

TABLE 54. DH-4 High Chromium Basalt Metallics Analyses

Microprobe Chemical Analyses of Metallic Oxides Referred
to a Molecule of $(\text{Fe}^{+2}, \text{Mg}, \text{Mn}, \text{Cr})_2(\text{Ti}^{+4})_2\text{O}_6$

Sample	Ti	Mg	Fe	Mn	Cr	Σ Mg, Fe,Mn,Cr	Crystal Size, μm	Mole %	
								Magnetite	Ilmenite
A4009	0.958	0.125	3.909	0.027	0.008	4.069	75x125	76.5	23.5
A4009	1.895	0.190	1.999	0.021	--	2.210	50x100	14.3	85.7
A4012	1.895	0.380	1.792	0.020	0.006	2.198	50x110	13.8	86.2
A4012	1.868	0.349	1.876	0.021	0.006	2.252	7x100	17.1	82.9
A4012	1.849	0.451	1.824	0.017	0.003	2.295	25x30	19.4	80.6
A4012	1.877	0.437	1.774	0.017	0.006	2.234	60x75	16.0	84.0
A4013	1.874	0.265	1.975	0.012	--	2.252	10x50	16.8	83.2
A4013	1.853	0.299	1.975	0.020	--	2.294	10x15	19.2	80.8
A4013	1.949	0.259	1.823	0.020	--	2.102	25x125	7.3	92.7
A4013	1.625	0.344	2.376	0.031	--	2.751	7x25	40.9	59.1
A4014	1.883	0.184	2.006	0.026	0.006	2.222	25x35	15.3	84.7
A4014	1.010	0.191	3.741	0.027	0.007	3.966	40x80	74.5	25.5
A4015	1.990	0.156	1.837	0.027	--	2.020	4x10	1.5	98.5
A4015	1.994	0.179	1.889	0.037	--	2.105	5x5	5.3	94.7

faster than the center, are next in size, while the smallest are near the flow top. This same iron-titanium distribution can be seen in the sections on photomicrographs and x-ray emission photos.

Note that chromium in the A4013 metallics is below the detection limit. Another examination of this high chromium sample was required to locate the chromium. The results of the reexamination are given in the chromium section.

Metallics Scans

There were no metallic oxide crystals large enough to scan in samples A4010, A4011 and A4016. Also, the feldspars, pyroxenes and metallics in A4012 and A4013 were analyzed, but not scanned. The scanning was done primarily to note any mineralogical differences across contacts, although A4013 was later examined in detail to determine the mineralogical location of its high chromium content. Scans across metal oxide crystals are given in Figures 57 through 59. Chromium oxide contents are given along with FeO, TiO₂ and SiO₂ contents where applicable. It appears very likely that these metallics are ilmenite-titaniferous magnetites although no direct petrographic evidence was found to support this.

Groundmass Compositions

The groundmass compositions, as determined by microprobe analysis, are given in Table 55. In terms of the iron and titanium, the least differentiation occurred in A4010 and A4016. This, once again, shows the effects of rapid cooling on the degree of differentiation. Iron and titanium differentiation by diffusion into large metallic oxide crystals is a good indication of the prevailing cooling rate.

Chromium

The compositions of three of the smaller metallic oxide crystals are given in Table 57. Two of them are chromites, or chrome spinels.

The chromite series is a subgroup of the much larger spinel group of minerals. Within the spinel group, there is a spinel series (spinel, gahnite, hercynite and galaxite; MgAl₂O₄, ZnAl₂O₄, FeAl₂O₄ and MnAl₂O₄, respectively), a

FIGURE 57. Scan Across a Metal Oxide Crystal in A4009

FIGURE 58. Scans Across Metal Oxides Crystals (A and B) in A4014

FIGURE 59. Scans Across Metal Oxides Crystals (A and B) in A4015

TABLE 55. DH-4 High Chromium Basalt Groundmass and Whole Rock Analyses

Groundmass Compositions from Electron Microprobe Chemical Analyses.

"W" Analyses are Whole Rock Analyses.

Sample	Wt %											Total
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	P ₂ O ₅	MnO	
A4009	72.1	14.7	4.3	9.9	<0.3	0.4	<0.2	0.5	<0.2	<0.2	<0.1	101.9
A4009	65.0	14.7	4.0	8.3	--	1.3	--	1.1	--	--	--	94.4
A4009	59.5	19.5	6.7	4.5	--	4.0	--	1.0	--	--	--	95.2
A4009W	51.0	13.3	2.4	0.3	7.4	10.2	0.05	10.8	1.7	--	0.17	97.32
A4010	62.3	13.5	<1.3	5.3	1.4	3.9	0.3	9.8	<0.2	0.9	<0.1	97.4
A4010	57.0	10.9	3.4	4.0	0.8	3.9	0.3	10.1	2.5	0.7	--	93.6
A4010	52.5	12.0	2.9	2.7	1.2	5.1	0.3	11.5	2.5	0.7	--	91.4
A4010W	52.0	13.6	2.4	0.9	5.8	9.0	0.08	10.8	1.0	--	0.17	96.55
A4011	63.1	11.7	<1.3	4.0	0.3	3.8	0.2	8.6	2.4	0.7	<0.1	94.5
A4011	66.8	13.4	3.0	3.8	0.6	4.1	0.2	7.5	1.9	1.0	--	102.3
A4011	63.9	13.7	<1.3	3.2	0.8	4.1	0.4	6.2	1.2	0.8	--	94.3
A4011W	50.0	14.1	2.3	0.9	6.1	9.0	0.06	11.1	1.6	--	0.17	95.33
A4012	(Groundmass altered to clays)											
A4012W	49.0	15.6	2.2	0.1	9.2	10.3	0.05	9.8	1.3	--	0.17	97.72

TABLE 55 (continued)

Sample	Wt %											Total
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	P ₂ O ₅	MnO	
A4013	66.1	9.4	<1.3	4.6	3.3	4.8	<0.2	6.6	1.3	0.6	<0.1	96.7
A4013	66.0	11.3	2.6	6.2	<0.3	4.3	0.2	7.7	1.6	1.1	--	101.0
A4013	65.0	9.5	<1.3	4.4	1.4	6.1	<0.2	7.1	1.0	0.6	--	95.1
A4013W	50.0	15.7	2.2	0.3	9.0	10.6	0.04	10.1	1.4	--	0.17	99.51
A4014	61.1	11.6	2.4	6.6	2.9	8.3	0.2	4.4	0.3	4.1	<0.1	101.9
A4014	76.5	10.8	1.6	7.7	<0.3	0.5	<0.2	1.5	0.5	<0.2	--	95.1
A4014	72.3	11.1	1.8	6.8	2.5	1.3	0.3	3.4	0.5	--	--	100.0
A4014W	51.0	15.1	2.4	0.8	7.6	9.7	0.05	10.7	1.6	--	0.17	99.12
A4015	72.6	12.8	<1.3	10.2	<0.3	0.7	0.2	2.0	0.4	<0.2	<0.1	98.9
A4015	70.5	12.7	2.3	8.5	--	0.7	0.4	2.0	0.7	--	--	97.8
A4015	74.1	13.8	<1.3	6.0	--	1.1	0.2	2.3	0.6	--	--	98.1
A4015W	51.0	13.9	2.4	1.4	6.0	8.8	0.08	11.5	1.7	--	0.17	96.95
A4016	62.9	11.7	<1.3	2.6	2.4	5.3	0.3	12.1	3.0	1.3	<0.1	101.6
A4016	64.4	10.7	--	2.8	2.0	4.8	0.3	12.0	3.1	1.1	--	101.2
A4016	62.2	10.5	---	4.7	1.4	4.1	0.2	11.1	3.0	1.8	--	99.0
A4016W	53.0	13.9	2.8	2.0	5.1	8.1	0.11	11.6	1.8	--	0.19	98.60

magnetite series (magnesioferrite, maghemite, franklinite, magnetite, ulvospinel, jacobsonite and trevorite; MgFe_2O_4 , $\alpha\text{-Fe}_2\text{O}_3$, ZnFe_2O_4 , FeFe_2O_4 , Fe_2TiO_4 , MnFe_2O_4 and NiFe_2O_4 , respectively) and a chromite series (magnesiochromite and chromite; MgCr_2O_4 and FeCr_2O_4 , respectively). The above minerals are end-members of their respective series and intermediate compositional mixtures are the rule. Iron, for example, can replace much of the magnesium in magnesiochromite, or iron and aluminum can replace chromium in either end-member. The analyses in Table 56 were referred to 32 oxygens. A normal chromite would then be $\text{Fe}_8\text{Cr}_{16}\text{O}_{32}$. The cations that fit into the chromium position, such as Al, Ti and Fe^{+3} , should add up to sixteen in Table 56. Magnesium, calcium and manganese all belong in the Fe^{+2} position of the spinel structure and should total eight in sum. Probably the second analysis of Table 56 should not be referred to as chromite. It is too high in iron and titanium to be a chromite. It could be called a chrome-bearing, titaniferous magnetite.

TABLE 56. Compositions of Some Metallic Oxides from A4013, DH-4 High Chromium Basalt

				Crystal Size, μm
Ti	1.918			8x10
Mg	0.181	$\Sigma \text{ Mg, Cr, Mn, Fe} = 2.157$		
Cr	0.003			
Mn	0.022	Ilmenite = 88.9%, Magnetite = 11.1%		
Fe	1.951			
Al	0.693	Mg	1.504	2x4
Ti	5.246	Ca	0.091	
Cr	1.785	Mn	0.146	
Fe ⁺³	8.261	Fe ⁺²	6.262	
Σ	15.985	Σ	8.003	
Al	3.625	Mg	3.748	12x25
Ti	0.519	Ca	0.096	
Cr	8.171	Mn	0.153	
Fe ⁺³	3.680	Fe ⁺²	4.003	
Σ	15.995	Σ	8.000	
				Chromite (Chrome-spinel)

The last analysis of Table 56 is an intermediate between chromite and magnesiochromite, having nearly half the iron substitute by magnesium, and in addition, has nearly half the chromium substituted by aluminum and iron.

In any case, the chrome-bearing magnetite and chromites are the source of the high chromium content of A4013 whole rock analyses as shown by the spinel scan in Figure 62.

During the course of A4013 reexamination, additional microprobe scanning was performed. These are presented on the following pages. There is little doubt as to the high chromium content of the small spinel crystals. Electron microprobe scans also are given for plagioclase and pyroxene. The feldspar crystal scan shown in Figure 60 is of interest because the iron content also was included. Note the very uniform iron content across the crystal, and that this crystal contains more iron oxide than it does potash.

The questions previously asked have been satisfactorily answered, with the possible exception of the first. Probably this flow unit (samples A4010 through A4015) does not belong with the Pomona flow unit. The prevalence of bytownite feldspars and augite, with very little variation, and the high magnesium content of the augites, shows that the formational and cooling history of this unit was certainly not comparable to that of the Pomona.

The answers to the last two questions are less ambiguous. It is possible to recognize a contact from groundmass analyses and metallic oxide crystal sizes and distribution. The location of the high chromium whole rock content of A4013 was identified as small chrome-bearing magnetites and chromites in the sample.

SILLUSI-UMATILLA MEMBER

During the course of drilling several core wells into the Columbia River basalt flows, a flow distinctively high in barium content was discovered by the ARHCO geological staff. The high barium flow was located in wells DDH-1, DH-2 and DDH-3, and at several locations on the surface south of the project at least to Sillusi Butte near Umatilla, Oregon. Wells DH-4 and DH-5 have shown no evidence of the high barium flow.

The high barium flow contains from 3000 to 3500 ppm Ba in the whole rock analyses, about five to six times as much barium as the rest of the flows in the series. This property

FIGURE 60. Scan Across a Feldspar Crystal in A4013

FIGURE 61. Scan Across a Pyroxene Crystal in A4013

FIGURE 62. Scan Across a Spinel Crystal in A4013

makes the high barium flow an excellent marker flow for use in stratigraphic correlations. For this reason, the mineralogy of the high barium flow was investigated in some detail as part of specific flow unit mineralogy investigations.

Feldspars

Sixty-eight feldspar crystals from the various samples were analyzed on the electron microprobe unit. These samples are identified by drill hole number followed by the depth in feet from the surface. Where this identification also coincides with an ARHCO sample number, the ARHCO sample number is also given in parentheses. The only two exceptions to the above identification procedure are Al215 and Al216, both surface samples from near Sillusi Butte. The surface samples Al215 and Al216 are vertically separated by 60 feet and laterally separated by half a mile. The 68 feldspar contents are given in Table 57. The reader should keep in mind that these analyses represent an area on the crystal of only $1 \mu\text{m}^2$. As the feldspar crystal scans given later in this report will show, this small area may or may not be representative of the whole crystal composition. Iron is always present in the analyses of the feldspar crystal sections, and is very likely present as an integral part of the feldspar crystal structure. Barium also is present in rather widely varying amounts in the crystal structure.

The feldspars vary in overall composition (sodium, calcium and potassium content only, used as classificational criteria) from bytownite to orthoclase, with several compositions referred to as transitional. The transitional feldspars, five in number, fall close to, but just outside of the normal compositional boundaries as shown in Figure 63. The reason for referring to these five feldspars as transitional will be explained during a later discussion of the feldspar scans. Several of the scanned feldspars showed extraordinary changes in composition across the crystal. Analysis of a small area on one of the transition zones could yield a composition that fell outside the normal compositional boundaries. This will become clearer as the later-given scans are examined.

Note in Table 58 that the orthoclase content of these feldspars is generally higher than the 1 to 4% contained in the feldspars from the other flows. Of the 65 good analyses, 35 are labradorites; 18 are andesines; 5 are transitional; 3 are anorthoclases; 3 are orthoclases; and 1 is bytownite.

TABLE 57. High Barium Basalt Feldspar Analyses

Contents of 68 Feldspar Molecules as Computed from the Microprobe Chemical Analyses. The feldspar molecule contains 32 oxygens. The three analyses marked with asterisks are considered to be substandard. The initial sample number refers to the core well and the second number to the depth from the surface in feet. Comparable DDH-3 sample numbers are given in parentheses.

Sample	Si	Al	Si+Al	Ca	K	Na	Fe	Ba	(Ca,K,Na, Fe,Ba)
1-679	10.624	5.116	15.740	1.677	0.304	2.078	0.185	0.027	4.270
1-679	9.989	5.799	15.788	2.010	0.209	1.919	0.122	0.029	4.288
1-679	11.035	4.785	15.870	1.399	0.400	1.688	0.175	0.034	3.697*
1-694	11.217	4.450	15.667	1.355	0.506	1.976	0.237	0.059	4.132
1-694	10.448	5.338	15.786	1.564	0.259	2.006	0.386	0.014	4.230
1-694	9.899	5.896	15.795	1.980	0.254	1.743	0.167	0.014	4.157
1-730	9.229	6.471	15.700	2.286	0.195	1.586	0.159	<0.012	4.226
1-730	9.789	5.980	15.769	1.971	0.176	1.900	0.129	0.013	4.189
1-730	10.434	5.433	15.867	1.956	0.240	1.489	0.143	0.020	3.847
1-757	10.167	5.676	15.843	2.038	0.219	1.660	0.159	0.015	4.091
1-757	10.139	5.547	15.686	2.113	0.231	1.704	0.121	<0.012	4.169
1-757	10.517	5.352	15.869	1.982	0.223	1.455	0.117	<0.012	3.777
1-788	10.439	5.327	15.766	1.866	0.185	2.075	0.121	0.014	4.262
1-788	10.393	5.380	15.773	1.828	0.237	1.886	0.140	0.015	4.104
1-788	10.160	5.487	15.647	1.978	0.221	1.786	0.145	0.023	4.152
2-243	10.183	5.576	15.759	2.026	0.266	1.717	0.079	0.022	4.110
2-243	10.961	4.629	15.590	1.862	0.239	2.029	0.109	0.029	4.269
2-243	10.179	5.483	15.662	2.097	0.198	1.478	0.259	0.023	4.054
2-281	10.732	5.100	15.832	1.557	0.158	2.165	0.133	0.035	4.049
2-281	10.225	4.811	15.036	3.229	0.164	0.675	0.184	<0.012	4.252
2-281	11.449	4.483	15.932	0.384	1.281	2.225	0.135	0.105	4.131
2-324	10.314	5.536	15.850	1.872	0.180	1.950	0.118	0.014	4.134
2-324	11.358	4.468	15.826	0.201	2.113	1.649	0.086	0.013	4.062
2-324	10.445	5.482	15.927	1.698	0.159	1.761	0.208	0.021	3.847
2-324	10.145	5.251	15.396	2.030	0.121	1.163	0.840	0.022	4.176
2-363	11.385	4.534	15.919	0.945	0.608	2.086	0.103	0.035	3.777
2-363	10.083	5.630	15.713	2.054	0.120	1.568	0.267	0.022	4.032
2-363	10.160	5.624	15.784	2.073	0.147	1.671	0.240	0.023	4.154
2-390	10.304	5.387	15.691	1.805	0.263	1.796	0.141	0.037	4.041
2-390	9.982	5.914	15.896	2.102	0.162	1.691	0.122	0.014	4.091
2-390	10.107	5.685	15.792	1.957	0.256	1.783	0.168	0.014	4.178
(A2021)									
3-868	10.373	5.456	15.829	2.102	0.189	1.471	0.124	0.015	3.901
3-868	10.723	5.054	15.777	1.937	0.238	1.445	0.171	0.022	3.813
3-868	10.394	5.224	15.618	2.120	0.162	1.671	0.167	0.021	4.141

TABLE 57 (continued)

<u>Sample</u>	<u>Si</u>	<u>Al</u>	<u>Si+Al</u>	<u>Ca</u>	<u>K</u>	<u>Na</u>	<u>Fe</u>	<u>Ba</u>	<u>ΣCa,K,Na, Fe,Ba</u>
(A2022)									
3-876	10.583	5.302	15.885	1.642	0.193	2.090	0.099	----	4.024
3-876	10.043	5.896	15.939	1.904	0.133	1.790	0.204	----	4.031
3-876	10.514	5.143	15.657	2.052	0.242	1.838	0.134	0.022	4.298
(A2023)									
3-900	10.298	5.518	15.816	1.814	0.267	1.939	0.111	----	4.131
3-900	10.652	5.134	15.786	1.580	0.272	2.308	0.104	0.021	4.285
3-900	10.312	5.549	15.861	2.042	0.285	1.365	0.158	0.027	3.878
(A2024)									
3-924	10.660	5.125	15.785	1.862	0.236	1.685	0.155	0.014	3.952
3-924	10.063	5.669	15.732	2.398	0.164	1.565	0.107	----	4.234
3-924	10.544	5.254	15.798	1.844	0.293	1.112	0.464	0.022	3.735
(A2025)									
3-938	12.464	3.195	15.659	1.091	0.626	2.140	0.122	0.086	4.065
3-938	11.802	3.762	15.564	1.906	0.222	1.737	0.097	0.023	3.985
3-938	11.339	3.990	15.329	2.196	0.296	1.650	0.145	0.023	4.310*
(A2026)									
3-952	11.286	4.543	15.829	1.595	0.285	1.735	0.171	0.036	3.822
3-952	10.557	5.206	15.763	1.986	0.195	1.704	0.128	0.015	4.028
3-952	10.928	4.751	15.679	1.735	0.264	1.898	0.173	0.030	4.100
(A2027)									
3-1000	10.530	5.483	16.013	1.714	0.216	1.850	0.173	0.044	3.997
3-1000	10.704	5.080	15.784	2.047	0.143	1.380	0.141	0.022	3.733
3-1000	10.562	5.060	15.622	2.230	0.163	1.629	0.137	0.021	4.180
(A2028)									
3-1032	10.293	5.678	15.971	1.878	0.181	1.682	0.074	0.014	3.829
3-1032	11.715	4.216	15.931	0.272	1.783	1.196	0.243	0.242	3.736
3-1032	11.583	4.241	15.824	0.900	0.699	2.018	0.107	0.107	3.831
(A2029)									
3-1060	11.891	4.086	15.977	0.525	1.129	2.179	0.079	0.081	3.993
3-1060	12.131	3.940	16.071	0.352	1.305	2.180	0.076	0.057	3.970
3-1060	10.582	5.119	15.701	1.888	0.166	1.726	0.295	0.029	4.104
3-114	10.664	5.136	15.800	1.787	0.213	1.689	0.217	0.015	3.921
3-114	10.974	4.841	15.815	1.427	0.326	1.910	0.168	0.079	3.910
3-114	11.854	4.304	16.158	1.095	0.279	0.708	0.168	0.079	2.329*
A1216	10.305	5.568	15.873	1.991	0.169	1.691	0.095	0.022	3.968
A1216	11.038	4.968	16.006	1.244	0.335	2.115	0.094	0.059	3.847
A1216	10.191	5.731	15.922	2.004	0.172	1.608	0.113	0.015	3.912
A1216	11.400	4.702	16.102	0.877	0.545	2.291	0.074	0.077	3.864
A1215	10.509	5.499	16.008	1.627	0.254	1.752	0.076	0.028	3.737
A1215	10.275	5.703	15.978	1.893	0.166	1.623	0.093	0.015	3.790
A1215	11.836	4.656	16.492	0.640	0.615	2.350	0.306	0.091	4.002

TABLE 58. High Barium Basalt Feldspar Compositions

Feldspar Compositions as Determined from the Chemical Data of Table 57. Substandard analyses were deleted but the order of listing is otherwise the same.
Ab = albite; An = anorthite; Or = orthoclase.

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
1-679	51.2	41.3	7.5	Andesine	25x25
1-679	46.3	48.6	5.1	Labradorite	75x75
1-694	51.5	35.3	13.2	Transitional	25x75
1-694	52.4	40.8	6.8	Andesine	10x60
1-694	43.8	49.8	6.4	Labradorite	75x100
1-730	39.0	56.2	4.8	Labradorite	25x60
1-730	47.0	48.7	4.3	Labradorite	25x125
1-730	40.4	53.1	6.5	Labradorite	25x75
1-757	42.4	52.0	5.6	Labradorite	75x75
1-757	42.1	52.2	5.7	Labradorite	75x125
1-757	39.7	54.2	6.1	Labradorite	25x40
1-788	50.3	45.2	4.5	Andesine	50x75
1-788	47.7	46.3	6.0	Andesine	75x100
1-788	44.8	49.7	5.5	Labradorite	25x25
2-243	42.9	50.5	6.6	Labradorite	750x1500
2-243	49.1	45.1	5.8	Andesine	25x25
2-243	39.2	55.6	5.2	Labradorite	25x75
2-281	55.8	40.1	4.1	Andesine	150x200
2-281	16.6	79.4	4.0	Bytownite	25x25
2-281	57.2	9.9	32.9	Anorthoclase	50x150
2-324	48.7	46.8	4.5	Andesine	50x250
2-324	41.6	5.1	53.3	Orthoclase	50x250
2-324	48.7	46.9	4.4	Andesine	12x50
2-324	35.0	61.3	3.7	Labradorite	30x75
2-363	57.3	26.0	16.7	Transitional	25x125
2-363	41.9	54.9	3.2	Labradorite	100x200
2-363	43.0	53.3	3.8	Labradorite	50x100
2-390	46.5	46.7	6.8	Labradorite	50x50
2-390	42.7	53.1	4.1	Labradorite	10x50
2-390	44.6	49.0	6.4	Labradorite	75x75
(A2021)					
3-868	39.1	55.9	5.0	Labradorite	65x185
3-868	39.9	53.5	6.6	Labradorite	35x125
3-868	42.3	53.6	4.1	Labradorite	35x150

TABLE 58 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Feldspar</u>	<u>Crystal Size, μm</u>
	<u>Ab</u>	<u>An</u>	<u>Or</u>		
(A2022)					
3-876	53.3	41.8	4.9	Andesine	50x75
3-876	46.8	49.7	3.5	Labradorite	75x100
3-876	44.4	49.7	5.9	Labradorite	25x75
(A2023)					
3-900	48.3	45.1	6.6	Andesine	50x75
3-900	55.5	38.0	6.5	Andesine	25x25
3-900	37.0	55.3	7.7	Labradorite	25x100
(A2024)					
3-924	44.5	49.2	6.2	Labradorite	110x175
3-924	37.9	58.1	4.0	Labradorite	110x750
3-924	34.2	56.8	9.0	Labradorite	20x100
(A2025)					
3-938	55.5	28.3	16.2	Transitional	30x200
3-938	49.3	45.0	5.7	Andesine	125x500
(A2026)					
3-952	48.0	44.1	7.9	Andesine	25x100
3-952	43.9	51.1	5.0	Labradorite	140x275
3-952	48.7	44.5	6.8	Andesine	35x100
(A2027)					
3-1000	49.0	45.3	5.7	Andesine	50x50
3-1000	38.7	57.3	4.0	Labradorite	75x125
3-1000	40.5	55.5	4.1	Labradorite	25x100
(A2028)					
3-1032	45.0	50.2	4.8	Labradorite	162x400
3-1032	36.8	8.4	54.8	Orthoclase	90x175
3-1032	55.8	24.9	19.3	Transitional	40x100
(A2029)					
3-1060	56.8	13.7	29.5	Transitional	70x175
3-1060	56.8	9.2	34.0	Orthoclase	30x125
3-1060	45.7	49.9	4.4	Labradorite	50x50
3-1114	45.8	48.4	5.8	Labradorite	35x100
3-1114	52.1	39.0	8.9	Andesine	25x50
Al216	43.9	51.7	4.4	Labradorite	90x350
Al216	57.3	33.7	9.0	Andesine	30x110
Al216	42.5	53.0	4.6	Labradorite	45x100
Al216	61.7	23.6	14.7	Anorthoclase	45x100
Al215	48.2	44.8	7.0	Andesine	150x675
Al215	44.1	51.4	4.5	Labradorite	187x300
Al215	65.2	17.8	17.0	Anorthoclase	20x100

FIGURE 63. Graph of Feldspar Compositions

Ab = $\text{NaAlSi}_3\text{O}_8$

An = $\text{CaAl}_2\text{Si}_2\text{O}_8$

Or = KAlSi_3O_8

Feldspar Scans

The following section presents the results of several feldspar crystal scans with the electron microprobe unit.

The zoning of plagioclases is a common occurrence. This is not too surprising because the sodium and calcium must diffuse to sites on the growing feldspar crystal through a viscous magma, and diffusion rates for sodium and calcium are different in such a medium. Ewart¹⁹ has reported up to 50 zones in a single, high calcium, plagioclase crystal. However, and this is an important observation, the differences involved are generally of only 1 to 2% anorthite in successive zones. Some of the feldspars from the high barium flow, on the other hand, show some massive changes in composition on scanning for calcium, sodium, potassium and barium. An example is seen in Figure 71, a scan across a feldspar crystal in DH-2-324 feet. On the low scan distance end, the crystal is a plagioclase, probably an andesine. Note also that the low initial metal oxide values reflect the fact that the lower part of the scan probably passed over another mineral, or phase, here. Toward the middle of the scan, the various oxide values change rather drastically in some cases. K₂O increases; BaO increases for about 30 μ m; CaO decreases; and Na₂O stays essentially the same in amount (Na₂O has the largest inherent analytical error). This middle zone has been referred to as transitional in the earlier feldspar analyses. It is easily seen how difficult it would be to analyze a representative 1 μ m² on this crystal.

Finally, the crystal grades into an orthoclase at the higher scan distances. Note that this change from plagioclase to orthoclase is gradual, not abrupt; i.e., this is not an orthoclase crystal that has grown later alongside the plagioclase crystal. The single crystal continued to grow through a marked change in the ratios of chemical constituents supplied to it through time. The growth interval must have been very long to reach the implied degree of chemical differentiation. The feldspar scan shown for DH2-363 feet in Figure 72 indicates several changes in feed or growth constituents. There are three zones of plagioclase, and at least three zones of anorthoclase or orthoclase in the same crystal, with transitional zones between them.

Some of the large feldspars, such as DH-2-243 feet shown in Figure 69, are a single plagioclase phase except on the edges, and the edge changes may be partly due to either scanning off the edge or scanning across another mineral at the edge.

FIGURE 64. Scan Across a Feldspar Crystal in DDH-1 - 679 feet

FIGURE 65. Scan Across a Feldspar Crystal in DDH1 - 694 feet

FIGURE 66. Scans Across Feldspar Crystals in DDH1 - 730 feet

FIGURE 67. Scan Across a Feldspar Crystal in DDH1 - 757 feet

FIGURE 68. Scan Across a Feldspar Crystal in DDH1 - 788 feet

FIGURE 69. Scan Across a Feldspar Crystal in DH2 - 243 feet

FIGURE 70. Scan Across a Feldspar Crystal in DH2 - 281 feet

FIGURE 71. Scan Across a Feldspar Crystal in DH2 - 324 feet

FIGURE 72. Scan Across a Feldspar Crystal in DH2 - 363 feet

FIGURE 73. Scan Across a Feldspar Crystal in DH2 - 390 feet

FIGURE 74. Scan Across a Feldspar Crystal in DDH3 - 868 feet (A2021)

FIGURE 75. Scan Across a Feldspar Crystal in DDH3 - 876 feet (A2022)

FIGURE 76. Scan Across a Feldspar Crystal in DDH3 - A2023 (900 feet)

FIGURE 77. Scan Across a Feldspar Crystal in DDH3 - A2024 (924 feet)

FIGURE 78. Scan Across a Feldspar Crystal in DDH3 - 938 feet (A2025)

FIGURE 79. Scan Across a Feldspar Crystal in DDH3 - 952 feet (A2026)

FIGURE 80. Scan Across a Feldspar Crystal in DDH3 - 1000 feet (A2027)

FIGURE 81. Scan Across a Feldspar Crystal in DDH3 - A2028 (1032 feet)

FIGURE 82. Scans Across Feldspar Crystals in DDH3 - 1060 feet (A2029)

FIGURE 83. Scans Across Two Feldspar Crystals in DDH3 - 1114 feet

FIGURE 84. Scan Across a Feldspar Crystal from Sillusi Butte Sample A1215

FIGURE 85. Scan Across a Feldspar Crystal from Sillusi Butte Sample S1216

The barium content and distribution in the feldspars as revealed by these scans is interesting. In the feldspars shown in Figures 70 and 81, barium oxide content exceeds 3% by weight. Feldspars containing in excess of 2 wt% BaO may be considered barium varieties. In general, the barium content tends to follow the potassium content of the feldspars, probably because barium feldspars are structurally very similar to potassium feldspars.

The compositional changes occurring across many of these feldspar crystals is remarkable. The widest oscillations reported in feldspar composition occur in the intermediate composition plagioclases. In many such basalts, the feldspar core consists of a bytownite. The bytownite cores are surrounded by narrow zones of more sodium-rich plagioclase. For example, Edwards²⁰ has shown that the groundmass feldspars in the olivine basalt-trachyte province of central Victoria vary between An₆₀ and An₂₅ (labradorite to oligoclase) and Larsen and Irvine²¹ have shown the composition of the San Juan lava plagioclase phenocrysts to vary between An₈₃ and An₁₁ (bytownite to oligoclase). Even in the above two extreme cases of plagioclase zoning (alkali feldspars are not normally appreciably zoned), the compositional range is meager compared to the range shown by many of the high barium flow feldspars.

Compositional oscillations of the K-series feldspars were present but very subdued in magnitude, similar to that described by Ewart. This type of compositional zoning can be contrasted with that occurring in the high barium flow feldspars.

Pyroxenes

Pyroxene compositions based on 63 microprobe analyses are given in Table 59. Two of the analyses were substandard. The analytical limits on pyroxenes are more stringent than those imposed on feldspars because the feldspars contain substantial amounts of sodium. Sodium is the lightest element that can be determined by microprobe analysis and presents the largest inherent errors in its determination. Note the absence of chromium in these pyroxenes in quantities above the detection limit of 0.1 wt% CrO₃.

The pyroxenes are identified in Table 60 and graphed as to iron, magnesium and calcium content in Figure 86. Of the 61 analyses, 49 were augites, 6 ferroaugites, 2 salites, 1 subcalcic augite, 1 subcalcic ferroaugite, 1 intermediate

TABLE 59. High Barium Basalt Pyroxene Analyses

Pyroxene Compositions, Based on the Molecule $(\text{Mg}, \text{Fe}^{+2}, \text{Ca}, \text{Ti}, \text{K}, \text{Mn}, \text{Al})_2 (\text{Al}, \text{Si})_2 \text{O}_6$, as Determined from the Microprobe Chemical Analyses. Analyses marked with an asterisk are substandard.

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	Σ	Crystal Size, μm
1-679	1.946	0.054	2.000	0.668	0.489	0.741	0.046	0.005	0.010	0.018	1.977	25x50
1-679	1.975	0.025	2.000	0.618	0.452	0.727	0.089	0.005	0.010	0.017	1.918	15x25
1-679	2.106	---	2.106	0.479	0.547	0.529	0.044	0.051	0.009	0.073	1.732*	15x50
1-694	1.925	0.057	1.982	0.768	0.502	0.739	0.022	0.003	0.009	---	2.043	25x75
1-694	1.858	0.061	1.919	0.866	0.532	0.736	0.024	0.004	0.010	---	2.172	175x200
1-694	1.939	0.023	1.962	0.841	0.606	0.584	0.020	---	0.016	---	2.067	35x50
1-730	1.948	0.027	1.975	0.812	0.555	0.650	0.023	---	---	---	2.040	25x40
1-730	1.898	0.061	1.959	0.767	0.450	0.823	0.036	0.004	---	---	2.080	10x50
1-730	2.044	---	2.044	0.521	0.434	0.827	0.033	---	0.007	0.038	1.860	25x25
1-757	1.992	0.008	2.000	0.784	0.386	0.724	0.027	---	0.006	0.034	1.961	12x30
1-757	1.929	0.068	1.997	0.828	0.416	0.721	0.035	---	0.006	---	2.006	40x50
1-757	1.894	0.106	2.000	0.787	0.448	0.783	0.011	---	0.006	0.005	2.040	25x25
1-788	1.768	0.065	1.833	0.771	0.540	0.990	0.032	0.003	---	---	2.336*	50x50
1-788	1.862	0.138	2.000	0.684	0.543	0.749	0.031	0.004	---	0.020	2.031	10x25
1-788	1.969	0.031	2.000	0.742	0.611	0.585	0.020	0.005	0.016	0.013	1.992	25x25
2-243	1.900	0.059	1.959	0.778	0.524	0.742	0.029	---	0.010	---	2.083	100x100
2-243	1.933	0.067	2.000	0.535	0.465	0.781	0.030	0.025	0.010	0.114	1.960	25x30
2-243	1.900	0.049	1.949	0.782	0.521	0.760	0.026	---	0.013	---	2.102	75x125
2-281	1.939	0.035	1.974	0.684	0.558	0.782	0.017	---	0.012	---	2.053	25x50
2-281	1.922	0.035	1.957	0.774	0.544	0.733	0.020	---	0.013	---	2.084	50x70
2-281	1.855	0.107	1.962	0.806	0.455	0.811	0.028	---	---	---	2.100	200x200
2-324	1.928	0.040	1.968	0.753	0.497	0.782	0.020	---	0.013	---	2.065	75x75
2-324	1.995	---	1.995	0.662	1.113	0.185	0.008	---	0.032	---	2.000	75x100
2-324	1.899	0.052	1.951	0.816	0.421	0.829	0.025	---	0.009	---	2.100	25x160

TABLE 59 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	Σ	Crystal Size, μm
2-363	1.992	0.008	2.000	0.553	0.603	0.773	0.024	0.003	0.017	0.006	1.979	25x25
2-363	1.928	0.032	1.960	0.733	0.447	0.851	0.027	---	0.010	---	2.068	25x25
2-363	1.905	0.050	1.955	0.787	0.493	0.768	0.026	0.004	0.013	---	2.091	40x50
2-390	1.924	0.070	1.994	0.768	0.458	0.750	0.031	0.005	0.006	---	2.018	25x40
2-390	1.884	0.106	1.990	0.839	0.439	0.727	0.031	---	0.006	---	2.042	200x175
2-390	1.806	0.069	1.875	0.533	0.813	0.763	0.079	0.010	0.013	---	2.211	25x50
3-868 (A2021)	(No Pyroxenes Located)											
3-876 (A2022)	1.987	0.013	2.000	0.734	0.450	0.691	0.029	0.003	0.010	0.041	1.958	50x75
3-876	2.032	---	2.032	0.663	0.467	0.686	0.025	0.004	0.009	0.039	1.893	20x45
3-876	2.008	---	2.008	0.661	0.685	0.501	0.027	0.004	0.010	0.047	1.935	30x40
3-900 (A2023)	1.972	0.028	2.000	0.727	0.362	0.689	0.031	0.014	---	0.112	1.935	50x75
3-900	1.873	0.064	1.937	0.826	0.412	0.864	0.027	0.004	---	---	2.133	15x20
3-900	1.928	0.072	2.000	0.525	0.523	0.701	0.130	0.009	0.009	0.009	1.906	25x50
3-924 (A2024)	1.907	0.050	1.957	0.783	0.478	0.779	0.029	0.005	0.010	---	2.084	200x300
3-924	1.984	0.016	2.000	0.712	0.560	0.637	0.028	---	0.013	0.019	1.969	27x30
3-924	1.949	0.047	1.996	0.836	0.415	0.720	0.027	0.003	0.006	---	2.007	60x80
3-938 (A2025)	2.090	---	2.090	0.516	0.406	0.794	0.025	---	0.006	0.031	1.778	125x325
3-938	2.049	---	2.049	0.445	0.542	0.787	0.035	0.003	0.013	0.028	1.853	40x150
3-938	2.042	---	2.042	0.503	0.493	0.765	0.035	---	0.010	0.050	1.856	125x175
3-952 (A2026)	1.989	0.011	2.000	0.776	0.560	0.579	0.018	0.004	0.013	0.026	1.976	25x35
3-952	1.977	0.023	2.000	0.719	0.439	0.721	0.029	0.003	0.010	0.041	1.952	25x25
3-952	1.974	0.026	2.000	0.625	0.514	0.702	0.045	0.004	0.014	0.045	1.949	35x75
3-1000 (A2026)	2.074	---	2.074	0.478	0.546	0.752	0.024	---	0.014	0.009	1.823	25x25
3-1000	1.989	0.011	2.000	0.629	0.545	0.751	0.025	---	0.010	0.013	1.973	25x50
3-1000	2.000	---	2.000	0.711	0.820	0.218	0.021	0.125	0.023	0.083	2.001	25x40

TABLE 59 (continued)

Sample	Si	Al	Si+Al	Mg	Fe	Ca	Ti	K	Mn	Al	Σ	Crystal Size, μm
3-1032 (A2028)	1.949	0.023	1.972	0.749	0.497	0.772	0.020	---	0.010	---	2.048	60x85
3-1032	1.980	0.014	1.994	0.675	0.485	0.807	0.018	0.005	0.014	---	2.004	40x80
3-1032	1.946	0.023	1.969	0.753	0.519	0.748	0.020	---	0.013	---	2.053	50x60
3-1060 (A2029)	1.936	0.064	2.000	0.650	0.547	0.696	0.056	0.003	0.013	0.009	1.974	35x75
3-1060	1.986	0.014	2.000	0.648	0.490	0.761	0.026	0.003	0.013	0.027	1.968	50x75
3-1060	1.979	0.021	2.000	0.686	0.430	0.773	0.029	0.003	0.010	0.034	1.965	50x75
3-1114	2.026	---	2.026	0.669	0.447	0.677	0.032	0.004	0.007	0.055	1.891	50x50
3-1114	2.013	---	2.013	0.587	0.434	0.776	0.036	0.003	0.007	0.065	1.908	50x75
3-1114	1.992	0.008	2.000	0.700	0.427	0.758	0.023	0.004	0.010	0.041	1.963	15x25
Al216	1.951	0.023	1.974	0.763	0.685	0.561	0.018	0.004	0.017	---	2.048	30x34
Al216	1.966	0.032	1.998	0.632	0.598	0.717	0.026	0.005	0.016	---	1.994	30x32
Al216	1.897	0.056	1.953	0.938	0.409	0.718	0.022	0.004	0.009	---	2.100	75x130
Al215	1.964	0.023	1.987	0.790	0.515	0.677	0.021	---	0.013	---	2.016	90x135
Al215	1.892	0.090	1.982	0.824	0.437	0.756	0.029	---	0.006	---	2.052	100x140
Al215	1.929	0.050	1.979	0.854	0.424	0.742	0.020	---	0.007	---	2.047	250x500

TABLE 60. High Barium Basalt Pyroxene Compositions

Percentages of Magnesium, Iron and Calcium Silicates
Comprising the Pyroxenes of Table 59.

<u>Sample</u>	<u>Molecular %</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
1-679	35.2	25.8	39.0	Augite
1-679	34.4	25.2	40.5	Augite
1-694	38.2	25.0	36.8	Augite
1-694	40.6	24.9	34.5	Augite
1-694	41.4	29.9	28.7	Augite
1-730	40.3	27.5	32.2	Augite
1-730	37.6	22.1	40.3	Augite
1-730	29.3	24.3	46.4	Salite
1-757	41.4	20.4	38.2	Augite
1-757	42.1	36.7	21.2	Subcalcic Augite
1-757	39.0	22.2	38.8	Augite
1-788	34.6	37.9	27.5	Ferroaugite
1-788	38.3	30.2	31.5	Augite
2-243	38.1	25.6	36.3	Augite
2-243	30.0	26.1	43.9	Augite
2-243	37.9	25.2	36.9	Augite
2-281	33.8	27.6	38.6	Augite
2-281	37.8	26.5	35.7	Augite
2-281	38.9	22.0	39.1	Augite
2-324	37.1	38.5	24.5	Subcalcic Ferroaugite
2-324	33.8	56.8	9.5	Ferriferrous Pigeonite
2-324	39.5	20.4	40.1	Augite
2-363	28.7	31.3	40.1	Augite
2-363	36.1	22.0	41.9	Augite
2-363	38.4	24.1	37.5	Augite
2-390	38.8	23.2	38.0	Augite
2-390	41.8	21.9	36.3	Augite
2-390	25.3	38.5	36.2	Ferroaugite

TABLE 60 (continued)

<u>Sample</u>	<u>Molecular %</u>			<u>Pyroxene Identification</u>
	<u>MgSiO₃</u>	<u>FeSiO₃</u>	<u>CaSiO₃</u>	
3-876 (A2022)	39.1	24.0	36.9	Augite
3-876	36.5	25.7	37.7	Augite
3-876	35.8	27.1	37.1	Augite
3-900 (A2023)	40.9	20.3	38.8	Augite
3-900	39.3	19.6	41.1	Augite
3-900	30.0	29.9	40.1	Ferroaugite
3-924 (A2024)	38.4	23.4	38.2	Augite
3-924	37.3	29.3	33.4	Augite
3-924	42.4	21.0	36.5	Augite
3-938 (A2025)	30.1	23.6	46.3	Salite
3-938	25.1	30.5	44.4	Ferroaugite
3-938	28.6	28.0	43.4	Ferroaugite
3-952 (A2026)	40.5	29.3	30.2	Augite
3-952	38.3	23.4	38.4	Augite
3-952	34.0	27.9	38.1	Augite
3-1000 (A2027)	26.9	30.8	42.3	Ferroaugite
3-1000	32.7	28.3	39.0	Augite
3-1000	40.6	46.9	12.5	Intermediate Pigeonite
3-1032 (A2028)	37.1	24.6	38.3	Augite
3-1032	34.3	24.7	41.0	Augite
3-1032	37.3	25.7	37.0	Augite
3-1060 (A2029)	34.3	28.9	36.8	Augite
3-1060	34.1	25.8	40.1	Augite
3-1060	36.3	22.8	40.9	Augite
3-1114	37.3	24.9	37.8	Augite
3-1114	32.7	24.2	43.1	Augite
3-1114	37.1	22.7	40.2	Augite
A1216	38.0	34.1	27.9	Augite
A1216	32.5	30.7	36.8	Augite
A1216	45.4	19.8	34.8	Augite
A1215	39.9	26.0	34.2	Augite
A1215	40.9	21.7	37.5	Augite
A1215	42.3	21.0	36.7	Augite

FIGURE 86. Graph of Pyroxene Compositions

pigeonite and 1 ferriferous pigeonite. This is the first instance of identification of the relatively high calcium salites. A relatively high number of ferroaugites also are present, high iron content being characteristic of the later crystallizing pyroxenes.

Pyroxene Scans

Several pyroxene crystals were scanned for magnesium, calcium and iron. Scans across pyroxene crystals for calcium, magnesium and iron in the high barium flow samples are presented in Figures 87 through 108. In general, these pyroxenes are moderately zoned, with higher iron on the crystal edges and lower iron in the crystal center. Most of the pyroxenes are augites, but a ferro-hypersthene crystal is shown in Figure 94. The most drastic compositional changes are probably shown in Figure 96. At low scan distance to about 15 μm , the pyroxene is a pigeonite. Above 15 μm , it is an augite.

Metallics

Detailed microphotographic and microprobe work on the metallics in the high barium flow was conducted in an effort to positively identify the mineralogical phases present. Previous work had indicated only that areas of ilmenite were definitely present along with at least one other titaniferous iron oxide phase. It was also pointed out that because the microprobe does not determine oxygen or iron charge state (Fe^{+2} or Fe^{+3}), the titaniferous iron phase could be magnetite, though no micro-textural evidence could be found for referring to the phase as magnetite. For the high barium flow metallics, detailed work has located typical magnetite-ilmenite textural relations due to exsolution.

The textural relations of hematite-ilmenite or ilmenite-hematite exsolution bodies are distinctive.²² The guest hematite or ilmenite shows a seriate arrangement in parallel rows in the host phase. The physical appearance is similar to that made by lighter mineral concretions in a biotite gneiss. Typical magnetite-ilmenite exsolution textures are quite different. Usually the ilmenite lamellae or blades are oriented on the (111) planes of the magnetite. In the magnetite structure, every third and seventh plane consists of oxygen atoms only, while in ilmenite every third (0001) plane consists of oxygen atoms only. If the planes are superimposed on one another, the oxygen positions in the two

FIGURE 87. Scan Across a Pyroxene Crystal in DDH1 - 679 feet

FIGURE 88. Scan Across a Pyroxene Crystal in DDH1 - 694 feet

FIGURE 89. Scan Across a Pyroxene Crystal in DDH1 - 730 feet

FIGURE 90. Scan Across a Pyroxene Crystal in DDH1 - 757 feet

FIGURE 91. Scan Across a Pyroxene Crystal in DDH1 - 788 feet

FIGURE 92. Scan Across a Pyroxene Crystal in DH2 - 243 feet

FIGURE 93. Scan Across a Pyroxene Crystal in DH2 - 281 feet

FIGURE 94. Scan Across a Pyroxene (Ferrohypersthene) Crystal in DDH2 - 324 feet

FIGURE 95. Scan Across a Pyroxene Crystal in DH2 - 324 feet

FIGURE 96. Scan Across a Pyroxene Crystal in DH2 - 363 feet

FIGURE 97. Scan Across a Pyroxene Crystal in DH2 - 390 feet

FIGURE 98. Scan Across a Pyroxene Crystal in DDH3 - 876 feet (A2022)

FIGURE 99. Scan Across a Pyroxene Crystal in DDH3 - A2023 (900 feet)

FIGURE 100. Scan Across a Pyroxene Crystal in DDH3 - A2024 (924 feet)

FIGURE 101. Scan Across a Pyroxene Crystal in DDH3 - 938 feet (A2025)

FIGURE 102. Scans Across Pyroxene Crystals in DDH3 - 952 feet (A2026)

FIGURE 103. Scan Across a Pyroxene Crystal in DDH3 - 1000 feet (A2027)

FIGURE 104. Scan Across a Pyroxene Crystal in DDH3 - A2028 (1032 feet)

FIGURE 105. Scan Across a Pyroxene Crystal in DDH3 - 1060 feet (A2029)

FIGURE 106. Scan Across a Pyroxene Crystal in DDH3 - 1114 feet

FIGURE 107. Scan Across a Pyroxene Crystal from Sillusi Butte Sample A1215

FIGURE 108. Scan Across a Pyroxene Crystal from Sillusi Butte Sample A1216

planes practically coincide.²³ Viewed from a cut section, the ilmenite lamellae give rise to near 60° or 30° angles at their juncture. Several other microtextures of ilmenite-magnetite minerals resulting from increasing degrees of oxidation and diffusion (exsolution) are recognized.²⁴ These are: 1) trellis intergrowths of thin ilmenite lamellae in all sets of (111) planes of the host magnetite, 2) sandwich intergrowths of thick ilmenite lamellae predominantly in one set of (111) planes, 3) granules of ilmenite within the magnetite, and 4) granules or lamellae of ilmenite on the external borders of the magnetite. All types may occur alone or together in different grains of the same rock. The most distinctive or recognizable microtexture, however, is the first occurrence. It is this first definite microtexture that has been identified in the present work. No evidence of ilmenite-hematite microtextures was found in the high barium flow metallics with hematite occurring as host and ilmenite as guest.

The microprobe chemical analyses of metallics are given in Table 61. The mole percent of magnetite and ilmenite may be given because only these two minerals are present. The mole percent of each constituent was obtained by assuming a one-to-one ratio for titanium and iron, and putting the remainder of the iron + magnesium + manganese + chromium into the magnetite structure. These constituents additionally fit quite well into the magnetite (spinel) structure.

Note that the chromium apparently is concentrated here in the metallics. In some of the previous flow units, the chromium was split between the pyroxenes and metallics. If chromium prefers the metallics, and more precisely the magnetite or spinel structure portion of the metallics, this condition should be reflected by some inverse relationship between titanium and chromium content in the metallics. The inverse relationship was confirmed by computing a correlation coefficient from the metallic analyses. This correlation coefficient was -0.538, where ± 0.302 would be a significant coefficient at the 1% confidence level. Hence, as the amount of titanium (ilmenite) in the metallic increases, the amount of magnetite (and chromium) decreases.

Groundmass Compositions

The groundmass microprobe analyses are given in Table 62. Whole rock analyses are given for comparison where these were available. The analyses represent varying degrees of chemical differentiation. Sample 3-868 (A2021), for example, shows

TABLE 61. High Barium Basalt Metallics Analyses

Microprobe Chemical Analyses of Metallic Oxides Referred to a Molecule of $(\text{Fe}^{+2}, \text{Mg}, \text{Mn}, \text{Cr})_2(\text{Ti}^{+4})_2\text{O}_6$.

Sample	Ti	Mg	Fe	Mn	Cr	$\Sigma \text{Mg, Fe}$ Mn, Cr	Crystal Size, μm	Mole %	
								Magnetite	Ilmenite
1-679	1.953	0.128	1.931	0.026	0.003	2.088	25x30	6.5	93.5
1-679	1.325	0.071	3.226	0.030	0.007	3.334	30x60	60.3	39.7
1-679	1.309	0.090	3.249	0.031	0.004	3.374	25x75	61.2	38.8
1-694	2.004	0.109	1.851	0.022	0.003	1.985	35x75	--	100.0
1-694	1.314	0.099	3.217	0.036	0.007	3.359	45x50	60.9	39.1
1-694	1.556	0.091	2.745	0.033	0.007	2.876	50x125	45.9	54.1
1-730	1.949	0.189	1.870	0.027	0.005	2.091	30x60	6.8	93.2
1-730	1.280	0.111	3.275	0.032	0.007	3.425	10x20	62.6	37.4
1-730	1.395	0.071	3.081	0.035	0.007	3.194	12x100	56.3	43.7
1-757	1.199	0.285	3.270	0.025	0.007	3.587	60x100	66.6	33.4
1-757	1.198	0.235	3.321	0.026	0.007	3.589	20x60	66.6	33.4
1-757	1.236	0.128	3.357	0.021	0.007	3.513	75x100	64.8	35.2
1-788	1.286	0.174	3.196	0.036	0.007	3.413	40x60	62.3	37.7
1-788	1.959	0.114	1.930	0.030	0.003	2.077	20x40	5.7	94.3
1-788	1.379	0.071	3.114	0.035	0.007	3.227	50x75	57.3	42.7
2-243	1.164	0.254	3.368	0.030	0.007	3.659	75x100	68.2	31.8
2-243	1.691	0.286	2.305	0.028	---	2.619	75x100	35.4	64.6
2-243	1.544	0.175	2.690	0.027	0.006	2.898	75x150	46.7	53.3
2-243	1.888	0.189	1.988	0.029	0.006	2.212	150x200	14.6	85.4
2-243	1.231	0.123	3.370	0.035	0.004	3.532	150x200	65.1	34.9
2-281	0.888	---	4.175	0.026	0.007	4.208	100x150	78.9	21.1
2-281	1.057	---	3.839	0.025	0.007	3.871	100x150	72.7	27.3
2-281	0.911	---	4.140	0.027	0.004	4.171	50x50	78.2	21.8

TABLE 61 (continued)

Sample	Ti	Mg	Fe	Mn	Cr	Σ Mg, Fe Mn, Cr	Crystal Size, μ m	Mole %	
								Magnetite	Ilmenite
2-324	1.237	0.172	3.309	0.024	0.007	3.512	130x164	64.8	35.2
2-324	0.980	0.131	3.860	0.027	0.008	4.026	150x175	75.7	24.3
2-324	1.057	0.196	3.638	0.030	0.007	3.871	25x50	72.7	27.3
2-363	1.012	0.201	3.711	0.031	0.011	3.954	175x225	74.4	25.6
2-363	0.905	0.182	3.948	0.026	0.011	4.167	50x75	78.3	21.7
2-363	0.951	0.158	3.892	0.026	0.007	4.083	25x75	76.7	23.3
2-390	1.045	---	3.860	0.027	0.008	3.895	50x75	73.2	26.8
2-390	1.926	0.100	2.020	0.020	0.003	2.143	85x110	10.1	89.9
2-390	0.358	---	5.227	0.019	0.013	5.258	85x110	93.2	6.8
2-390	1.511	---	2.931	0.025	0.007	2.963	200x300	49.0	51.0
3-868 (A2021)	1.336	0.210	3.032	0.042	0.015	3.299	15x75	59.5	40.5
3-868	1.342	0.118	3.109	0.046	0.015	3.288	60x75	59.2	40.8
3-868	1.341	0.087	3.151	0.050	0.011	3.299	50x50	59.4	40.6
3-868	1.605	0.065	2.655	0.047	0.007	2.774	50x60	42.1	57.9
3-868	1.580	0.091	2.613	0.093	0.015	2.812	45x75	43.8	56.2
3-876 (A2022)	1.964	0.111	1.922	0.029	0.003	2.065	26x60	4.9	95.1
3-876	1.280	0.141	3.231	0.035	0.011	3.418	50x75	62.6	37.4
3-876	1.981	0.093	1.917	0.020	0.003	2.033	25x25	2.6	97.4
3-900 (A2023)	1.230	0.273	3.217	0.030	0.007	3.527	50x100	65.1	34.9
3-900	1.260	0.274	3.158	0.026	0.007	3.465	30x40	63.6	36.4
3-900	1.394	0.150	3.014	0.027	0.008	3.199	50x50	56.4	43.6
3-924 (A2024)	1.788	0.238	2.151	0.026	0.003	2.418	75x100	26.1	73.9
3-924	1.878	0.182	2.037	0.025	---	2.244	30x35	16.3	83.7
3-924	1.988	0.106	1.887	0.030	---	2.023	20x140	1.7	98.3
3-938 (A2025)	1.271	0.009	3.388	0.037	0.008	3.442	60x120	63.1	36.9
3-938	1.302	0.063	3.275	0.036	0.007	3.381	75x130	61.5	38.5
3-938	1.354	0.062	3.174	0.045	0.004	3.285	50x75	58.8	41.2
3-952 (A2026)	1.143	0.163	3.483	0.044	0.008	3.698	30x75	69.1	30.9
3-952	1.196	0.219	3.324	0.031	0.011	3.585	200x200	66.6	33.4
3-952	1.240	0.183	3.279	0.036	0.007	3.505	50x75	64.6	35.4

TABLE 61 (continued)

Sample	Ti	Mg	Fe	Mn	Cr	EMg,Fe Mn,Cr	Crystal Size, μ m	Mole %	
								Magnetite	Ilmenite
3-1000 (A2027)	1.073	---	3.810	0.033	0.004	3.847	50x125	72.1	27.9
3-1000	1.990	---	1.991	0.030	---	2.021	75x130	1.5	98.5
3-1000	1.015	0.048	3.871	0.027	0.008	3.954	30x50		
3-1032 (A2028)	1.946	0.150	1.932	0.026	---	2.108	85x135	7.7	92.3
3-1032	1.899	0.162	2.007	0.034	---	2.203	70x70	13.8	86.2
3-1032	0.954	0.130	3.924	0.026	0.004	4.084	60x120	76.6	23.4
3-1060 (A2029)	1.420	0.110	2.995	0.034	0.007	3.146	25x50	54.9	45.1
3-1060	1.946	0.117	1.965	0.027	---	2.109	75x100	7.7	92.3
3-1060	1.945	0.142	1.922	0.028	0.006	2.098	100x150	7.3	92.7
3-1114	0.930	0.110	3.960	0.034	0.012	4.116	50x70	77.4	22.6
3-1114	1.506	---	2.960	0.029	---	2.989	20x60	49.6	50.4
3-1114	1.922	0.076	2.050	0.030	---	2.156	10x75	10.9	89.1
Al216	1.886	0.193	1.996	0.039	---	2.228	90x140	15.4	84.6
Al216	0.572	0.175	4.626	0.029	0.008	4.838	80x80	88.2	11.8
Al216	1.210	0.204	3.306	0.026	0.015	3.551	70x70	65.9	34.1
Al215	1.131	0.129	3.549	0.037	0.007	3.722	90x90	69.6	30.4
Al215	1.165	0.156	3.467	0.036	0.004	3.663	95x225	68.2	31.8
Al215	1.121	0.184	3.516	0.037	0.007	3.744	115x125	70.1	29.9

TABLE 62. High Barium Groundmass and Whole Rock Analyses

Groundmass Compositions from Electron Microprobe Chemical Analyses.
 "W" analyses are whole rock analyses.

Sample	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	Wt %		BaO	FeO	TiO ₂	P ₂ O ₅	Total
					MgO	CaO					
1-679	74.4	14.2	4.2	6.8	<0.3	1.4	0.3	2.3	<0.2	<0.2	103.6
1-679	67.7	13.4	1.3	7.1	--	1.0	0.2	2.6	--	--	93.3
1-679	71.1	14.2	2.3	7.5	--	1.6	0.3	3.0	--	--	100.0
1-694	62.4	17.4	2.7	8.1	--	2.3	0.6	2.7	1.5	1.0	98.7
1-694	65.1	20.1	<1.3	8.9	--	2.0	1.1	0.6	--	--	97.8
1-694	65.5	13.4	--	7.4	--	1.6	0.3	6.4	1.3	0.5	96.4
1-730	71.7	13.0	--	8.0	--	0.6	0.2	2.3	1.0	--	96.8
1-730	67.5	18.5	--	5.1	--	3.4	0.8	1.1	0.5	--	96.9
1-730	71.5	13.9	2.1	8.2	--	1.3	0.7	2.6	1.0	--	101.3
1-757	66.9	10.0	1.3	4.9	--	5.2	0.5	13.2	--	--	102.0
1-757	60.1	11.0	1.3	5.3	--	5.7	0.3	15.4	--	--	99.1
1-757	55.4	13.1	3.2	4.0	--	4.4	0.4	11.1	--	--	91.6
1-788	75.3	11.8	--	6.9	--	0.9	<0.2	0.9	0.6	--	96.4
1-788	74.5	11.1	2.5	6.3	--	0.6	--	2.0	0.6	--	97.6
1-788	74.4	12.0	1.5	8.1	--	0.5	--	1.5	0.5	--	98.5
2-243	74.0	7.9	2.0	9.4	--	0.6	0.8	0.8	0.2	--	95.7
2-243	64.0	10.6	3.6	9.1	--	1.5	1.6	0.6	--	--	91.0
2-243	70.5	10.2	--	8.9	--	0.6	0.6	0.9	0.4	--	92.1
2-281	65.6	15.8	4.1	9.5	--	0.9	0.3	1.5	--	--	97.7
2-281	72.3	11.7	2.0	6.4	--	0.4	0.2	2.0	0.6	--	95.6
2-281	65.6	17.4	4.1	9.1	--	0.9	0.4	1.3	0.2	--	99.0
2-324	65.0	22.0	--	9.6	--	1.3	1.5	0.6	--	--	100.0
2-324	63.0	23.6	6.1	8.8	--	1.9	1.2	0.5	--	--	105.1
2-324	67.0	19.8	5.1	11.8	--	0.5	0.3	0.5	--	--	105.0

TABLE 62 (continued)

Sample	Wt %										Total
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	P ₂ O ₅	
2-363	79.4	11.8	2.4	5.4	---	0.3	0.3	0.8	---	---	100.4
2-363	61.4	18.6	3.9	10.8	---	0.4	0.9	0.4	---	---	96.4
2-363	61.5	20.7	7.3	8.0	---	1.7	1.5	0.4	---	---	101.1
2-390	62.1	10.1	3.9	8.1	---	4.1	---	7.9	1.7	1.5	99.4
2-390	68.7	15.6	2.1	8.6	---	3.1	0.7	3.1	1.5	0.8	104.2
2-390	65.4	15.9	2.5	7.5	---	1.6	0.5	4.7	1.0	0.5	99.6
3-868 (A2021)	56.9	12.7	2.8	4.3	1.0	5.9	0.9	10.3	1.9	1.1	97.8
3-868	54.2	11.2	2.4	4.2	2.5	8.8	0.5	10.2	2.6	1.1	97.7
3-868	59.2	11.5	--	4.8	1.7	7.6	0.6	11.0	2.5	1.2	100.1
3-868W	57.6	13.0	3.26	2.17	2.3	5.9	0.33	8.7	2.15		95.41
3-876 (A2022)	73.6	16.2	--	6.2	---	2.2	---	2.4	0.5	1.0	102.1
3-876	68.2	11.0	4.2	10.3	0.4	0.6	---	1.2	0.3	---	96.2
3-876	75.7	11.9	--	5.8	---	0.5	---	2.1	0.8	---	96.8
3-876W	58.2	13.0	3.0	2.37	3.8	6.3	0.34	13.7	2.86		103.57
3-900 (A2023)	62.3	17.8	3.3	3.6	---	5.9	0.8	5.0	2.0	0.8	101.5
3-900	60.1	12.1	2.2	4.3	---	5.0	0.6	9.1	1.8	0.8	96.0
3-900	57.2	10.8	1.9	4.8	---	5.7	0.5	15.8	4.0	1.3	102.0
3-900W	57.2	14.0	3.2	2.55	3.0	5.8	0.34	8.4	2.66		97.15
3-924 (A2024)	68.0	14.6	5.5	3.9	---	1.0	0.4	5.4	1.3	---	100.1
3-924	58.5	19.3	7.3	5.0	---	2.8	2.2	0.4	---	---	95.5
3-924	60.0	22.0	8.3	4.1	---	1.6	2.6	0.4	---	---	99.0
3-924W	57.5	13.8	3.3	2.5	2.9	5.9	0.36	11.8	2.4		100.46
3-938 (A2025)	84.1	7.1	--	7.8	---	1.1	---	2.5	1.3	0.3	104.2
3-938	74.7	10.7	1.1	4.4	---	5.5	0.9	1.2	0.2	1.0	99.7
3-938	78.2	7.0	--	6.7	---	1.4	---	2.9	1.1	---	97.3
3-938W	58.5	13.7	3.3	2.8	3.0	6.1	0.37	12.3	2.3		102.37

TABLE 62 (continued)

Sample	Wt. %										Total
	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	MgO	CaO	BaO	FeO	TiO ₂	P ₂ O ₅	
3-952 (A2026)	72.2	12.8	---	5.8	0.7	2.2	0.3	4.0	1.3	0.5	99.8
3-952	71.0	11.8	---	7.1	0.5	1.6	0.6	3.9	1.1	0.3	97.9
3-952	61.8	10.2	---	6.8	1.0	4.0	0.8	8.5	2.3	0.5	95.9
3-952W	59.0	14.0	3.2	2.7	2.7	5.7	0.37	12.3	2.3		102.27
3-1000 (A2027)	65.6	19.1	3.6	9.9	---	1.3	1.7	0.8	---	---	102.0
3-1000	65.6	16.7	2.6	8.8	---	1.1	0.2	1.5	---	---	96.5
3-1000	66.2	17.5	3.0	9.9	---	1.0	0.9	0.5	---	---	99.0
3-1000W	57.0	13.0	3.4	2.6	2.9	5.7	0.38	12.6	2.3	---	99.88
3-1032 (A2028)	64.8	18.6	6.1	5.8	---	5.5	0.9	0.2	---	---	101.9
3-1032	52.7	13.5	5.2	4.0	---	10.4	0.4	3.7	---	6.3	96.2
3-1032W	57.1	12.7	3.4	2.6	3.0	5.8	0.39	12.6	2.2		99.79
3-1060 (A2029)	64.1	15.8	5.0	7.2	0.3	1.6	1.0	0.6	---	---	95.6
3-1060	67.1	14.4	3.8	7.4	---	1.0	0.3	0.7	---	---	94.7
3-1060	67.5	15.9	4.2	7.4	---	1.4	0.8	0.6	---	---	97.8
3-1060W	55.5	12.4	3.3	2.5	4.3	5.9	0.34	12.4	2.3		98.94
3-1114	69.1	14.5	2.2	9.7	---	0.3	---	1.7	1.3	---	98.8
3-1114	73.8	14.8	---	9.3	---	0.7	---	0.8	---	---	99.4
3-1114	77.3	9.0	---	5.7	1.2	0.9	---	10.0	0.8	---	104.9
Al215	67.3	21.0	4.5	5.1	---	0.8	1.7	0.4	---	---	100.8
Al215	69.5	12.7	2.6	4.6	---	0.2	---	4.2	0.5	---	94.3
Al215	66.2	20.5	4.4	4.7	---	0.8	1.7	0.4	---	---	98.7
Al216	67.7	20.1	4.5	5.1	---	2.3	0.6	1.0	---	0.6	101.9
Al216	63.8	16.3	4.0	4.6	---	5.2	0.7	0.8	---	2.0	97.4
Al216	61.8	20.0	5.7	5.0	---	1.3	2.4	0.4	---	---	96.6

very little chemical differentiation, and must have cooled very rapidly. There is a little less magnesium and sodium in the groundmass and a little more potassium, barium and iron, but otherwise little difference between whole rock and groundmass analyses. Sample 3-938 (A2025), on the other hand, 42 feet from the middle of the 276-foot-thick, high barium flow in well DDH-3, is highly differentiated. The groundmass here is depleted in iron, magnesium, calcium and sodium, and very high in silica and potassium. Cooling rate apparently greatly influences the degree of chemical differentiation, as would be expected.

In general, the groundmasses are enriched in silica and potassium and depleted in magnesium, calcium, iron and sometimes sodium.

Metallics Scans

The scan interval used here was 2 μm , rather than the 5 μm used on the feldspar and pyroxene scans. The ilmenite has proceeded in many cases (DH-2-363 feet) to exsolve or segregate on an edge of the magnetite crystal. The typical, nearly-homogeneous titaniferous magnetite contains 25 to 28% TiO_2 , while the most exsolved portions of a metallic contain as little as 7 wt% TiO_2 . Ilmenite occurs where the wt% TiO_2 exceeds 40.

The SiO_2 wt% is given in some of the scans because it is often present in the metallic crystal in substantial amounts. The first scan of metal oxides in DDH-1-694 feet, for example, shows a considerable SiO_2 content, averaging 15 wt% SiO_2 across the crystal center. Many of the other metallics show siliceous patches, and silica near the crystal phase boundaries. Apparently phase separations are not as sharp as they appear to be in the optical photomicrographs.

Accessory Minerals

Most of the samples contained accessory apatite, and four typical analyses are presented in Table 63. Hydroxyl, fluorine and chlorine were not analyzed, but were assumed to sum to two in the analysis. These apatites also are very similar to those found in the other flow units.

Several sulfur-bearing metallics were located in the high barium flow samples. In two instances, the mineral was definitely pyrite. The remainder of the sulfur-bearing

FIGURE 109. Scan Across a Metal Oxide Crystal in DDH1
679 feet

FIGURE 110. Scan Across a Metal Oxide Crystal in DDH1 - 679 feet

FIGURE 111. Scans Across Metal Oxide Crystals in DDH1 - 694 feet

FIGURE 112. Scans Across Metal Oxides Crystals in DDH1 - 730 feet

FIGURE 113. Scan Across Metal Oxide Crystal in DDH1 - 757 feet

FIGURE 114. Scans Across Metal Oxide Crystals in DDH1 - 788 feet

FIGURE 115. Scan Across a Metal Oxide Crystal in DH2 - 243 feet

FIGURE 116. Scan Across a Metal Oxide Crystal in DH2 - 281 feet

FIGURE 117. Scan Across a Metal Oxide Crystal in DH2 - 324 feet

FIGURE 118. Scan Across a Metal Oxide Crystal in DH2 - 363 feet

FIGURE 119. Scan Across a Metal Oxide Crystal in DH2 - 390 feet

FIGURE 120. Scan Across a Metal Oxide Crystal in DH2 - 390 feet

FIGURE 121. Scan Across a Metallic Oxide Crystal in DDH3 - 868 feet (A2021)

FIGURE 122. Scans Across Metallic Oxide Crystals in DDH3 - 876 feet (A2022)

FIGURE 123. Scan Across a Metal Oxide Crystal in DDH3 - A2023 (900 feet)

FIGURE 124. Scan Across a Metal Oxide Crystal in DDH3 - 924 feet (A2024)

FIGURE 125. Scan Across a Metal Oxide Crystal in DDH3 - 938 feet (A2025)

FIGURE 126. Scan Across a Metallic Oxide Crystal in DDH3 - 952 feet (A2026)

FIGURE 127. Scan Across a Metal Oxide Crystal in DDH3 - 1000 feet (A2027)

FIGURE 128. Scans Across Metal Oxide Crystals in DDH3 - 1032 feet (A2028)

FIGURE 129. Scan Across a Metallic Oxide Crystal in DDH3 - 1060 feet (A2029)

FIGURE 130. Scan Across a Metal Oxide Crystal in DDH3 - 1114 feet

FIGURE 131. Scan Across a Metal Oxide Crystal from Sillusi Butte Sample A1215

FIGURE 132. Scan Across a Metal Oxide Crystal from Sillusi Butte Sample A1216

TABLE 63. High Barium Basalt Apatite Analyses

Typical Analyses of Accessory Apatites Based on
the Molecule $(\text{Mg,Ca,Fe}^{+2})_{10}(\text{PO}_4)_6(\text{OH,F,Cl})_2$.
Crystal size varied from $3 \times 5 \mu\text{m}$ to $15 \times 100 \mu\text{m}$.

<u>Sample</u>	<u>Mg</u>	<u>Ca</u>	<u>Fe</u>	<u>$\Sigma\text{Mg,Ca,Fe}$</u>	<u>PO_4</u>	<u>$\Sigma\text{OH,F,Cl}$</u>
1-679	0.63	8.36	0.47	9.48	6.00	2.00
1-788	--	8.66	1.28	9.94	6.00	2.00
2-243	0.31	9.20	0.11	9.62	6.00	2.00
2-281	--	9.92	0.19	10.11	6.00	2.00

metallics could be referred to as pyrrhotites, but probably represent immiscible sulfide segregations due to their wide iron-sulfur variability ratios. The sulfide analyses are given in Table 64.

Secondary Minerals

Several clay analyses are presented in Table 65. These are the typical, dioctahedral, high-iron clays, very similar to those found in the other flow units. They probably result from late-stage action during flow unit cooling on groundmass and olivines when present.

Barium Distribution

The whole rock, groundmass and feldspar barium contents are compared in Table 66. The barium appears to be in the groundmass (probably including submicro-crystalline feldspars) in some cases and in the feldspars in other cases. From earlier microprobe work, for example, it was decided that the barium in 3-924 (A2024) was probably in the groundmass, and in 3-1032 (A2028), in the feldspars. These new results tend to substantiate the earlier evaluation, but it should be kept in mind that the feldspar and groundmass areas analyzed were very small, and could represent a highly biased distribution result. Sample 3-876 (A2022) is a good example of bias. One might ask where the barium went in this case. In most cases, though, enough barium is probably contained in the feldspars and groundmass to account for the bulk of the barium shown for the whole rock analyses.

Optical Photomicrographs

Photomicrographs of the various high barium flow samples are given in the following pages. The magnification is noted under each photograph. The 80- and 160-power magnifications are generally views of the flow fabric. The plain reflected light photos are designated "A", and the polarized reflected light photos, "B".

The lightest minerals in the 80- and 160-power photos are the metallics. The next lightest in color are the pyroxenes, followed by the lath-like feldspars and even darker groundmass. There are often many small pyroxene crystals surrounding the edges of the feldspar laths. The darkest areas are the clays, or altered minerals and groundmass. The 800-magnification

TABLE 64. High Barium Basalt Sulfide Analyses

Analyses of Sulfur-Containing Metallics. Sample 1-757 was a pyrite crystal contained in a sectioned metallic oxide crystal.

<u>Sample</u>	<u>Fe</u>	<u>S</u>	<u>Mineral Identification</u>	<u>Crystal Size, μm</u>
1-694	0.62	1.00	Immiscible sulfide	5x5
1-757	1.00	2.09	Pyrite	10x12
2-243	0.92	1.00	Immiscible sulfide	5x5
2-281	1.00	1.00	Immiscible sulfide	15x25
3-938 (A2025)	0.86	1.00	Immiscible sulfide	5x5
3-952 (A2026)	1.00	2.08	Pyrite	30x50
3-1000 (A2027)	0.81	1.00	Immiscible sulfide	20x20
3-1060 (A2029)	0.80	1.00	Immiscible sulfide	12x35
3-1114	0.82	1.00	Immiscible sulfide	10x10

TABLE 65. High Barium Basalt Clay Mineral Analyses

Composition of Several Clay Minerals Found in the High Barium Flow Samples.

<u>Sample</u>	<u>Al</u>	<u>Octahedral</u>		<u>Σ</u>	<u>Tetrahedral</u>	
		<u>Fe</u>	<u>Mg</u>		<u>Al</u>	<u>Si</u>
1-679	0.372	1.292	0.465	2.129	0.251	3.749
1-694	0.010	1.695	0.449	2.154	0.345	3.655
1-730	0.043	1.501	0.756	2.300	0.473	3.527
1-788	0.150	1.762	0.177	2.089	0.420	3.580
3-868 (A2021)	0.289	1.531	0.137	1.957	0.063	3.937
3-876 (A2022)	0.046	1.449	0.654	2.149	0.123	3.877
3-876	0.164	1.709	0.161	2.034	0.270	3.730
3-938 (A2025)	0.044	1.766	0.262	2.072	0.285	3.715

TABLE 66. Distribution of Barium in the High Barium Basalt
Barium Contents of the Whole Rock, Groundmass and Feldspar
Analyses, Where Available.

<u>Sample</u>	<u>Whole Rock</u>	<u>Ba, ppm</u>	
		<u>Groundmass</u>	<u>Feldspar</u>
1-679	---	2687	3583
1-679		1791	3583
1-679		2687	4478
1-694	---	5374	7165
1-694		9852	1791
1-694		2687	1791
1-730	---	1791	<1790
1-730		7165	1791
1-730		6270	2687
1-757	---	4478	1791
1-757		2687	<1790
1-757		3583	<1790
1-788	---	<1790	1791
1-788		<1790	1791
1-788		<1790	2687
2-243	---	7165	2687
2-243		14330	3583
2-243		5374	2687
2-281	---	2687	4478
2-281		1791	<1790
2-281		3583	13434
2-324	---	13435	1791
2-324		10748	1791
2-324		2687	2687
2-324		---	2687
2-363	---	2687	4478
2-363		8061	2687
2-363		13435	2687
2-390	---	<1790	4478
2-390		6270	1791
2-390		4478	1791

TABLE 66 (continued)

<u>Sample</u>	<u>Whole Rock</u>	<u>Groundmass</u>	<u>Feldspar</u>
3-868 (A2021)	2998	8060	7165
3-868		4478	9852
3-868		5374	9852
3-876 (A2022)	3048	<1790	<1790
3-876		<1790	<1790
3-876		<1790	2687
3-900 (A2023)	3082	7165	<1790
3-900		5374	2687
3-900		4478	3582
3-924 (A2024)	3190	3582	1791
3-924		19703	<1790
3-924		23286	2687
3-938 (A2025)	3350	<1790	10747
3-938		8060	2687
3-938		<1790	2687
3-952 (A2026)	3280	2687	4478
3-952		5374	1791
3-952		7165	3582
3-1000 (A2027)	3370	15225	5374
3-1000		1791	2687
3-1000		8060	2687
3-1032 (A2028)	3470	8060	1791
3-1032		3582	30450
3-1032		12538	13434
3-1060 (A2029)	3070	8956	9852
3-1060		2687	7165
3-1060		7165	3582
3-1114	----	<1790	1791
3-1114		<1790	9852
3-1114		<1790	9852
A1215	----	15225	3582
A1215		<1790	1791
A1215		15225	10747
A1216	----	5374	2687
A1216		6269	7165
A1216		21494	1791
A1216		---	9852

DDH-1

A

80X

B

160X

C

800X

D

800X

679'

A

80X

B

160X

C

800X

D

800X

694'

A

80X

B

160X

C

800X

D

800X

730'

A 80X

B 160X

C 800X

D 800X

788'

A 80X

B 160X

C 800X

D 800X

751'

E

800X

F

800X

788'

C

800X

D

800X

E

800X

F

800X

243'

C 800X

D 800X

E 800X

F 800X

281'

A **80X**

B **160X**

C **800X**

D **800X**

324'

E

800X

F

800X

324'

A

80X

B

160X

363'

C 800X

D 800X

E 800X

F 800X

363'

A

80X

B

160X

C

800X

D

800X

390'

DDH-3

A

80X

B

160X

C

800X

D

800X

A2021

A 80X

B 160X

C 800X

D 800X

A2022

A

80X

B

160X

C

800X

D

800X

A2023

A

800 X

A2025

B

800 X

A

80 X

A2027

B

160 X

C 800X

D 800X

E 800X

F 800X

A2027

C 800X

D 800X

E 800X

F 800X

A2029

A 80X

B 160X

C 800X

D 800X

A2026

E

800X

F

800X

A2026

A

80X

B

160X

1114'

C 800X

D 800X

E 800X

F 800X

1114'

photos were obtained after viewing some of the metallics in the petrographic microscope, and are primarily to show these.

Several of the metallics seem to be homogeneous, as the 800-power photos for DDH-1-679 and DDH-1-694 feet indicate, for example. Other metallics have separated into two phases. These last two sets of photos also show polishing scratches that can be distinguished from other features by their random orientation. Finally, evidence for exsolution of ilmenite from magnetite is apparent in the 800-power photos from DH-2-234 feet, DDH-3-A2025 and DDH-3-A2026. The reason for this type of zoning was discussed under "Metallics", an earlier section of this report. It was the discovery of this type of zoning that allowed the positive identification of magnetite and ilmenite as the two phases present in these metallics.

FLOW UNIT CORRELATIONS

Perhaps the most basic part of the mineralogical data are the whole rock analyses. Consequently, these were treated statistically to ascertain possible constituent interrelationships useful in correlations. The preliminary results were interesting, and the method of data treatment, results and implications of these results will be given in some detail.

The whole rock analyses were taken from the well sections. There were 128 basalt analyses on DDH-3, 173 analyses on DH-4 and 73 analyses for DH-5. In the last well, all of the analyses were not given on the section.

More than half of the well section is not represented, so that 73 analyses do not suffice for a representative sample of DH-5 rock analyses.

Correlation is a statistical measurement of the mutual relationship between two measured quantities.²⁵ There are standard numerical procedures for determining the correlation coefficient that can be found in any elementary statistics text. The statistical correlation coefficient, designated as r , is an estimate of the correlation coefficient of the whole population, designated as ρ (rho). It is usually not possible to obtain anything but an unbiased sample of the population from which to derive an estimate of the population correlation coefficient. In our case, the analyses are of rock samples selected from the section, and as such, represent unbiased samples of the whole section.

The correlation coefficient can vary between the limits or plus or minus one. With $r = 0$, there is no correlation between the two sets of measurements. Negative values for r indicate that large values for one measurement are associated with small values of the other measurement. Positive r values indicate a direct relationship.

Ratios of element oxides are often misused in correlations. Normally, the assumption is made that there is no correlation between the measured values ($\rho = 0$), and the derived correlation coefficient is tested numerically at the 5% level of significance with the hypothesis ($\rho = 0$) rejected or retained based on this test. However, the measurements (ratios of element oxides) can assume a relationship to each other called "closure" which is inherent in the manner in which the ratios are derived and plotted. A good example is given by Table 67. Two sets of values are given under X_1 and X_2 that are not

TABLE 67.²⁵ Correlations of Some Ratios with Common Elements
Compared to the Original Correlation of X_1 and X_2

<u>X_1</u>	<u>X_2</u>	<u>X_1</u>	<u>$X_1 + X_2$</u>	<u>X_1</u>	<u>X_2/X_1</u>
32	18	32	50	32	0.562
31	13	31	44	31	0.419
28	22	28	50	28	0.786
24	17	24	41	24	0.708
44	11	44	55	44	0.250
53	19	53	72	53	0.358
9	16	9	25	9	1.778
35	23	35	58	35	0.657
33	23	33	56	33	0.697
31	18	31	49	31	0.581
$r = 0$		$r = 0.945$		$r = -0.854$	

correlated ($r = 0$). By adding a common element (X_1) to X_2 , correlation between the next two sets of values become 0.945 and -0.854, respectively. In other words, a common element in the last two examples gives rise to "closure", or can induce a correlation in two sets of data (X_1 and X_2) that are actually uncorrelated when the common element is removed. $\rho = 0$ is not the proper test hypothesis for the last two sets. It is not too difficult to misinterpret correlations between data sets containing common elements. When, for example, potassium is used for one variable and potassium/rubidium, the other, an inherent correlation between these variables arises whether the two are actually correlated or not. Chayes²⁶ gives a numerical method for estimating the correlation value to be expected from closure, but we have chosen a ratio relationship ($\text{Na}_2\text{O}/\text{Na}_2\text{O} + \text{K}_2\text{O}$ vs. $\text{MgO}/\text{MgO} + \text{FeO}$) or oxides for which the appropriate expectation is that the correlation between the two variables will be, in fact, zero.

The data and analysis for wells DDH-3 and DH-4 are given in the Appendix. DH-5 data were not included because analyses exist for less than half of the cored section.

A plot of K_2O vs. MgO for DDH-3 rock analysis data is given in Figure 133. Attempting to graphically estimate a correlation coefficient would be difficult, hence the numerical deviation of r in all cases. The circle and line on Figure 133 will be explained later.

The whole rock analyses were examined for mutual relationships, or correlations, between element oxides and oxide ratios. These analyses represent samples from many flow units that are separated by time intervals. The only way that the changes in flow unit constituents can be correlated is through their relationship to the same source area or areas. It is known, for example, that olivine, the magnesium-rich pyroxenes, and to some extent the calcium-rich plagioclases are the first mineral phases to crystallize in a basaltic magma, and could occur before or during flow unit extrusion. Potassium and most of the iron would tend to remain in the source magma at this crystallization stage. One would expect, then, a negative and rather high correlation between potassium and magnesium because the magnesium is being removed in the source magma while the potassium stays in the liquid. If the mineral phases containing the magnesium tend to sink, or otherwise become segregated, in the source magma so that the extruded flow appears to decrease in magnesium and increase in potassium, the result could be a negative and rather high correlation between changes in magnesium and potassium content over the time interval represented by the extruded flow units.

FIGURE 133. Data for K₂O - MgO Correlation from DDH-3 Whole Rock Analyses. The estimate of Y, $Y = 3.24408 + (-0.437363)(X)$

$$r_{12} = 0.706$$

$$K_2O = Y$$

$$MgO = X$$

For the same reasons, no correlation between potassium and iron, both of which tend to remain in the melt at this early crystallization stage, could be expected.

The correlation coefficient for potassium and magnesium is negative and rather high for the flow units represented in DDH-3 and DH-4 and there is no correlation between potassium and iron in the flow units of either well section, as shown in Table 68. Note that in all cases where there are valid correlations in Table 68, they are associated with a high confidence level. For DDH-4, for example, degrees of freedom are 171 (or $n-2$) and the associated r value at the 1% level of significance is 0.196 (sign ignored), and for DDH-3, degrees of freedom are 126 and r at 1% level is 0.228. One percent significance means that upon sampling the section for analysis, and choosing 173 and 128 samples from DH-4 and DDH-3, respectively, the correlation coefficient (r) will equal 0.196 or 0.228 (sign ignored) once out of 100 times of choosing 173 and 128 samples due to chance or accidents of sampling.

There are several probable reasons as to why these correlations are not exactly the same. For one thing, DH-4 and DDH-3 are about 28 miles apart. Flow units traveling any distance would pick up and incorporate extraneous material, which would tend to weaken correlations as a result of source area relationships. Also, the two well sections may not have had exactly the same sources for lava extrusion. This is suggested by the high barium flow, missing in DH-4.

Sodium and potassium could be expected to be correlated to some extent because they are both removed into the same mineral (feldspar) although potassium is removed to a lesser extent than sodium. This correlation also should be positive, as it is. It was noted that the whole rock analyses for the high barium flow in DDH-3 fit in very well with the other flow unit whole rock analyses in DDH-3, except for the alkali content. Na_2O and K_2O are consistently higher in the high barium flow. Higher alkali content is characteristic of sills because there is a tendency for flows of the same composition to lose small amounts of alkalis. Sills greater than 40 miles in length are known, so the length of the high barium flow does not rule out its being a sill. Such an hypothesis, however, would have to be substantiated by field relations.

Correlations between flow unit constituents do not imply that flow unit crystallization in any way caused the correlations. Events in the source magma caused the correlations in the constituents of the whole rock flow unit analyses, not what happened to the flow units after extrusion. The flow

TABLE 68. Correlations of Constituents from Whole Rock Analyses

Well	$\text{CaO}-\text{FeO}$	$\text{K}_2\text{O}-\text{MgO}$	$\text{K}_2\text{O}-\text{FeO}$	$\text{Na}_2\text{O}-\text{MgO}$	$\text{Na}_2\text{O}-\text{FeO}$	$\text{Na}_2\text{O}-\text{CaO}$	$\text{MgO}-\text{FeO}$	$\text{MgO}-\text{CaO}$	$\text{Na}_2\text{O}-\text{K}_2\text{O}$	$\frac{\text{Na}_2\text{O}}{\text{Na}_2\text{O}+\text{K}_2\text{O}} - \frac{\text{MgO}}{\text{MgO}+\text{FeO}}$
DDH-3	+0.0768*	-0.706	-0.0897*	-0.352	-0.335	-0.431	-0.0928*	+0.829	+0.291	+0.665
DDH-4	-0.0902*	-0.678	-0.0957*	-0.708	-0.317	-0.330	-0.0763*	+0.559	+0.552	+0.572

* = no correlation ($\rho = 0$)

units themselves are separated by time intervals. There can be no meaningful correlations between the constituents of entities that are independent and separated in time. The only common connection between the flow units is the source area or areas that persisted through the time represented by the flow units. The separation of melt and early formed crystals (olivine, pyroxenes) in a source magma is a common occurrence. The density of the melt would be about 2.65 while the pyroxenes and olivine is closer to 3.35. According to Jaeger,²⁷ a pyroxene crystal of 1 mm radius would sink about 160 meters/year in such a melt or magma. Jaeger also suggests that aggregates of plagioclase and pyroxene also may commonly become segregated. As soon as a flow unit is extruded from the magma, the constituents of the whole rock analysis are set, and related to other flow unit constituent changes by the common history of crystal segregation occurring in the source magma. What happens during crystallization of the extruded flow unit after extrusion is immaterial in terms of the whole rock constituent correlation, as long as minimal amounts of constituents are lost during the flow crystallization process.

To return to the correlations, calcium and magnesium are both removed into the pyroxenes, especially during early crystallization, so a positive, high correlation would be expected, and one does occur (see Table 68). The data for MgO-CaO correlation are shown graphically in Figure 134. Sodium and iron can be correlated due to segregation of pyroxene-plagioclase in the source magma.

The lack of correlation between calcium and iron or magnesium and iron represents a more complex situation. Magnesium and iron, for example, are removed into the same minerals during early crystallization in the source magma. However, the earliest pyroxenes are highest in magnesium while the later pyroxenes are highest in iron. Much of the iron tends to stay in the melt as well. Olivines also were crystallizing, probably somewhat earlier in the sequence. It is difficult to predict how the magnesium and iron in the extruded flows should be correlated under these circumstances. The net result seems to be no correlation between magnesium and iron, or calcium and iron.

The correlation of sodium/sodium plus potassium to magnesium/magnesium plus iron, expressed as oxides, is positive and high. With slow, progressive and related changes in extruded flow unit chemical constituents taking place as a result of crystal segregation in the source magma (or essentially no changes at

FIGURE 134. Data for MgO - CaO Correlation from DDH-3 Whole Rock Analyses. The estimate of Y, $Y = 1.70758 + 0.829147 (X)$

$$r_{12} = 0.829$$

$$\text{MgO} = Y$$

$$\text{CaO} = X$$

all in some cases), it is less difficult to understand that the flow units are close relatives.

The line shown in Figure 133 is the regression line for the change in K_2O in relation to MgO . Numerically, the estimate of K_2O , (Y), is equal to $a + b(X)$, the slope-intercept line form. In this case, $Y = 3.24408 + (-0.437363) (X)$. Points on this line can be obtained by substituting values for X into the equation. It is of interest to select a small area, such as that encircled in Figure 137, and determine which samples in the section these points represent (see Table 69). Several of the points in Table 69 represent more than one sample. However, the samples fall into four groups. The largest group, with nine of the 16 samples, varies from A2111 to A2121. A2016, A2018 and A2019 constitute the second group, A2045 and A2046 the third, and A2058 and A2059 the fourth group.

All of the above sample groupings are represented in the section of DDH-3 by single flow units, with the possible exception of the large group of nine samples. It appears that this group is also from a single flow (3066 to 3354 feet), but there are several feet of core missing, so that this is not certain. A2016, A2018 and A2019 are from a single flow (680-768 feet), as are A2045 and A2046 (1536-1608 feet) and A2058 and A2059 (1906-1938 feet).

The implication of having four flow units occurring in widely separated parts of the section and having nearly the same K_2O to MgO ratio is that correlated changes in K_2O and MgO in the source magma are not taking place in a simple manner from the base of the section upwards. While the changes in K_2O and MgO in the source magma are always correlated, the changes do not always occur in the same direction. For the changes in MgO and K_2O to always hold to the same direction a very quiescent magma source would be required, preferably with a slow, steady rate of temperature decline, which would allow the process of crystallization and crystal segregation to proceed without interruption. This is obviously not the case when numerous extrusions have occurred.

The statistical computations were made on a computer. In addition, several were hand-computed to check on program results.

Several of the flow unit constituents are correlated over the well sections as a result of on-going, physical-chemical changes taking place in the source magma. Though the flow unit constituents are often correlated, the changes in source magma chemistry are not necessarily unidirectional. For

TABLE 69. Samples Represented by the Points Encircled in Figure 133

<u>K₂O, wt%</u>	<u>MgO, wt%</u>	<u>Whole Rock Analysis Sample No.</u>
1.8	3.6	A2159
1.7	3.5	A2111
1.6	3.5	A2120
1.5	3.6	A2121
1.7	3.8	A2019
1.6	4.1	A2018
1.4	4.1	A2046
1.4	3.7	A2119, A2114
1.4	3.8	A2117
1.3	3.6	A2016, A2113, A2115, A2116
1.2	3.7	A2045, A2058

TABLE 70. Statistical Computations

DDH-3CaO = x_1 , FeO = x_2

$\Sigma x_1 = 986.4$	$\Sigma x_2 = 1686.51$	$n = 128$
$\Sigma (x_1)^2 = 7724.420$	$\Sigma (x_2)^2 = 22438.904$	$\Sigma (x_1 x_2) = 13009.235$
$(\Sigma x_1)^2/n = 7601.445$	$(\Sigma x_2)^2/n = 22221.219$	$(\Sigma x_1)(\Sigma x_2)/n = 12996.668$
$\Sigma (x_1 - \bar{x}_1)^2 = 122.975$	$\Sigma (x_2 - \bar{x}_2)^2 = 217.685$	$\Sigma (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) = 12.567$

$$r_{12} = \Sigma (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) / \sqrt{[\Sigma (x_1 - \bar{x}_1)^2][\Sigma (x_2 - \bar{x}_2)^2]} = 0.0768$$

K₂O = x_1 , MgO = x_2

$\Sigma x_1 = 153.13$	$\Sigma x_2 = 599.3$	$n = 128$
$\Sigma (x_1)^2 = 230.475$	$\Sigma (x_2)^2 = 2929.03$	$\Sigma (x_1 x_2) = 663.125$
$(\Sigma x_1)^2/n = 183.194$	$(\Sigma x_2)^2/n = 2805.94$	$(\Sigma x_1)(\Sigma x_2)/n = 716.959$
$\Sigma (x_1 - \bar{x}_1)^2 = 47.281$	$\Sigma (x_2 - \bar{x}_2)^2 = 123.09$	$\Sigma (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) = -53.834$

$$r_{12} = -0.706$$

K₂O = x_1 , FeO = x_2

$\Sigma x_1 = 153.13$	$\Sigma x_2 = 1686.51$	$n = 128$
$\Sigma (x_1)^2 = 230.475$	$\Sigma (x_2)^2 = 22438.904$	$\Sigma (x_1 x_2) = 2008.517$
$(\Sigma x_1)^2/n = 183.194$	$(\Sigma x_2)^2/n = 22221.219$	$(\Sigma x_1)(\Sigma x_2)/n = 2017.617$
$\Sigma (x_1 - \bar{x}_1)^2 = 47.281$	$\Sigma (x_2 - \bar{x}_2)^2 = 217.685$	$\Sigma (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) = -9.10$

$$r_{12} = -0.0897$$

TABLE 70 (continued)

Na₂O = X₁, MgO = X₂

$\Sigma X_1 = 357.15$	$\Sigma X_2 = 599.3$	$n = 128$
$\Sigma (X_1)^2 = 1008.27$	$\Sigma (X_2)^2 = 2929.03$	$\Sigma (X_1 X_2) = 1658.798$
$(\Sigma X_1)^2/n = 996.532$	$(\Sigma X_2)^2/n = 2805.94$	$(\Sigma X_1)(\Sigma X_2)/n = 1672.187$
$\Sigma (X_1 - \bar{X}_1)^2 = 11.738$	$\Sigma (X_2 - \bar{X}_2)^2 = 123.09$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -13.389$
	$r_{12} = -0.352$	

Na₂O = X₁, FeO = X₂

$\Sigma X_1 = 357.15$	$\Sigma X_2 = 1686.51$	$n = 128$
$\Sigma (X_1)^2 = 1008.27$	$\Sigma (X_2)^2 = 22438.904$	$\Sigma (X_1 X_2) = 4688.846$
$(\Sigma X_1)^2/n = 996.532$	$(\Sigma X_2)^2/n = 22221.219$	$(\Sigma X_1)(\Sigma X_2)/n = 4705.758$
$\Sigma (X_1 - \bar{X}_1)^2 = 11.738$	$\Sigma (X_2 - \bar{X}_2)^2 = 217.685$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -16.912$
	$r_{12} = -0.335$	

Na₂O = X₁, CaO = X₂

$\Sigma X_1 = 357.15$	$\Sigma X_2 = 986.4$	$n = 128$
$\Sigma (X_1)^2 = 1008.27$	$\Sigma (X_2)^2 = 7724.42$	$\Sigma (X_1 X_2) = 2735.903$
$(\Sigma X_1)^2/n = 996.532$	$(\Sigma X_2)^2/n = 7601.445$	$(\Sigma X_1)(\Sigma X_2)/n = 2752.287$
$\Sigma (X_1 - \bar{X}_1)^2 = 11.738$	$\Sigma (X_2 - \bar{X}_2)^2 = 122.975$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -16.384$
	$r_{12} = -0.431$	

TABLE 70 (continued)

MgO = X_1 , FeO = X_2

$\Sigma X_1 = 599.30$	$\Sigma X_2 = 1686.51$	$n = 128$
$\Sigma (X_1)^2 = 2929.03$	$\Sigma (X_2)^2 = 22438.904$	$\Sigma (X_1 X_2) = 7881.104$
$(\Sigma X_1)^2/n = 2805.94$	$(\Sigma X_2)^2/n = 22221.219$	$(\Sigma X_1)(\Sigma X_2)/n = 7896.293$
$\Sigma (X_1 - \bar{X}_1)^2 = 123.09$	$\Sigma (X_2 - \bar{X}_2)^2 = 217.685$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -15.189$
	$r_{12} = -0.0928$	

MgO = X_1 , CaO = X_2

$\Sigma X_1 = 599.3$	$\Sigma X_2 = 986.4$	$n = 128$
$\Sigma (X_1)^2 = 2929.03$	$\Sigma (X_2)^2 = 7724.420$	$\Sigma (X_1 X_2) = 4720.320$
$(\Sigma X_1)^2/n = 2805.94$	$(\Sigma X_2)^2/n = 7601.445$	$(\Sigma X_1)(\Sigma X_2)/n = 4618.355$
$\Sigma (X_1 - \bar{X}_1)^2 = 123.09$	$\Sigma (X_2 - \bar{X}_2)^2 = 122.975$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 101.965$
	$r_{12} = 0.829$	

Na₂O = X_1 , K₂O = X_2

$\Sigma X_1 = 357.15$	$\Sigma X_2 = 153.13$	$n = 128$
$\Sigma (X_1)^2 = 1008.27$	$\Sigma (X_2)^2 = 230.475$	$\Sigma (X_1 X_2) = 434.135$
$(\Sigma X_1)^2/n = 996.532$	$(\Sigma X_2)^2/n = 183.194$	$(\Sigma X_1)(\Sigma X_2)/n = 427.269$
$\Sigma (X_1 - \bar{X}_1)^2 = 11.738$	$\Sigma (X_2 - \bar{X}_2)^2 = 47.281$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 6.866$
	$r_{12} = 0.291$	

TABLE 70 (continued)

$$\frac{\text{Na}_2\text{O}}{\text{Na}_2\text{O} + \text{K}_2\text{O}} = X_1, \quad \frac{\text{MgO}}{\text{MgO} + \text{FeO}} = X_2$$

$\Sigma X_1 = 91.15$	$\Sigma X_2 = 33.453$	$n = 128$
$\Sigma (X_1)^2 = 65.767$	$\Sigma (X_2)^2 = 9.020$	$\Sigma (X_1 X_2) = 24.146$
$(\Sigma X_1)^2/n = 64.909$	$(\Sigma X_2)^2/n = 8.743$	$(\Sigma X_1)(\Sigma X_2)/n = 23.822$
$\Sigma (X_1 - \bar{X}_1)^2 = 0.858$	$\Sigma (X_2 - \bar{X}_2)^2 = 0.277$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 0.324$
	$r_{12} = 0.665$	

DH-4

$$\text{CaO} = X_1, \text{FeO} = X_2$$

$\Sigma X_1 = 1343.40$	$\Sigma X_2 = 2163.10$	$n = 173$
$\Sigma (X_1)^2 = 10849.80$	$\Sigma (X_2)^2 = 27378.57$	$\Sigma (X_1 X_2) = 16763.54$
$(\Sigma X_1)^2/n = 10431.928$	$(\Sigma X_2)^2/n = 27046.25$	$(\Sigma X_1)(\Sigma X_2)/n = 16797.159$
$\Sigma (X_1 - \bar{X}_1)^2 = 417.872$	$\Sigma (X_2 - \bar{X}_2)^2 = 332.32$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -33.619$
$r_{12} = \Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) / \sqrt{[\Sigma (X_1 - \bar{X}_1)^2][\Sigma (X_2 - \bar{X}_2)^2]} = -0.0902$		

$$\text{K}_2\text{O} = X_1, \text{MgO} = X_2$$

$\Sigma X_1 = 189.8$	$\Sigma X_2 = 771.8$	$n = 173$
$\Sigma (X_1)^2 = 234.70$	$\Sigma (X_2)^2 = 3660.64$	$\Sigma (X_1 X_2) = 795.35$
$(\Sigma X_1)^2/n = 208.231$	$(\Sigma X_2)^2/n = 3443.21$	$(\Sigma X_1)(\Sigma X_2)/n = 846.749$
$\Sigma (X_1 - \bar{X}_1)^2 = 26.469$	$\Sigma (X_2 - \bar{X}_2)^2 = 217.43$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -51.399$
	$r_{12} = -0.678$	

TABLE 70 (continued)

K₂O = X₁, FeO = X₂

$\Sigma X_1 = 189.8$	$\Sigma X_2 = 2163.1$	$n = 173$
$\Sigma (X_1)^2 = 234.70$	$\Sigma (X_2)^2 = 27378.57$	$\Sigma (X_1 X_2) = 2364.18$
$(\Sigma X_1)^2/n = 208.231$	$(\Sigma X_2)^2/n = 27046.25$	$(\Sigma X_1)(\Sigma X_2)/n = 2373.16$
$\Sigma (X_1 - \bar{X}_1)^2 = 26.469$	$\Sigma (X_2 - \bar{X}_2)^2 = 332.32$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -8.98$
	$r_{12} = -0.0957$	

Na₂O = X₁, MgO = X₂

$\Sigma X_1 = 515.30$	$\Sigma X_2 = 771.8$	$n = 173$
$\Sigma (X_1)^2 = 1559.470$	$\Sigma (X_2)^2 = 3660.64$	$\Sigma (X_1 X_2) = 2247.10$
$(\Sigma X_1)^2/n = 1534.879$	$(\Sigma X_2)^2/n = 3443.21$	$(\Sigma X_1)(\Sigma X_2)/n = 2298.893$
$\Sigma (X_1 - \bar{X})^2 = 24.591$	$\Sigma (X_2 - \bar{X}_2)^2 = 217.43$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -51.793$
	$r_{12} = -0.708$	

Na₂O = X₁, FeO = X₂

$\Sigma X_1 = 515.30$	$\Sigma X_2 = 2163.10$	$n = 173$
$\Sigma (X_1)^2 = 1559.470$	$\Sigma (X_2)^2 = 27378.57$	$\Sigma (X_1 X_2) = 6414.36$
$(\Sigma X_1)^2/n = 1534.879$	$(\Sigma X_2)^2/n = 27046.25$	$(\Sigma X_1)(\Sigma X_2)/n = 6443.04$
$\Sigma (X_1 - \bar{X}_1)^2 = 24.591$	$\Sigma (X_2 - \bar{X}_2)^2 = 332.32$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -28.68$
	$r_{12} = -0.317$	

TABLE 70 (continued)

Na₂O = X₁, CaO = X₂

$\Sigma X_1 = 515.3$	$\Sigma X_2 = 1343.40$	$n = 173$
$\Sigma (X_1)^2 = 1559.470$	$\Sigma (X_2)^2 = 10849.80$	$\Sigma (X_1 X_2) = 3968.04$
$(\Sigma X_1)^2/n = 1534.879$	$(\Sigma X_2)^2/n = 10431.928$	$(\Sigma X_1)(\Sigma X_2)/n = 4001.468$
$\Sigma (X_1 - \bar{X}_1)^2 = 24.591$	$\Sigma (X_2 - \bar{X}_2)^2 = 417.872$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -33.428$
	$r_{12} = -0.330$	

MgO = X₁, FeO = X₂

$\Sigma X_1 = 771.8$	$\Sigma X_2 = 2163.1$	$n = 173$
$\Sigma (X_1)^2 = 3660.64$	$\Sigma (X_2)^2 = 27378.57$	$\Sigma (X_1 X_2) = 9629.680$
$(\Sigma X_1)^2/n = 3443.21$	$(\Sigma X_2)^2/n = 27046.25$	$(\Sigma X_1)(\Sigma X_2)/n = 9650.177$
$\Sigma (X_1 - \bar{X}_1)^2 = 217.43$	$\Sigma (X_2 - \bar{X}_2)^2 = 332.32$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = -20.497$
	$r_{12} = -0.0763$	

MgO = X₁, CaO = X₂

$\Sigma X_1 = 771.8$	$\Sigma X_2 = 1343.4$	$n = 173$
$\Sigma (X_1)^2 = 3660.64$	$\Sigma (X_2)^2 = 10849.80$	$\Sigma (X_1 X_2) = 6161.840$
$(\Sigma X_1)^2/n = 3443.21$	$(\Sigma X_2)^2/n = 10431.928$	$(\Sigma X_1)(\Sigma X_2)/n = 5993.272$
$\Sigma (X_1 - \bar{X}_1)^2 = 217.43$	$\Sigma (X_2 - \bar{X}_2)^2 = 417.872$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 168.568$
	$r_{12} = 0.559$	

TABLE 70 (continued)

Na₂O = X₁, K₂O = X₂

$\Sigma X_1 = 515.30$	$\Sigma X_2 = 189.80$	$n = 173$
$\Sigma (X_1)^2 = 1559.470$	$\Sigma (X_2)^2 = 234.70$	$\Sigma (X_1 X_2) = 579.43$
$(\Sigma X_1)^2/n = 1534.879$	$(\Sigma X_2)^2/n = 208.231$	$(\Sigma X_1)(\Sigma X_2)/n = 565.34$
$\Sigma (X_1 - \bar{X}_1)^2 = 24.591$	$\Sigma (X_2 - \bar{X}_2)^2 = 26.469$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 14.09$
$r_{12} = 0.552$		

Na₂O
Na₂O + K₂O = X₁, MgO
MgO + FeO = X₂

$\Sigma X_1 = 127.755$	$\Sigma X_2 = 45.251$	$n = 173$
$\Sigma (X_1)^2 = 95.078$	$\Sigma (X_2)^2 = 12.308$	$\Sigma (X_1 X_2) = 33.753$
$(\Sigma X_1)^2/n = 94.343$	$(\Sigma X_2)^2/n = 11.836$	$(\Sigma X_1)(\Sigma X_2)/n = 33.416$
$\Sigma (X_1 - \bar{X}_1)^2 = 0.735$	$\Sigma (X_2 - \bar{X}_2)^2 = 0.472$	$\Sigma (X_1 - \bar{X}_1)(X_2 - \bar{X}_2) = 0.337$
$r_{12} = 0.572$		

example, the MgO - MgO graph for DDH-3 samples given in Figure 133 shows four round points at the extreme lower right for A2011, A2012, A2013 and A2014 (488-670 feet, the Pomona flow), while A2016, A2018 and A2019, from the flow immediately below the Pomona, are found with the circle in Figure 133. (A2017 is just outside the circle). Thus, adjacent flow units can be on the extreme ends of the regression line in Figure 133.

Another use of these data is indicated. On the extreme right of the K_2O - MgO regression line in Figure 133, note three solid square points. These three points are from K_2O - MgO data from A4007, A4008 and A4009 samples of the Pomona flow in DH-4 well. This proximity suggests that these data may be useful as an aid to flow unit identification where good correlations between constituents are found. If these changes in the source magma were graphed for the flow units from each well section, the well section graphs should tend toward matching when the same flow units from different well sections were lined up.

If the flow units from the various sections are related at least in part to the same source areas, the sections themselves must also be related. If we chose a set of constituents that are well-correlated, or constituents with a high correlation coefficient, there is a good probability that the same flow unit, extending over several well sections, can be recognized. There are several good constituent correlations including K_2O - MgO , MgO - CaO , and Na_2O/Na_2O+K_2O - $MgO/MgO+FeO$. The last two correlation coefficients are positive, however, which means that the constituent values tend to change in the same direction. The values for MgO/CaO , then, would tend to change very little. Since some such index as the above will have to be used to identify each flow unit, it would be advantageous to choose a constituent pair with a high negative correlation coefficient, if available. An index from these constituents should give the largest range in values because the high values of one are associated with the low values of the other. The K_2O - MgO correlation coefficient from well sections three and four has such a high negative value that the flow units from the sections can be identified with an index K_2O/MgO . The correlation coefficient was derived from samples of the sections with flow units ignored. The K_2O/MgO values cannot be directly used for flow unit identification unless they are grouped by flow units. This was accomplished by taking a mean K_2O/MgO for each flow. The K_2O/MgO values for each flow were summed and divided by the number of samples in that unit flow.

The K_2O/MgO mean indices for the various flows in DDH-3, DH-4 and selected flows in DH-5 and DDH-1 are given in Table 71.

TABLE 71. K₂O/MgO Indices and Correlations for the Various Flow Units from the Well Section Whole Rock Analyses. The straight-sided brackets indicate known flow units or flow unit groups.

<u>DDH-3</u>	<u>DH-4</u>	<u>DH-5</u>	<u>DDH-1</u>	<u>Flow Groups</u>
0.1121	{0.1977			
0.1952	{0.2000			
0.3075	{0.0223			
0.0708	{0.0358	0.0685	0.0670	Pomona
0.4068	{0.1143			
0.8397	0.3753		0.7984	High Barium
0.1827	{0.1842			
0.2368	{0.1731			
0.2738	{0.2009			
0.3280	{0.2012			
0.2722	{0.2002	0.2423		High Chromium
0.2559	{0.1797			
0.2624	{0.2181			
0.3017	0.3387			
0.2415	0.1868			
0.2601	0.1818			
0.2405	0.1591			
0.2014	0.1410			
0.4709	{0.2307			
0.2037	{0.2333	0.2569		Low Chromium
0.1493	{0.2318			
0.1549	0.1273			
0.1417	0.2182			
0.1946	0.1662			
0.4775	0.2865			
0.4124	0.3441			
0.1815	{0.4838			
0.0988	{0.4509			
	0.3984			
	0.3284			
	0.2905			
	0.3538			
	{0.4253			
	{0.4588			
	0.3066			
	{0.3677			
	{0.3589			
	0.2518			

The flow unit depth and thickness is given in Table 72 in the same order. The straight-sided brackets identify flow units that have been grouped and identified. These include the Pomona, the high barium flow, a high chromium group and a low chromium group. The curved brackets between the DDH-3 and DH-4 columns are suggested groupings and correlations. The Pomona is a distinctive and easily identifiable group, apparently found in all of the well sections. Another flow unit is included in the Pomona in DH-4. The mean K_2O/MgO index for these three flow units is 0.0575, which is a good fit with the other Pomona well section values.

The high barium flow gives a high K_2O/MgO index value in DDH-3 and DDH-1. The high barium flow is obviously missing from DH-4 well section.

The high chromium flow unit matches fairly well the correlation between sections except that three more units have been included in the DH-4 group because they have similar K_2O/MgO indices. On the other hand, the low chromium flow indices seem to indicate that perhaps too many units have been included in the low chromium group in DDH-3 and DH-4 sections.

In addition to the above, several other tentative section correlations were made in Table 72 based on K_2O/MgO flow unit indices. In general, the correlations between well sections of known flow units are very good. The indices of the high chromium group in DH-4 are a little low compared to the same flows in DDH-3 and DH-5, but are acceptable. The fact that the two section correlations agree as well as they do is encouraging. All of the other information, chemical, petrographic, stratigraphic mineralogical, etc., should be applied before the validity of any correlation is judged, however.

TABLE 72. Depth and Thickness of Flow Units in Feet Given in the Same Order as in Table 71.

<u>DDH-3</u>	<u>DH-4</u>	<u>DH-5</u>	<u>DDH-1</u>
220-284	22-28		
298-354	28-44		
354-456	44-92		
488-669	92-167	324-460	254-442
678-768	167-344		
842-1118	344-402		664-794
1160-1292	402-496		
1319-1464	496-507		
1464-1535	510-540		
1535-1608	540-623		
1608-1690	623-764	909-1049	
1690-1746	764-814		
1746-1906	814-888		
1906-1948	888-986		
1948-1982	986-1088		
1982-2024	1088-1125		
2024-2160	1125-1156		
2160-2200	1156-1233		
2200-2372	1233-1282		
2372-2578	1282-1320	1416-1685	
2578-2760	1320-1479		
2760-2860	1488-1510		
2860-2984	1510-1590		
2984-3065	1590-2216		
3065-3170	2216-2302		
3170-3354	2302-2434		
3354-3467	2434-2544		
3467-3540	2544-2918		
	2918-3042		
	3042-3202		
	3202-3282		
	3282-3414		
	3414-3504		
	3504-3636		
	3636-3734		
	3734-3791		
	3791-3896		
	3896-4112		

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APPENDIX A

SAMPLE NUMBER CORRELATIONS WITH SAMPLE LOCATIONS

APPENDIX

SAMPLE LOCATIONS

BOREHOLE SAMPLES

Borehole locations are shown on Plate 1 of this report. Lithologic logs of each borehole showing sample locations are given in Reference 1 below.

- DDH-3

A-2002	A-2023	A-2044	A-2064	A-2097
A-2006	A-2024	A-2045	A-2067	A-2098
A-2009	A-2025	A-2046	A-2068	A-2102
A-2011	A-2026	A-2048	A-2072	A-2105
A-2012	A-2027	A-2050	A-2079	A-2109
A-2013	A-2028	A-2053	A-2083	A-2116
A-2014	A-2029	A-2056	A-2087	A-2123
A-2018	A-2033	A-2059	A-2089	A-2128
A-2021	A-2038	A-2060	A-2092	A-2133
A-2022	A-2041	A-2061	A-2094	

- DH-4

A-4007	A-4012
A-4008	A-4013
A-4009	A-4014
A-4010	A-4015
A-4011	

- DH-5

A-5006
A-5007
A-5008
A-5009
A-5010
A-5011

TYPE SECTION SAMPLES

Basalt Unit

Location Reference

- Saddle Mountain Basalt

Ward Gap	A-1278	1
Pomona	A-1268	1
Umatilla	A-1215	1
	A-1216	

TYPE SECTION SAMPLES (continued)

<u>Basalt Unit</u>			<u>Location Reference</u>
• Wanapum Basalt			
Roza	K-5066	K-5078	2
	K-5068	K-5096	
	K-5070	K-5098	
	K-5072	K-5099	
	K-5074	K-5101	
	K-5076		
Frenchman Springs	A-1281		1
Sentinel Gap	K-5033		2
	K-5035		
	K-5126		
Sand Hollow	K-5008		2
	K-5009		
	K-5086		
	K-5089		
	K-5095		
Ginkgo	K-5013	K-5133	2
	K-5015	K-5135	
	K-5017	K-5136	
	K-5018	K-5137	
	K-5020	K-5139	
	K-5131	K-5140	
	K-5132		
	K-5037		3
• Grande Ronde Basalt			
Museum	K-5010		4
Rocky Coulee	K-5026		5

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2. C. W. Myers, Yakima Basalt Flows Near Vantage and From Core Holes in the Pasco Basin, Washington, Ph.D. Dissertation, University of California at Santa Cruz, California (1973).
3. None, Location is mouth of Sand Hollow near Vantage, Washington (SW 1/4, SE 1/4, Sec. 28, T17N, R23E).

REFERENCES (Continued)

4. None, Location is near the Museum Building for the Ginkgo Petrified Forest State Park near Vantage, Washington.
(NW 1/2, NE 1/4, Sec. 19, T17N, R23E)
5. None, Location is along abandoned highway approximately one-half mile north of east abutment, Vantage, Washington bridge across Columbia River.
(SE 1/4, NE 1/4, Sec. 20, T17N, R23E)

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