UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geochemical data for Jurassic diabase and basalt of the northern Culpeper basin, Virginia

by

K. Y. Lee[1], B.D. Leavy[2], and David Gottfried[1]

Open-File Report 84 - 771

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1]U. S. Geological Survey
Reston, Virginia

[2]New Mexico Institute of
Mining and Technology
Socorro, New Mexico

List of figures, tables and appendixes

Appendix

Geochemical data for Jurassic diabase and basalt of the northern Culpeper basin, Virginia
by
K. Y. Lee, B. D. Leavy, and David Gottfried

Geology of the Culpeper basin, Virginia

The Culpeper basin (fig. 1) is a north-northeast-trending faulted trough at the innner margin of the Piedmont geologic province along the east front of the Blue Ridge. The basin is about 20 km (12.4 miles) wide and extends for about 140 km (87 miles) north from the Rapidan River across the Potomac River and terminates near Frederick, Maryland. It is part of a belt of similar Newark rift-basin structures, all of early Mesozoic age, which lie along the east coast of North America from Florida to Nova Scotia.

The sedimentary rocks of the Culpeper basin are part of the Newark Supergroup and comprise a distinctive sequence of clastic strata (Culpeper Group) ranging in age from Late Triassic to Early Jurassic (Cornet, 1977). The Triassic section is predominantly non-marine sandstone and siltstone ("red beds") with a variety of lenticular conglomerates and minor amounts of shale. The Jurassic sequence also contains red beds and lenticular conglomerates but is characterized by a series of intercalated basalt flows and lacustrine gray and black shales.

Most of the Culpeper Group is intruded and locally metamorphosed by dikes, sills, and stocks of tholeiitic diabase (Lee, 1977, 1979, 1980; Lindholm, 1979); the Hartford, Newark, and Gettysburg basins (fig. 1) include similar igneous rocks (Puffer and Lechler, 1980). This report deals with a suite of samples from several diabase intrusives and basalt flows in the northern part of the Culpeper basin in Virginia (Appendix 1A, 1B, and fig. 2).

Sampling and analysis

The rocks discussed herein were collected by K. Y. Lee, in conjunction with reconnaissance mapping in the northern Culpeper basin. Forty-four outcrop or quarry samples from 4 diabase intrusive bodies and 7 outcrop samples from 3 basalt flows (Appendix 1A, 1B, and fig. 2) were analyzed quantitatively for 12 major elements by atomic absorption spectrophotometry (Shapiro, 1975) (Table 1 and Appendix 2A, 2B). Semiquantitative spectrographic measurements (Dorrzapf, 1973) were performed for 31 trace elements, including 11 rare-earth elements (REE) (Appendix 3A, 3B, and 3C).

Twenty-nine analyses of fresh or slightly altered diabase appear in Table 1. The remaining 15 diabase samples and all 7 basalt samples were so altered that their major element and mobile trace element compositions are not representative of the fresh rock (Appendix 2A and 2B). Most of the fresh and altered diabase samples are medium crystalline rocks taken from the interior of the intrusive bodies. Samples 215 and 216, however, are from the chilled margin and are aphanitic to very finely crystalline, and samples 100, 103, 106, 111a, and 195 are late-phase pegmatitic or granophyric differentiates.

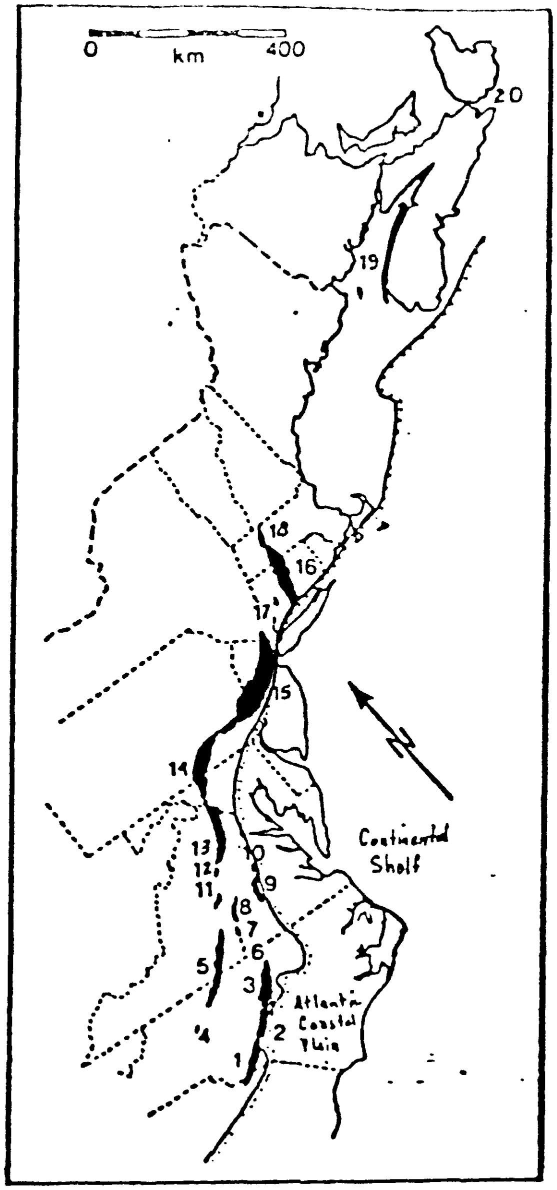

Figure 1. The Newark Supergroup of eastern North America. Exposed basins.

1. Wadesboro (N.C.-S.C.)
2. Sanford (N.C.)
3. Durham (N.C.)
4. Davie County (N.C.)
5. Dan River and Danville (N.C.-Va.)
6. Scottsburg (Va.)
7. Basins north of Scottsburg (Va.)
8. Farmville (Va.)
9. Richmond (Va.)
10. Taylorsville (Va.)
11. Scottsville (Va.)
12. Barboursville (Va.)
13. Culpeper (Va.-Md.)
14. Gettysburg (Md.-Pa.)
15. Newark (N.J.-Pa.-N.Y.)
16. Hartford (Conn.)
17. Pomperaug (Conn.)
18. Deerfield (Mass.)
19. Fundy or Minas (Nova Scotia-Cda.)
20. Chedabucto (Nova Scotia-Cda.)

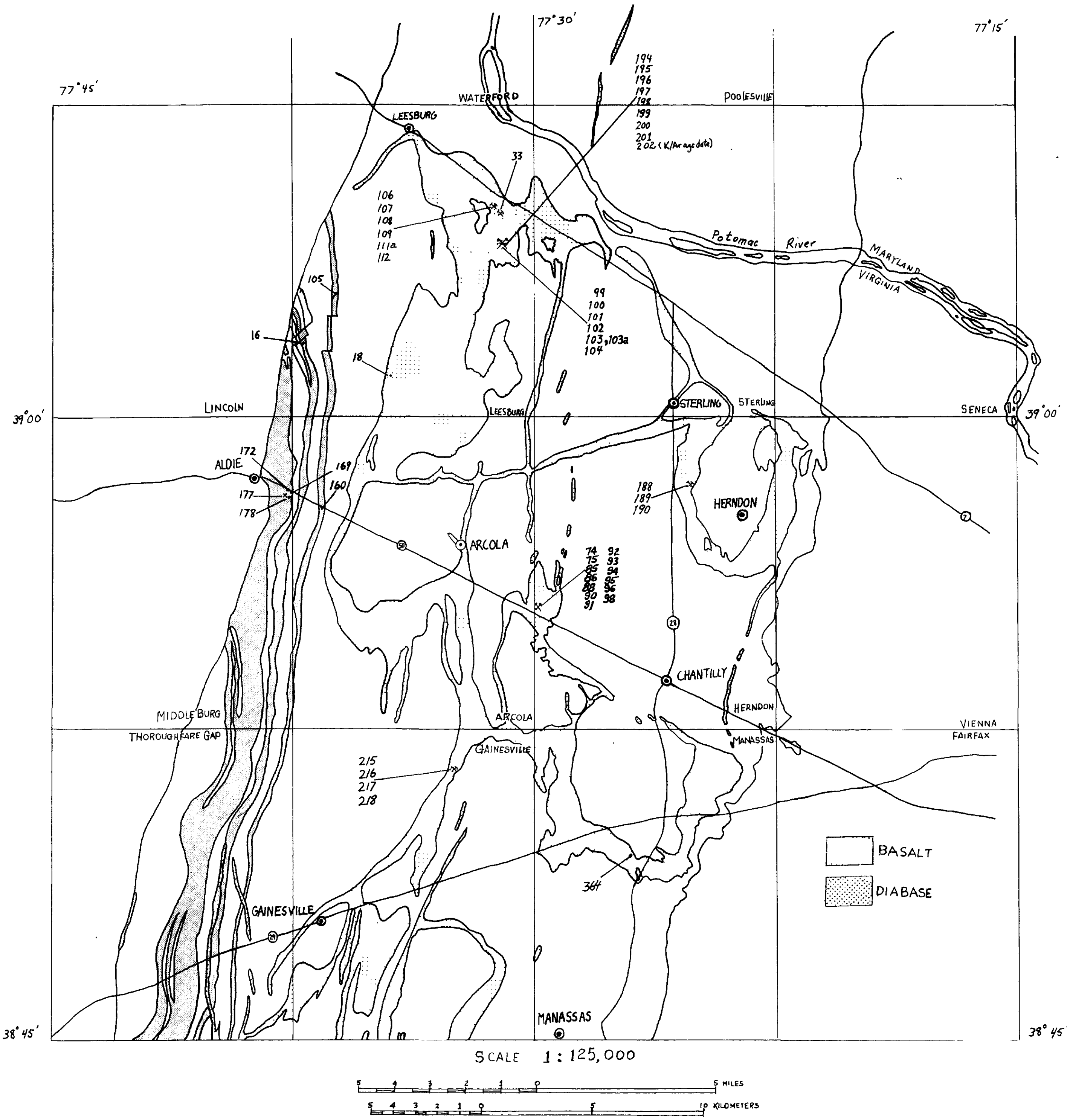

Figure 2. Locations of chemically analyzed Jurassic diabase and basalt samples, northern Culpeper basin, Virginia

Geochemistry of lower Mesozoic diabase in Eastern North America

Comprehensive studies of lower Mesozoic diabase in the central and southern Appalachians, and recently the northern Appalachians, have identified a number of chemical types among these rocks (Weigand and Ragland, 1970; Smith and others, 1975; Gottfried and others, 1977; Papezik and Hodych, 1980), which had been thought to be uniform in composition. Three major chemical types (Weigand and Ragland, 1970) dominate this basaltic group: 1) olivine-normative; 2) high-TiO_2, quartz-normative; and 3) low-TiO_2, quartz-normative. A fourth type, the high-Fe_2O_3 (ΣFe as Fe_2O_3), quartz-normative type, is less common and is considered to be a result of local differentiation processes (Weigand and Ragland, 1970; Puffer and Lechler, 1980).

To date, no comprehensive published studies have included analyses of the diabases of the Culpeper basin, although geochemical work on the related basalts has been reported by Puffer and others (1982), Sutter and others (1983), and Leavy and Puffer (1983). Mineralogic and petrographic data for the Culpeper diabases were reported by Shannon (1924), Linskold (1961), and Lee (1979, 1980).

Major element geochemistry of the Culpeper diabases

Major element chemistry and normative mineralogy of the 29 selected diabase samples from the northern Culpeper basin (Table 1) show them to be high-TiO_2, quartz- and hypersthene-normative rocks, comparable to the high-TiO_2, quartz-normative type of Wiegand and Ragland (1970), and very similar to the York Haven type diabase from the Gettysburg basin (Smith and others, 1975). The origin and interrelationships of these magma types have been discussed by several workers (Weigand and Ragland, 1970; Ragland and others, 1971; Smith and others, 1975; Puffer and others, 1981). The range in variation in the major element chemistry of the Culpeper diabases probably represents various stages of differentiation of a high-TiO_2, quartz-normative magma. Emplacement of these rocks was probably coeval with that of similar rocks in the other early Mesozoic basins in eastern North America (Raymond, 1982; Raymond and others, 1982; Sutter and others, 1983).

Conventional K-Ar ages were determined on a hornblende concentrate separated from a granophyre (584) and a plagioclase concentrate from a medium-crystalline diabase (202) (table 2 and fig. 2). The ages of the granophyre (188 $\pm$6 my) and the diabase (182 $\pm$6 my) are essentially the same within analytical certainties (table 2). Whereas the diabase sample locality (202) is shown on figure 2, the granophyre locality is approximately 46 miles S. 23° W. of sample 202.

Minor and trace element geochemistry of the Culpeper diabases

No conclusive statements can be made about the chemistry of the Culpeper diabases on the basis of the semiquantitative analyses reported here (Appendix 3A, 3B, and 3C). However, the data for Zr, Y, Pb, and Sr are comparable, in most cases to within 20 percent, to quantitative XRF analyses of Culpeper basin diabase (Leavy, unpub. data), and Zr and Y in the analyzed basalts are also comparable to that in basalts analyzed by Ragland (unpub. data) and Leavy

TABLE 1. WHOLE-ROCK MAJOR ELEMENT COMPOSITIONS OF RELATIVELY FRESH DIABASE FROM THE NORTHERN CULPEPER BASIN, VA.

Analysts: Floyd Brown, Lowell Artis, Herbert Kirschenbaum, Hezekiah Smith, and Leonard Shapiro (1973, 1974, 1975)

Oxide (Wt%) W#	18 181306	33 181322	85 181855	86 181856	91 181859	93 181851	95 181853	98 181840	99 181841	101 181843	102 181844	107 181835	108 181836
SiO_2	51.6	53.2	53.2	52.8	52.9	53.3	51.9	52.9	53.6	53.1	53.9	53.0	52.6
TiO_2	1.2	1.0	1.1	1.1	1.1	1.1	1.2	1.1	1.2	1.3	1.3	1.1	1.1
Al_2O_3	15.3	16.9	15.9	16.0	16.6	15.3	16.2	15.8	16.0	15.5	15.3	17.0	17.0
Fe_2O_3	2.4	1.4	1.6	1.4	1.6	1.6	2.4	1.4	1.7	1.8	1.8	2.2	2.3
FeO	7.4	6.8	7.1	7.5	6.7	7.3	6.2	7.4	7.5	7.9	7.9	6.7	6.1
MnO	0.12	0.10	0.11	0.11	0.11	0.11	0.08	0.12	0.12	0.11	0.12	0.10	0.10
MgO	6.1	5.9	7.0	7.2	6.4	6.8	6.4	7.2	5.5	5.5	5.7	6.0	5.9
CaO	9.4	10.9	10.8	11.4	10.5	11.0	10.8	11.1	10.4	9.8	10.3	10.7	11.1
Na_2O	2.4	2.2	2.2	2.1	2.6	2.2	2.5	2.1	2.5	2.6	2.3	2.3	2.4
K_2O	1.0	0.43	0.80	0.73	0.73	0.71	0.69	0.66	0.90	0.80	0.71	0.80	0.69
P_2O_5	0.17	0.13	0.17	0.10	0.14	0.15	0.13	0.64	0.37	0.45	0.46	0.30	0.24
CO_2	0.07	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02
H_2O^+	1.5	0.76	1.0	0.54	1.2	1.0	1.8	0.82	0.91	1.6	0.68	0.82	1.0
Total	99	100	101	101	101	101	101	101	101	101	101	101	101
Normative Minerals													
Q	4.5	6.57	4.05	2.88	3.07	4.51	3.43	4.21	5.57	5.66	7.56	5.27	4.96
OR	6.08	2.57	4.74	4.31	4.35	4.24	4.16	3.91	5.33	4.78	4.20	4.72	4.10
AB	20.90	18.80	19.83	18.85	23.54	19.98	22.89	18.93	21.20	22.23	19.50	19.42	20.40
AN	28.84	35.31	31.27	32.07	31.74	30.12	31.55	31.86	29.83	28.55	29.39	33.63	33.73
WO	7.33	7.54	8.54	9.40	8.03	9.74	8.94	7.69	8.06	7.53	7.83	7.23	8.30
EN	15.64	14.84	19.40	19.88	17.83	19.00	18.02	19.96	13.72	13.84	14.22	14.91	14.76
FS	10.14	9.96	8.55	9.28	7.97	8.94	6.53	9.39	10.63	11.21	11.12	8.84	7.70
FO	---	---	---	---	---	---	---	---	---	---	---	---	---
FA	---	---	---	---	---	---	---	---	---	---	---	---	---
MT	3.58	2.05	1.68	1.46	1.69	1.69	2.56	1.15	2.47	2.64	2.62	3.18	3.35
IL	2.35	1.92	1.54	1.53	1.55	1.55	1.70	1.54	2.28	2.49	2.47	2.08	2.10
AP	0.41	0.31	0.36	0.29	0.21	0.21	0.21	1.34	0.88	1.08	1.90	0.71	0.57
CC	0.16	0.14	0.03	0.03	0.03	0.03	0.03	0.00	0.05	0.02	0.02	0.02	0.05

TABLE 1 (CONT'D): WHOLE-ROCK MAJOR ELEMENT COMPOSITIONS OF RELATIVELY FRESH DIABASE FROM THE NORTHERN CULPEPER BASIN, VA.

Oxide (Wt %) W#	190 182501	194 182502	195 182503	196 182504	197 182505	198 182506	199 182507	200 182508	201 182509	202 182510	215 182517	216 182518	217 182519	218 182520	364 184774
SiO_2	56.8	56.0	54.2	55.7	54.1	54.6	54.0	54.0	54.6	53.2	51.5	52.6	52.7	53.8	54.0
TiO_2	1.8	1.6	2.8	2.7	1.3	0.99	1.4	1.3	1.3	1.4	1.2	1.4	1.5	1.6	1.3
Al_2O_3	16.0	17.2	12.7	13.6	17.0	16.1	15.6	15.9	14.8	14.6	14.5	15.0	15.7	14.4	15.9
Fe_2O_3	1.5	2.0	3.7	2.8	1.6	1.3	1.6	1.4	1.5	1.3	2.6	1.6	2.0	2.2	1.6
FeO	8.4	6.6	10.0	8.8	7.2	7.8	7.6	7.6	7.7	8.8	7.3	8.1	7.6	7.7	7.3
MnO	0.16	0.14	0.22	0.19	0.17	0.18	0.18	0.16	0.18	0.19	0.21	0.18	0.19	0.11	0.12
MgO	3.2	3.2	3.1	3.0	4.7	5.1	5.6	5.2	5.5	5.4	6.6	6.4	5.5	5.3	5.0
CaO	8.7	9.1	6.8	7.2	10.2	10.4	10.4	10.2	9.9	9.8	9.8	9.6	9.8	9.4	10.0
Na_2O	2.4	3.0	2.7	2.8	2.8	2.7	2.4	2.6	2.4	2.3	2.0	2.1	2.3	2.6	2.5
K_2O	0.95	0.81	1.6	1.5	0.60	0.54	0.57	0.62	0.69	0.59	0.75	0.71	0.70	0.92	0.71
P_2O_5	0.33	0.27	0.48	0.45	0.21	0.21	0.19	0.27	0.25	0.20	0.15	0.19	0.20	0.26	0.27
CO_2	0.02	0.07	0.03	0.04	0.04	0.03	0.03	0.05	0.01	0.01	0.03	0.02	0.03	0.06	0.06
H_2O^+	0.68	0.47	1.1	0.14	0.62	0.57	0.47	0.58	0.64	0.67	1.4	0.82	0.84	1.2	0.59
Total	101	101	100	99	101	101	100	100	100	99	99	99	99	100	100
Normative Minerals[1/]															
Q	13.83	11.01	12.50	13.56	6.43	6.46	7.35	6.88	8.06	7.50	6.60	6.66	7.18	7.88	8.02
OR	5.60	4.79	9.62	8.97	5.55	3.19	3.38	3.69	4.18	3.58	4.59	4.29	4.21	5.53	4.25
AB	20.26	25.39	23.24	23.99	23.71	22.86	20.40	22.16	22.10	19.90	17.51	18.15	19.82	22.37	21.42
AN	30.00	31.08	18.11	20.36	32.07	30.23	30.24	30.09	28.28	28.41	29.36	30.04	31.00	25.32	30.44
WO	4.50	4.95	5.35	5.25	7.08	8.28	8.41	7.84	8.28	8.33	8.24	7.19	7.09	8.34	7.36
EN	7.95	7.97	7.85	7.56	11.72	12.71	14.01	13.04	15.58	13.75	17.01	16.28	13.95	13.42	12.61
FS	11.48	8.09	11.28	9.86	10.08	11.96	10.70	11.03	9.59	13.42	10.00	11.82	10.37	10.05	10.29
FO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FA	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MT	2.17	2.90	5.46	4.11	2.32	1.89	2.33	2.04	1.61	1.94	3.90	2.37	2.95	3.24	2.35
IL	3.41	3.04	5.41	5.19	2.47	1.88	2.67	2.49	1.86	2.73	2.36	2.72	2.90	3.09	2.50
AP	0.78	0.64	1.16	1.08	0.50	0.50	0.45	0.64	0.43	0.48	0.37	0.46	0.48	0.63	0.65
CC	0.05	0.16	0.07	0.09	0.09	0.07	0.07	0.12	0.03	0.02	0.07	0.05	0.07	0.14	0.14

[1/] Based on analyses recalculated to 100 percent water-free oxides; $Fe_2O_3/FeO + Fe_2O_3$ ratio assumed to be 0.15.

Table 2.--K-Ar AGES AND ANALYTICAL DATA OF HORNBLENDE AND PLAGIOCLASE CONCENTRATES FROM GRANOPHYRE AND DIABASE OF THE CULPEPER BASIN, VIRGINIA

(Analysts: R. F. Marvin, H. H. Mehnert, and V. M. Merritt, 1980, U.S. Geological Survey)

Sample Field sample No.	Lab. No.	Mineral	K_2O (wt. percent)	[1]Ar^{40} 10^{-10} moles/g	[1]Ar^{40} (wt. percent)	[1]Ar^{40}/K^{40}	Age (m.y.)[2] $\pm 2\Sigma$
584	D2787H	Hornblende	1.535	4.378	95	0.0115	188 $\pm$6
202	D2786P1	Plagioclase	1.005	2.770	72	0.0111	182 $\pm$6

[1]Radiogenic argon

[2]Constants: $K_2O\lambda_\epsilon = 0.581 \times 10^{-10}/yr.$

$\lambda_\beta = 4.962 \times 10^{-10}/yr.$

$K^{40} = 1.167 \times 10^{-4}$

Sample Locations

Sample No. 584, D2787H, hornblende concentrate, was separated from a pink porphyritic granophyre which intrudes the Culpeper Group. Sample was collected at 38°27'54"N, 77°51'15"W (rounded hill on south side of Mountain Run and Virginia State Road 669); Germanna Bridge quad., Culpeper County, Virginia.

Sample No. 202, D2786P1, plagioclase concentrate, was obtained from a gray, medium-grained diabase sample which was collected at 39°04'15"N, 77°31'00"W in an abandoned quarry (Luck Quarry) on the east side of Goose Creek, Leesburg quad., Loudoun County, Virginia. The diabase body intruded the upper part of the Balls Bluff Siltstone (Upper Triassic).

(Leavy and Puffer, 1983). If these semiquantitative data are considered to be meaningful, certain observations may be made: 1) the diabase and basalt reported here show the same moderately light REE-enriched character as the high-TiO_2, quartz-normative diabases in eastern North America (Ragland and others, 1971); 2) a negative Eu anomaly, indicative of plagioclase fractionation, is apparent in some of the analyzed rocks; and 3) the decrease in Ni/Co, from 2-3 to approximately 0.5, is correlated with a decrease in MgO from approximately 7 to 3 percent, which also suggests extensive differentiation of the diabase magma (Fleischer, 1968).

References cited

Cornet, B., 1977, The palynostratigraphy and age of the Newark Supergroup: Ph.D. dissertation, the Pennsylvania State University, 506 p.

Dorrzapf, A. F., 1973, Spectrochemical computer analysis - Argon-oxygen DC arc method for silicate rocks: U.S. Geological Survey Journal Research, v. 1, no. 5, p. 559-562.

Fleischer, Michael, 1968, Variation of the ratio Ni/Co in igneous rock series: Journal of Washington Academy of Sciences, v. 58, p. 108-117.

Gottfried, David, Annell, C. S., and Schwarz, L. J., 1977, Geochemistry of subsurface basalt from the deep core hole (Clubhouse Crossroads Core 1) near Charleston, South Carolina; Magma type and tectonic implications, in D. W. Rankin, ed., Studies related to the Charleston, South Carolina Earthquake of 1886 - A preliminary report: U.S. Geological Survey Professional Paper 1028-G, p. 91-113.

Leavy, B. D., and Puffer, J. H., 1983, Physical and chemical characteristics of four Jurassic basalt units in the Culpeper basin, Virginia: Geological Society America Abstracts with Programs, v. 12, p. 92.

Lee, K. Y., 1977, Triassic stratigraphy in the northern part of the Culpeper basin, Virginia and Maryland: U.S. Geological Survey Bulletin 1411-C, 17 p.

______ 1979, Triassic-Jurassic geology of the northern part of the Culpeper basin, Virginia and Maryland: U.S. Geological Survey Open-file report 79-1557, scale 1:24,000, 16 pl., 29 p.

______ 1980, Triassic-Jurassic geology of the southern part of the Culpeper basin, Virginia-Maryland: U.S. Geological Survey Open-file report 80-468, scale 1:24,000, 18 pl., 19 p.

Lindholm, R. C., 1979, Geologic history and stratigraphy of the Triassic-Jurassic Culpeper basin, Virginia: Geological Society America Bulletin (pt. 2, microfiche), v. 90, no. 11, p. 1702-1736.

Linskold, J. E., 1961, Geology and petrology of the Gainesville, Virginia quadrangle: M.S. thesis, George Washington University, 50 p.

Papezik, V. S., and Hodych, J. P., 1980, Early Mesozoic diabase dikes of the Avalon Peninsula, Newfoundland; Petrochemistry, mineralogy, and origin: Canadian Journal Earth Science 17, p. 1417-1430.

Puffer, J. H., and Lechler, P., 1980, Geochemical cross-sections through the Watchung Basalt of New Jersey: Geological Society America Bulletin (part 2, microfiche), v. 90, p. 156-197.

Puffer, J. H., Hurtubise, D. O., Geiger, F. J., and Lechler, P., 1981, Chemical composition and stratigraphic correlation of Mesozoic basalt units of the Newark basin, New Jersey, and the Hartford basin, Connecticut: Geological Society America Bulletin (part 2, microfiche), v. 92, p. 515-553.

Puffer, J. H., DePlacido, A. M., Hurtubise, D. O., and Leavy, B. D., 1982, Chemical compositions of the igneous flow units of the Culpeper basin, Virginia: Geological Society America Abstracts with Programs, v. 10, p. 33.

Ragland, P. C., Brunfelt, A. D., and Weigand, P. W., 1971, Rare-earth abundances in Mesozoic dolerite dikes from eastern United States: in Activation analysis in geochemistry and cosmochemistry, A. O. Brunfelt and E. Steinnes, eds., Oslo, Universitetsfarloget, p. 227-235.

Raymond, C. A., 1982, Paleomagnetism of lower Mesozoic basaltic lavas, dikes, and sills of the Culpeper basin, northern Virginia: B.S. thesis, University of Georgia.

Raymond, C. A., Elwood, B. B., Chaves, L., and Leavy, B. D., 1982, Paleomagnetic analyses of lower Mesozoic diabase and basalt from the central and southern Appalachians: Geological Society America Abstracts with Programs, v. 11, p. 76.

Shannon, E. V., 1924, The mineralogy and petrology of the intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: U.S. National Museum Proc. 66, Art. 2, 86 p.

Shapiro, L., 1975, Rapid analysis of silicate, carbonate, and phosphate rocks - revised edition: U.S. Geological Survey Bulletin 1401, 76 p.

Smith, R. C., II, Rose, A. W., and Lanning, R. M., 1975, Geology and geochemistry of Triassic diabase in Pennsylvania: Geological Society America Bulletin, v. 86, no. 7, p. 943-955.

Sutter, J. F., Arth, J. G., and Leavy, B. D., 1983, $^{40}Ar/^{39}Ar$ age spectrum dating and strontium isotope geochemistry of diabase sills from the Culpeper basin, Virginia: Geological Society America Abstracts with Programs 12, p. 92.

Weigand, P. W., and Ragland, P. C., 1970, Geochemistry of Mesozoic dolerite dikes from eastern North America: Contributions Mineralogy Petrology, v. 29, no. 3, p. 195-214.

APPENDIX 1A: DIABASE SAMPLE LOCATIONS

SAMPLE #	LATITUDE (N)	LONGITUDE (W)	USGS 7 1/2' QUAD	COMMENTS
18	39°01'00"	77°34'30"	Leesburg	South side of Goose Creek, 90 m east of VA 621 bridge at Evergreen Mills
33	39°04'53"	77°31'07"	Leesburg	Cut face in northern section of Virginia Trap Rock Quarry, 710 m S 12° W of junction VA 7 and VA 653
74	38°55'30"	77°29'52"	Herndon	Northwest side of Chantilly Stone Quarry, 150 m south of Dulles Airport boundary
75	"	"	"	"
85	38°55'20"	77°29'58"	"	Central section of Chantilly Crushed Stone Quarry
86	"	"	"	"
88	"	"	"	"
90	"	"	"	"
91	"	"	"	"
92	"	"	"	"
93	"	"	"	"
94	"	"	"	"
95	"	"	"	"
96	"	"	"	"
98	"	"	"	"
99	39°04'15"	77°31'00"	Leesburg	20 m northeast of sample 100
100	"	"	"	Cut face in southeastern section of abandoned quarry east of Goose Creek
101	"	"	"	15 m west of sample 100
102	"	"	"	8 m west of sample 100
103	"	"	"	17 m east of sample 100
103a	"	"	"	"
104	"	"	"	21 m S 60° W of sample 103
106	39°05'00"	77°31'15"	"	Cut face in northeastern section of Virginia Trap Rock Quarry
107	"	"	"	0.5 m east of sample 106
108	39°05'00"	77°31'15"	"	Cut face in western section of Virginia Trap Rock Quarry
109	"	"	"	"
111a	"	"	"	10 m S10° E of sample 109
112	"	"	"	0.5 m north of sample 111a
188	38°58'23"	77°25'15'	Herndon	Cut face in western section of quarry 1760 m E of junction Crestview Drive and VA 606
189	"	"	"	20 m N 67° E of sample 188
190	"	77°25'12"	"	Cut face in quarry 1300 m S 48° E of intersection VA 28 and VA 606
194	39°04'13"	77°31'00"	Leesburg	Cut face in abandoned quarry east of Goose Creek
195	"	"	"	5 m below sample 194
196	"	"	"	10 m below sample 194
197	"	"	"	13 m below sample 194
198	"	"	"	16 m below sample 194
199	"	"	"	21 m below sample 194
200	"	"	"	29 m below sample 194
201	"	"	"	34 m below sample 194
202	"	"	"	37 m below sample 194
215	38°51'22"	77°32'27"	Gainesville	Cut face in eastern section of abandoned quarry north of Bull Run
216	"	"	"	1.5 m north of sample 215
217	"	"	"	3.0 m north of sample 215
218	"	"	"	5.0 m north of sample 215
364	38°49'45"	77°26'45"	Manassas	530 m S 44° W of intersection VA 28 and VA 267

APPENDIX 1B: BASALT SAMPLE LOCATIONS

SAMPLE #	LATITUDE (N)	LONGITUDE (W)	USGS 7 1/2' QUAD	COMMENTS
16	39°01'37"	77°37'15"	Leesburg	South side of Goose Creek, 200 m east of US 15 bridge
105	39°03'00"	77°36'00"	"	East side of roadcut on VA 650, 270 m N 32° E from junction VA 650 and VA 651, Gleedsville
160	38°57'55"	77°36'43"	Arcola	South side of roadcut on US 50, 80 m E. of Mount Zion Church
169	38°58'15"	77°37'37"	Middleburg	North side of roadcut on US 50, 400 m N 68° W of intersection US 50 and US 15
172	38°58'21"	77°37'49"	"	South side of roadcut on US 50, 400 m S 65° E from junction VA 631 and US 50
177	38°58'12"	77°37'57"	"	Abandoned quarry 500 m S 20° E from junction VA 631 and US 50
178	38°58'09"	77°37'55"	"	Roadcut 550 m south of junction US 50 and VA 631

APPENDIX 2A: WHOLE-ROCK MAJOR ELEMENT COMPOSITIONS OF ALTERED DIABASE FROM THE NORTHERN CULPEPER BASIN, VA.

Analysts: Floyd Brown, Lowell Artis, Herbert Kirschenbaum, Hezekiah Smith, and Leonard Shapiro (1973, 1974, 1975)

Oxide (Wt %) W#	74 181867	75 181866	88 181857	90 181858	92 181850	94 181852	96 181854	100 181842	103 181845	103a 181846	104 181847	106 181849	109 181837	111a 181838	112 181839	188 182499	189 182500
SiO_2	52.9	50.4	54.5	55.8	52.9	48.4	51.8	53.3	52.9	51.2	51.6	50.3	50.4	52.6	52.8	51.5	54.6
TiO_2	0.82	0.87	1.1	1.1	1.2	0.82	1.1	1.1	2.9	4.6	1.2	1.2	0.40	0.82	1.1	2.4	3.2
Al_2O_3	18.4	18.2	12.9	13.3	14.3	13.9	15.9	12.5	15.5	12.4	14.1	13.0	16.4	15.2	16.3	14.2	10.1
Fe_2O_3	2.7	8.6	2.0	2.1	1.8	3.7	2.5	1.2	1.0	3.1	1.8	1.6	1.5	1.4	1.8	2.2	0.60
FeO	4.4	1.5	6.0	5.8	7.4	7.1	6.3	7.6	4.2	8.5	6.8	5.3	4.6	7.4	6.3	8.6	5.3
MnO	0.07	0.08	0.14	0.15	0.20	0.20	0.08	0.17	0.44	0.69	0.16	0.12	0.06	0.21	0.15	0.20	0.14
MgO	5.1	4.1	6.3	6.3	7.0	6.0	6.6	7.0	4.4	4.6	6.8	6.1	3.6	7.1	5.9	4.1	6.1
CaO	10.7	4.2	11.1	6.9	7.8	14.7	10.8	10.0	11.3	8.5	11.3	13.9	10.7	7.2	10.3	8.9	14.6
Na_2O	2.7	2.2	3.0	4.8	4.0	2.2	2.3	4.1	4.3	3.1	2.6	1.4	3.4	4.7	2.9	3.9	3.6
K_2O	0.73	0.80	0.50	0.32	0.70	0.19	0.64	0.54	1.2	1.3	1.6	2.4	2.6	0.29	1.0	0.85	0.47
P_2O_5	0.12	0.11	0.12	0.19	0.14	0.21	0.14	0.74	0.37	0.46	0.17	0.16	0.07	0.23	0.62	0.20	0.12
CO_2	0.01	0.01	0.01	0.08	0.15	0.08	0.02	0.08	0.06	0.01	0.06	2.3	3.1	0.08	0.14	0.05	0.08
H_2O+	1.3	6.0	2.1	2.1	2.8	3.3	2.0	2.0	1.5	1.6	2.4	1.3	2.9	2.5	1.0	1.6	0.87
TOTAL	101	101	100	100	101	101	101	100	100	100	101	100	101	100	101	99	100

APPENDIX 2B: WHOLE-ROCK MAJOR ELEMENT COMPOSITIONS OF ALTERED BASALT FROM THE NORTHERN CULPEPER BASIN, VA.

Analysts: Floyd Brown, Lowell Artis, Herbert Kirschenbaum, Hezekiah Smith, and Leonard Shapiro (1973, 1974, 1975)

OXIDE (WT %) W #	16 181321	105 181848	160 182490	169 182492	172 182493	177 182495	178 182496
SiO_2	53.5	50.6	51.3	51.8	50.8	47.5	50.3
TiO_2	1.2	1.2	1.3	1.1	0.76	0.67	0.92
Al_2O_3	15.0	15.0	13.8	13.4	14.7	14.2	14.0
Fe_2O_3	3.0	2.8	2.7	6.6	2.3	3.3	2.5
FeO	9.4	7.5	7.4	6.2	8.1	6.1	8.6
MnO	0.16	0.13	0.19	0.20	0.19	0.21	0.20
MgO	4.9	7.6	7.7	4.7	7.9	6.3	6.9
CaO	8.5	11.1	5.9	6.9	9.1	12.9	6.4
Na_2O	2.6	1.8	4.5	4.3	2.7	2.7	4.2
K_2O	0.50	0.22	0.07	0.97	0.37	0.12	0.62
P_2O_5	0.18	0.11	0.15	0.18	0.19	0.09	0.11
CO_2	0.09	0.01	0.78	0.17	0.04	0.69	1.1
H_2O^+	0.93	1.6	3.1	2.0	1.9	3.2	3.2
TOTAL	101	101	100	99	100	99	99

APPENDIX 3A: SEMIQUANTITATIVE MINOR AND TRACE ELEMENT COMPOSITIONS OF RELATIVELY FRESH DIABASE FROM THE NORTHERN CULPEPER BASIN, VA.

Analysts: Janet D. Fletcher, Charles S. Annell, and Joseph L. Harris (1973, 1974, 1975)

ELEMENT (PPM) W #	18 181306	33 181322	85 181855	86 181856	91 181859	93 181851	95 181853	98 181840	99 181841	101 181843	102 181844	106 181849	107 181835	108 181836
Ag	--	--	0.13	0.11	--	0.10	0.12	--	.15	--	--	.53	--	--
B	--	--	16.2	--	12.6	16.7	12.2	--	--	--	--	13.1	--	--
Ba	128.0	105.0	152.0	110.0	142.0	149.0	146.0	106.0	157.0	164.0	154.0	902.0	124.0	122.0
Be	--	--	--	--	--	--	--	--	--		--	-- --	--	--
Mn	1660.0	1450.0	1460.0	1580.0	1520.0	1680.0	1320.0	1710.0	1770.0	1630.0	1790.0	1590.0	1570.0	1580.0
Mo	2.15	2.69	4.87	7.71	3.93	8.46	5.50	4.30	5.42	6.23	6.6	5.54	4.6	5.74
Nb	--	2.6	2.40	2.60	6.30	6.77	5.73	4.82	6.04	3.86	4.85	3.5	2.93	3.13
Pb	2.94	2.81	9.60	4.42	6.97	10.3	4.15	3.75	8.43	5.79	6.78	1.29	3.11	3.32
Sn	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sr	210.0	194.0	256.0	236.0	308.0	269.0	260.0	227.0	267.0	247.0	237.0	161.0	231.0	278.0
Zr	82.6	90.6	162.0	97.7	160.0	142.0	139.0	106.0	149.0	245.0	133.0	92.9	125.0	116.0
Co	30.3	27.9	49.0	51.6	48.0	55.7	45.0	50.7	47.1	41.5	42.9	29.1	42.4	43.4
Cu	74.9	57.5	58.0	42.3	59.4	64.3	60.9	73.3	59.6	87.0	70.6	135.0	71.0	63.3
Li	--	--	33.1	--	--	--	--	--	--	--	32.4	--	--	--
Ni	37.7	47.4	96.4	109.0	118.0	114.0	89.0	84.6	77.2	--	69.3	47.7	69.5	84.3
Zn	78.8	73.3	133.0	128.0	137.0	123.0	109.0	98.4	120.0	122.0	115.0	83.9	108.0	102.0
Cr	165.0	114.0	393.0	326.0	321.0	340.0	262.0	265.0	134.0	128.0	124.0	110.0	172.0	178.0
Ga	6.16	7.22	11.3	12.7	14.7	16.8	12.2	11.3	19.3	16.5	21.7	5.48	12.5	13.8
Sc	25.0	25.6	44.2	49.3	43.5	32.9	27.6	42.3	43.8	56.4	50.0	39.4	43.8	37.7
V	241.0	250.0	401.0	386.0	386.0	398.0	404.0	284.0	353.0	352.0	352.0	257.0	308.0	329.0
Ce	--	--	--	--	--	--	--	--	--	--	--	49.9	--	--
Eu	1.27	--	--	--	--	1.31	--	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--	--	--	--	19.5	--	--	--
Nd	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pr	6.75	--	--	--	--	--	--	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dy	--	5.22	--	--	8.41	7.49	7.36	--	5.72	8.53	--	6.06	--	6.2
• Gd	--	--	9.82	7.74	5.95	9.45	9.12	--	8.56	3.86	3.46	6.36	6.19	6.56
Ho	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Y	15.7	11.5	26.2	17.3	25.7	21.9	20.4	16.0	25.7	24.2	22.7	20.6	17.8	17.0
Yb	2.02	1.89	3.08	2.78	3.04	3.32	2.93	2.31	3.14	3.56	3.14	2.18	2.62	2.49

(--) below detection limit

APPENDIX 3A (CONT'D): SEMIQUANTITATIVE MINOR AND TRACE ELEMENT COMPOSITIONS OF RELATIVELY FRESH DIABASE FROM THE NORTHERN CULPEPER BASIN, VA.

ELEMENT (PPM) W #	190 182501	194 182502	195 182503	196 182504	197 182505	198 182506	199 182507	200 182508	201 182509	202 182510	215 182517	216 182518	217 182519	218 182520	364 184774
Ag	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--	--	--	--	--	--	--	40.2	21.1
Ba	186.0	169.0	295.0	278.0	171.0	113.0	108.0	112.0	128.0	121.0	132.0	131.0	137.0	165.0	189.0
Be	--	--	1.17	1.3	--	--	--	---	--	--	--	--	--	--	--
Mn	1510.0	1300.0	1960.0	1810.0	1570.0	1440.0	1630.0	1390.0	1570.0	1610.0	1750.0	1630.0	1550.0	1660.0	1230.0
Mo	2.94	4.03	6.89	4.93	3.45	2.26	4.63	4.28	2.42	2.32	3.95	3.99	4.45	4.55	--
Nb	3.41	2.6	9.27	6.32	--	--	2.59	2.23	--	--	--	--	--	2.24	--
Pb	3.53	4.54	13.1	8.96	2.95	2.67	1.58	2.15	2.69	2.1	3.96	2.64	4.31	3.53	13.6
Sn	--	--	3.55	3.91	--	--	--	--	--	--	--	--	--	--	--
Sr	210.0	212.0	270.0	201.0	290.0	184.0	173.0	191.0	186.0	183.0	178.0	189.0	193.0	231.0	281.0
Zr	181.0	103.0	286.0	393.0	104.0	52.8	95.7	86.8	88.6	83.2	103.0	107.0	82.1	109.0	157.0
Co	29.4	25.5	35.6	36.6	34.3	29.1	35.1	27.8	34.1	32.9	34.8	36.2	32.7	33.1	38.1
Cu	88.8	83.7	201.0	126.0	81.3	70.6	73.4	60.4	71.3	--	68.8	69.6	81.0	71.1	127.0
Li	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	21.6	28.9	26.6	23.3	32.8	34.5	50.7	39.6	44.2	41.4	56.5	60.2	53.8	43.3	72.0
Zn	92.8	81.7	162.0	97.0	99.5	77.1	77.6	77.7	77.7	87.6	98.7	97.9	107.0	97.3	128.0
Cr	9.86	9.79	20.4	12.0	50.4	67.5	109.0	78.9	97.4	42.5	202.0	185.0	147.0	143.0	66.3
Ga	12.2	11.0	12.0	13.1	9.72	6.31	6.61	5.82	7.21	6.43	5.41	8.14	7.3	8.32	20.7
Sc	30.5	34.3	29.8	35.2	30.1	27.3	53.5	32.7	45.9	51.4	24.6	35.2	32.8	21.8	41.0
V	264.0	245.0	483.0	287.0	246.0	183.0	264.0	233.0	233.0	270.0	275.0	271.0	237.0	289.0	235.0
Ce	--	--	131.0	122.0	--	--	--	--	--	--	--	--	--	--	98.6
Eu	1.33	--	--	--	1.5	--	--	--	127.0	--	--	--	--	--	--
La	--	--	24.6	24.1	--	--	--	--	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--	--	--	--	--	--	6.26	5.98	--
Pr	7.05	5.49	10.1	9.74	--	--	6.46	6.26	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dy	11.2	6.94	12.8	14.1	4.31	7.54	6.91	6.2	7.43	7.78	7.93	7.36	5.49	7.41	--
Gd	5.87	9.39	11.0	9.77	3.43	3.37	4.97	8.35	5.97	4.74	5.26	3.82	7.96	7.67	--
Ho	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Y	18.3	15.4	37.8	34.7	15.3	11.2	12.3	12.9	12.9	14.5	17.1	16.6	13.1	18.4	22.6
Yb	2.83	2.14	7.72	5.62	2.26	1.77	1.92	2.0	2.0	2.08	2.2	2.14	2.1	2.5	3.11

(--) below detection limit

APPENDIX 3B: SEMIQUANTITATIVE MINOR AND TRACE ELEMENT COMPOSITIONS OF ALTERED DIABASE FROM THE NORTHERN CULPEPER BASIN, VA

Analysts: Janet D. Fletcher, Charles S. Annell, and Joseph L. Harris (1973, 1974, 1975)

ELEMENT (PPM) W #	74 181867	75 181866	88 181857	90 181858	92 181850	94 181852	96 181854	100 181842	103 181845	103a 181846	104 181847	109 181837	111a 181838	112 181839	188 182499	189 182500
Ag	--	--	--	--	--	--	--	.16	--	--	--	--	--	--	--	--
B	--	--	14.2	--	10.8	--	11.2	--	27.9	--	20.9	--	--	13.9	70.9	12.8
Ba	134.0	181.0	72.8	--	88.3	4.18*	138.0	46.1	105.0	154.0	270.0	247.0	20.6	142.0	101.0	96.5
Be	-	--	--	1.31	--	--	--	--	--	--	--	--	--	--	--	--
Mn	1310.0	1120.0	1760.0	1820.0	1970.0	1990.0	1350.0	2080.0	1290.0	2300.0	1820.0	1060.0	2660.0	1980.0	1910.0	1390.0
Mo	3.72	2.99	5.59	2.52	4.20	6.37	3.86	7.34	1.9	3.49	2.69	2.53	6.49	5.22	--	6.69
Nb	3.73	--	4.21	6.07	2.47	--	6.52	3.71	3.4	8.64	--	--	4.99	7.42	--	5.07
Pb	3.67	5.67	3.70	29.8	4.74	2.52	6.47	4.48	5.15	3.76	2.9	1.28	3.08	3.38	3.0	1.8
Sn	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sr	283.0	177.0	177.0	180.0	207.0	20.6*	260.0	179.0	407.0	343.0	331.0	121.0	406.0	334.0	196.0	245.0
Zr	124.0	75.2	138.0	169.0	95.7	86.2	171.0	109.0	168.0	154.0	96.0	32.3	115.0	128.0	86.2	126.0
Co	32.5	34.9	43.1	44.2	43.6	41.5	60.4	39.9	28.6	62.7	51.5	61.8	49.0	39.6	40.6	33.7
Cu	42.7	47.5	59.1	29.3	372.0	42.4	63.0	87.4	37.3	85.6	234.0	336.0	21.2	76.3	500.0	18.3
Li	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	61.6	55.3	99.0	96.4	68.8	47.9	109.0	57.7	34.8	50.4	56.5	34.5	64.0	63.1	29.7	45.2
Zn	76.4	82.9	103.0	120.0	117.0	103.0	123.0	--	63.3	58.0	121.0	65.8	86.9	91.1	65.1	44.6
Cr	212.0	173.0	323.0	297.0	217.0	133.0	380.0	204.0	26.1	56.6	105.0	78.2	153.0	155.0	9.1	7.7
Ga	11.5	6.96	7.04	4.79	4.77	10.3	13.5	8.89	9.8	8.97	6.81	8.43	14.0	12.1	10.3	6.06
Sc	51.3	24.4	47.1	40.9	15.8	27.3	54.0	52.5	25.1	31.6	53.3	10.3	56.0	36.0	27.8	43.9
V	261.0	129.0	354.0	339.0	295.0	294.0	362.0	295.0	426.0	553.0	261.0	91.3	256.0	347.0	485.0	590.0
Ce	--	--	--	--	--	--	67.6	--	39.9	--	--	--	--	--	110.0	146.0
Eu	--	1.26	--	1.24	1.16	--	1.23	--	2.81	2.10	1.0	--	--	1.19	2.05	3.19
La	--	--	--	--	--	--	--	--	23.1	20.4	--	--	--	--	18.5	36.6
Nd	37.8	--	--	--	--	--	--	--	34.2	36.3	--	--	--	--	--	--
Pr	5.77	4.64	--	--	--	--	--	--	9.5	10.5	--	--	--	--	9.32	17.1
Sm	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.52
Dy	4.77	--	8.51	--	5.25	5.69	7.83	--	17.5	17.4	--	3.47	--	5.29	9.72	22.5
Gd	5.00	--	5.71	--	3.63	11.4	9.61	5.09	5.97	4.32	4.36	--	4.21	--	8.77	7.54
Ho	--	--	--	--	--	--	--	--	3.24	--	--	--	--	--	--	--
Y	16.3	21.6	22.6	27.9	17.5	14.8	27.1	19.3	42.4	29.8	18.5	7.8	16.8	17.3	19.1	42.5
Yb	1.79	2.29	2.93	3.14	2.44	2.20	3.35	2.83	5.65	6.20	2.24	1.19	2.33	2.68	3.96	7.83

(--) below detection limit

*May be analytical or typographic error in original report.

APPENDIX 3C: SEMIQUANTITATIVE MINOR AND TRACE ELEMENT COMPOSITIONS OF ALTERED BASALT FROM THE NORTHERN CULPEPER BASIN, VA

Analysts: Janet D. Fletcher, Charles S. Annell, and Joseph L. Harris (1973, 1974, 1975)

ELEMENT (PPM) W#	16 181321	105 181848	160 182490	169 182492	172 182493	177 182495	178 182496
B	--	--	--	16.7	--	29.8	17.5
Ba	148.00	128.0	71.5	229.0	83.1	27.8	246.0
Mn	2030.0	1680.0	1690.0	1870.0	1590.0	1740.0	1720.0
Mo	2.72	3.5	3.75	4.35	4.84	5.41	5.96
Nb	--	6.32	--	--	--	--	--
Pb	3.31	3.94	2.77	6.29	1.7	2.75	3.84
Sr	287.0	315.0	259.0	204.0	122.0	129.0	196.0
Zr	132.0	163.0	59.6	72.4	50.4	57.1	54.1
Co	35.9	58.3	28.8	34.2	35.6	31.2	36.3
Cu	22.6	51.6	71.6	37.4	51.4	66.4	52.0
Ni	13.1	88.1	49.8	18.6	44.3	40.3	29.0
Zn	110.0	113.0	79.6	97.9	79.1	79.3	82.3
Cr	11.2	286.0	239.0	21.6	196.0	156.0	120.0
Ga	9.43	8.45	4.79	8.16	3.47	6.58	6.71
Sc	34.1	--	36.2	25.1	59.6	50.2	27.1
V	357.0	372.0	201.0	272.0	244.0	210.0	263.0
Eu	--	--	1.12	--	--	--	--
Pr	--	--	3.72	--	--	--	4.84
Dy	4.61	6.22	6.98	5.51	6.31	5.92	4.0
Gd	6.42	10.4	4.91	7.87	6.33	7.34	7.17
Lu	--	3.16	--	--	--	--	--
Y	24.1	25.9	26.1	19.1	14.7	13.0	13.4
Yb	2.95	2.82	2.66	3.4	2.23	1.98	2.2

(--) below detection limit