COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

PREPARED IN COOPERATION WITH THE UNITED STATES
DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

PUBLICATION 40
TOTAL COUNT AERORADIOMETRIC
CONTOUR MAP OF THE
CULPEPER BASIN AND VICINITY, VIRGINIA

TOTAL – COUNT AERORADIOMETRIC CONTOUR MAP OF THE CULPEPER BASIN AND VICINITY, VIRGINIA

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1982

Radioactive isotopes in rocks emit a wide spectrum of gamma-ray radiation which is dominated by the elements uranium, thorium and potassium. This emission spectrum can be measured and analyzed, and the sources of the specific wave bands of radiation can be identified. Such measurement and analysis are best done using ground-based gamma-ray spectrometers, which allow one to quantify the amount of radioactive species present at a specific site, because ground-based radiometry allows a great degree of control over sampling and integrates the bulk effects of radioactive materials over a relatively small area. Aeroradiometric surveys, however, can uniquely show regional variations in radiation intensity. While such surveys are limited in resolution and accuracy in comparison to surface methods, some estimates of terrestrial radioelement contents and of relative surface radiation intensities may be made using airborne methods. After gamma-ray radiometric anomalies have been identified on a regional scale, ground data may be used to determine whether these variations in radiation intensity result from radionuclides in rocks exposed at the earth's surface or from cultural sources.

This aeroradiometric map of the Culpeper basin and vicinity shows variations in intensity of gamma-ray radiation from geologic sources that, for this map, were analyzed for the relative contributions of the elements potassium, uranium, and thorium. Reconnaissance ground-based gamma-ray spectrometry in areas containing specific lithologies was done to provide a calibration of the aeroradiometric map. Although the ground survey disclosed areas where man's activity may have altered the natural radioactivity pattern, the airborne survey shows that the regional variations in the Culpeper basin and vicinity are mainly controlled by the natural distribution of bedrock.

PROCEDURE AND INSTRUMENTATION

The spectral gamma-ray aeroradiometric survey of the Culpeper basin and vicinity was flown in May 1981 by EG&G geoMetrics under contract to the Virginia Division of Mineral Resources. The area in the northeastern part of the basin is in Dulles International Airport airspace, and no survey flights were allowed in this area during the 1981 survey. Several previous surveys have been flown in this area (see index).

The spectrometer used in the aerial survey was a geoMetrics GR-800-D gamma-ray spectrometer calibrated according to the requirements given by the Bendix Field Engineering Corporation (1977). The survey utilized about 3500 in³ of detector crystal, approximately 500 in³ of which were arranged in an upward-looking configuration (shielded from below by lead) to collect background data on the cosmic and atmospheric components. Atmospheric and cosmic sources generally account for a small portion of the total-count rate observed, but are highly variable with time, altitude, and prevailing atmospheric conditions. The data collected by the remaining 3000 in³ (unshielded) were corrected by subtraction of the cosmic and atmospheric values to yield the terrestrial component.

Data were collected at one-second intervals along flight lines that were spaced 0.75 miles (1.21 km) apart. The survey was flown in an east-west direction at an altitude of 500 feet (152 m.) The effective area of response of the survey equipment at 500 feet (152 m) is a circle approximately 1000 feet (305 m) in diameter; the radioactivity recorded is an average for that area. Each recorded measurement consisted of 256 channels of discrete spectrometer data ranging from 0.4 MeV up to 3.0 MeV, and a summed cosmic and atmospheric measurement from 3.0 MeV to 6.0 MeV. After reduction, the multi-channel spectrometer data yielded the contributions of the radionuclides K^{40}, Bi^{214} (daughter element of U^{238}), and Tl^{208} (daughter element of Th^{232}) to the total-count field, thereby allowing the characterization of anomalies as a function of the principal radioelements, potassium, uranium, and thorium, respectively.

Anomalous total-count values displayed on the map of the Culpeper basin are identified with "K," "U," and "T" labels depicting the radionuclide presumably causing the total-count anomaly. Total-count values greater or less than 1.5 standard deviations above or below the area-wide arithmetic mean were considered to be potential anomalies. Each energy window (K, U, Th) was then examined to see if the value for that specific element was within ± 1.5 standard deviations of the area-wide mean for that window. Only the central sample within a closed contour line on the map was retained, even though there may be several samples on either side of the peak value which are anomalous. The area-wide statistics for this survey are:

Variable	Mean	Standard Deviation
Total count	969.88 cps	298.77 cps
Potassium (potassium-40)	52.81 cps	26.73 cps
Uranium (bismuth-214)	17.49 cps	8.27 cps
Thorium (thallium-208)	31.55 cps	11.75 cps

In order to verify the spectral character of the aeroradiometric anomalies shown on the map, a ground-based four-channel gamma-ray spectrometer with a large volume (113 in³) sodium iodide detector was used to measure the components of the gamma-ray radiation field at 16 localities in the Culpeper basin and vicinity. Some of the sampled sites are east of the present survey area; however, these sites are located on rock types comparable in character to areas within the survey limits. Sites were selected mainly with regard to favorable rock exposures and accessibility. Comparison of their aeroradiometric character may be made by referring to the previous surveys (Neuschel, 1965; Blanchett and others 1966; U.S. Geological Survey, 1980) shown on index. The ground spectrometer data was reduced to radionuclide concentrations by use of the technique given by Stromswold and Kosanke (1977).

To achieve constant geometry at each locality, the detector unit of the instrument was suspended from a tripod about 1.5 feet above the surface. After temperature equilibration and standardization against a barium-133 gamma-ray source, the count-rate was measured at the following gamma-ray energies: (1) total count, all energy between 0.5 and 3.0 MeV; (2) 1.46 MeV from potassium-40; (3) 1.76 MeV from bismuth-214 in the uranium-238 series; and (4) 2.62 MeV from thallium-208 in the thorium-232 series. The counting time at each locality did not exceed 10 minutes. The data are summarized in Table 1. Duplicate measurements (A and B) were made at the same site without moving the tripod. Spectral radiometric averages of lithologic units in the Culpeper basin and vicinity based on ground measurements are given in table 2.

GENERAL GEOLOGY

The Culpeper and Barboursville basins in Virginia are parts of a belt of northeast-trending Mesozoic rift basins in eastern North America. In northern Virginia, the Culpeper basin is about 12 miles wide and extends from the Rapidan River north for about 90 miles to the Potomac River; in Maryland (beyond the map area), the basin continues northward for an additional 20 miles to just south of Frederick. Immediately south of the Culpeper basin, the Barboursville basin, a small faulted outlier of the Culpeper basin (Conley and Johnson, 1975), is about 2.5 miles wide and extends from Madison Mills south for about 10 miles to just south of Barboursville, the town after which the basin is named (Lee, 1980).

The sedimentary rocks in these basins belong to the "Culpeper Group," which ranges in age from Late Triassic to Early Jurassic (Cornet, 1977). The Triassic rocks are predominantly non-marine sandstones and siltstones ("red beds") with minor amounts of conglomerate. The Jurassic rocks also include "redbeds" (sandstones and siltstones), but the sequence is characterized by coarse fluvial conglomerates (Lindholm and others, 1979), black and gray lacustrine shale, siltstone and sandstone, and intercalated basalt flows. The entire "Culpeper Group" in the Culpeper basin is intruded and locally metamorphosed by dikes, sills and stocks of tholeiitic diabase of Early Jurassic age. Igneous rocks have not been reported in the Barboursville basin (Lee, 1977; 1979; 1980; Lindholm, 1977; 1978).

The Mesozoic sedimentary rocks in the Culpeper basin dip generally westward toward a major normal fault system that forms the linear western margin of the basin. The arcuate eastern margin displays both high-angle normal faults of relatively minor displacement and unconformable contacts with the basement rocks (Leavy, 1980; Lindholm, 1978). A variety of foliated metamorphic rocks of Precambrian and Early Paleozoic age underlie the basins and crop out around their margins (Virginia Division of Mineral Resources 1963). These rocks include metabasalt with interlayered arkose, felsic and mafic metavolcanic rocks, quartzite, phyllite, schist, gneiss, and carbonate rocks.

Table 1.—Ground spectral gamma-ray signatures of sites in the Culpeper basin and vicinity.

Sample Number[1]	7.5-minute quadrangle	UTM Zone	UTM Coordinates Northing Easting	Lithologic Type	Total counts per second	Percent K	eU[2] (ppm)	eTh[2] (ppm)	eU/K	eTh/K	eTh/eU
1A[3]	Herndon	18	4315000 288020	interbedded siltstone and sandstone	324	1.93 ± .05	2.90 ± .33	12.03 ± .49	1.5	6.9	4.4
1B[3]					327	1.81 ± .05	3.50 ± .35	11.91 ± .49	1.7	6.2	3.6
2A[3]	Herndon	18	4316250 286620	diabase	328	1.29 ± .04	2.36 ± .35	8.29 ± .36	1.8	6.5	3.5
2B[3]					337	1.22 ± .05	2.36 ± .35	7.99 ± .35	1.9	6.5	3.4
3A[3]	Herndon	18	4318140 286250	hornfels (siltstone)	378	2.67 ± .06	4.27 ± .46	14.49 ± .63	1.6	5.4	3.4
3B[3]					374	2.68 ± .06	3.99 ± .45	14.41 ± .63	1.5	5.4	3.6
4A[3]	Herndon	18	4318330 286150	siltstone	309	1.93 ± .05	2.97 ± .36	10.62 ± .48	1.5	5.6	3.6
4B[3]					306	1.92 ± .05	2.96 ± .35	10.02 ± .47	1.5	5.2	3.4
5A[3]	Herndon	18	4318200 286100	siltstone	319	1.97 ± .05	3.15 ± .35	10.77 ± .49	1.6	5.5	3.4
5B[3]					316	1.93 ± .05	3.11 ± .35	11.28 ± .49	1.6	5.8	3.6
6A	Leesburg	18	4326820 282970	hornfels (siltstone)	399	2.61 ± .06	4.63 ± .49	14.96 ± .66	1.8	5.3	3.2
6B					400	2.84 ± .06	4.86 ± .49	14.49 ± .66	1.7	5.1	3.0
7A	Waterford	18	4347130 281760	interbedded siltstone and limestone conglomerate	279	1.53 ± .04	2.90 ± .31	11.60 ± .44	1.9	7.6	4.0
7B					278	1.43 ± .04	3.07 ± .30	11.49 ± .43	2.1	8.0	3.7
8A	Waterford	18	4346850 280860	quartzite colluvium	320	2.35 ± .05	3.24 ± .39	10.84 ± .53	1.4	4.6	3.3
8B					319	2.35 ± .05	2.97 ± .39	10.76 ± .53	1.3	4.6	3.6
9A	Middleburg	18	4312770 271240	basalt	136	0.33 ± .02	0.82 ± .21	2.69 ± .17	2.5	8.1	3.3
9B					135	0.33 ± .01	0.85 ± .20	2.57 ± .24	2.5	7.7	3.0
10	Gordonsville	17	4232000 743440	siltstone	413	3.06 ± .08	4.72 ± .55	15.27 ± .76	1.5	5.0	3.2
11A	Gordonsville	17	4231600 742600	siltstone	526	4.86 ± .11	4.75 ± .74	16.08 ± 1.05	0.9	3.6	3.8
11B					525	5.00 ± .11	4.89 ± .74	17.70 ± 1.05	0.9	3.5	3.8
12A	Gordonsville	17	4231040 742640	siltstone	399	3.00 ± .08	3.89 ± .52	15.97 ± .76	1.3	5.3	4.1
12B					400	3.13 ± .08	4.00 ± .53	15.66 ± .77	1.3	5.0	3.9
13A	Unionville	18	4249900 245450	hornfels (sandstone)	456	3.39 ± .08	5.17 ± .58	15.94 ± .82	1.5	4.7	3.1
13B					456	3.37 ± .08	4.76 ± .58	16.19 ± .81	1.4	4.8	3.4
14A	Culpeper West	17	4253140 761900	hornfels (sandstone & siltstone)	365	2.01 ± .06	4.95 ± .46	15.37 ± .65	2.5	7.6	3.1
14B					362	2.00 ± .06	4.50 ± .44	15.15 ± .64	2.3	7.6	3.4
15A	Remington	18	4263970 257810	hornfels (siltstone)	310	1.51 ± .05	3.52 ± .38	14.04 ± .56	2.3	9.3	4.0
15B					309	1.49 ± .04	4.28 ± .35	12.98 ± .47	2.9	8.7	3.0
16A	Midland	18	4270550 267420	siltstone	368	2.71 ± .06	3.56 ± .44	13.46 ± .62	1.3	5.0	3.8
16B					366	2.66 ± .06	3.50 ± .44	13.61 ± .61	1.3	5.1	3.9

[1]Letters A and B indicate samples at the same locality; instrument not moved.
[2]eU (ppm) and eTh (ppm) indicate equivalent parts per million determined from counting of bismuth-214 and thallium-208, respectively.
[3]1, 2, 3, 4 and 5 are east of the survey sheet.

Table 2.—Spectral gamma-ray radiometric values * for lithologic units in the Culpeper basin

Lithology	Number of Localities	K (percent)	eU (ppm)	eTh (ppm)	eU/K	eTh/K	eTh/eU
Siltstone	6	2.9	3.8	13.9	1.3	4.8	3.7
Hornfels	5	2.5	4.5	14.8	1.8	5.9	3.3
Diabase	1	1.3	2.4	8.1	1.8	6.2	3.4
Basalt	1	0.3	0.8	2.6	2.6	8.1	3.3
Interbedded Siltstone and Sandstone	1	1.9	3.1	12.5	1.6	6.5	4.0
Interbedded Siltstone, Limestone Conglomerate	1	1.5	3.0	11.5	2.0	7.7	3.8
Quartzite Colluvium	1	2.4	3.1	10.8	1.3	4.5	3.5

*Average of two readings (A and B) per locality; siltstone and hornfels are averages for all localities (see table 1).

EVALUATION OF THE AERORADIOMETRIC SURVEY

The principal criterion for evaluating the quality of gamma-ray aeroradiometric surveys is the low and constant response of the airborne instrument over major bodies of water. Bodies of water within the Culpeper survey area have low radiometric signatures, indicating that location accuracy and instrument calibration are generally good.

The ground-spectrometer data indicate that the spectrally characterized aeroradiometric anomalies reflect actual variations in radionuclide abundance. Aeroradiometric anomalies situated over siltstone exposures that are characterized as KUT (Potassium-Uranium-Thorium) anomalies, for example, have ground spectra high in KUT (localities 10, 11, and 12, Table 1). Similarly, UT characterized aeroradiometric anomalies have ground spectra with strong U and T components. Other lithologic types show a similar correlation between airborne- and ground-spectrometer data. The small number of localities used to characterize the spectral signature of lithologic types may limit the statistical significance of the numbers, but a larger number of samples would probably not significantly change the results.

Previous work with aeroradiometric maps indicates that gamma-ray aeroradiometric anomalies associated with land used for agricultural purposes may be enhanced by radioactive fertilizers (Grosz, in press). Commonly used fertilizer mixtures consist of variable amounts of nitrate, potash, and phosphate applied in either liquid or granular form. Potash and phosphate are radioactive: potash because of potassium-40, and phosphate because of associated uranium.

The relatively poor correlation between the total-count channel counts of Table 1 and the contoured values of the aeroradiometric map is probably due in part to the effects of fertilizer, and in part to the fact that the airborne survey integrates radiation values from a much larger geographical area than the ground survey. A larger number of ground-survey values would probably correlate better with the airborne survey values.

RADIOMETRIC RESPONSE OF LITHOLOGIC UNITS

The diabase intrusive rocks in the Culpeper basin produce broad aeroradiometric (total-count) lows that range in values from 400 to 1000 cps (counts-per-second). The basalt flows also produce lows, but with a narrower range, from 700 to 1000 cps. The geographically narrow negative anomalies associated with the basalt are neither as continuous nor as well defined as those over diabase, because their steep westerly dip and thinness result in narrow linear exposures. Other radiometric lows include those in the vicinity of Culpeper, where lows were recorded over the Triassic greenstone conglomerate that was derived from Proterozoic Catoctin Metabasalt. In general, the mafic igneous units within the basin (diabase and basalt) and two mafic units outside the basin (Catoctin Metabasalt and Piney Branch Complex) yield consistently low radiometric values.

The aureole of metasedimentary rocks (baked zone, hornfels) adjacent to diabase intrusive rocks in the Culpeper basin form either a steep gradient or local radiometric highs, as opposed to the lows over the intrusive diabase. Daniels (1980) reports that areas immediately adjoining baked zones in Fairfax County have higher radiometric values than the areas of baked and intrusive rocks. He suggests that the thermal effects of the diabase intrusion may have extended beyond the mapped baked zone and that the highs may possibly be due to enrichment of radionuclides mobilized from rocks closer to the hot diabase.

Most of the prominent high anomalies south of Herndon are in red-brown siltstone. These anomalies are characterized by tightly closed contours with steep gradients, especially in areas where fresh siltstone is exposed in quarries or pits (Froelich and Leavy, 1982), or in hornfels formed by metamorphism of the siltstones. West and north of Herndon some radiometric highs are underlain by either limestone conglomerate or by quartz and schist-pebble conglomerate. The schist-pebble conglomerate also produces moderate highs in the Barboursville basin. Some pre-Mesozoic rocks that border the basin, notably acidic pelitic schists, metasiltstones, metagranitic rocks and quartzites produce local highs.

ACKNOWLEDGMENTS

The authors wish to thank the following: Albert J. Froelich, for his invaluable contribution to the interpretation of the radiometric response of the lithologic units in the survey area and for a careful review of the text; David L. Daniels, for his reviews and suggestions which resulted in an improved manuscript; and Shirley R. Pearson, Virginia Division of Mineral Resources, for her careful attention to detail and perseverance in drafting the final maps.

REFERENCES

Bendix Field Engineering Corporation, 1977, General procedure and documentation for normalization and calibration of airborne gamma-ray systems: Grand Junction Operations Specifications No. BFEC 1250-A.
Blanchett, Jean, Griscom, Andrew, and Vargo, J. L., 1966, Natural gamma aeroradioactivity map of the Seneca and part of the Sterling quadrangles, Montgomery County, Maryland, and Loudoun and Fairfax Counties, Virginia: U.S. Geological Survey Geophysical Investigations Map GP-564, scale 1:24,000.
Conley, J. F., and Johnson, S. S., 1975, Road log of the geology from Madison to Cumberland Counties in the Piedmont, central Virginia: Virginia Division of Mineral Resources, Virginia Minerals, v. 21, no. 4, p. 29-38.
Cornet, Bruce, 1977, The palynostratigraphy and age of the Newark Supergroup: Unpublished Ph. D. dissertation, Pennsylvania State University, 505 p.
Daniels, D. L., 1980, Geophysical-geological analysis of Fairfax County, Virginia: U.S. Geological Survey Open-File Report 80-1165, 66 p.
Froelich, A. J., and Leavy, B. D., 1982, Map showing mineral resources of the Culpeper basin, Virginia and Maryland: Availability and planning for future needs: U.S. Geological Survey Miscellaneous Investigations series Map I-1313-C, scale 1:125,000.
Grosz, A. E., in press, Application of total-count aeroradiometric maps to the exploration for heavy-mineral deposits in the Coastal Plain of Virginia, with a section on Field-spectrometer-data reduction by K. L. Kosanke: U.S. Geological Survey Professional Paper 1269.
Leavy, B. D., 1980, Tectonic and sedimentary structures along the eastern margin of the Culpeper basin, Virginia: Geological Society of America Abstracts with Programs, v. 12, no. 4, p. 182.
Lee, K. Y., 1977, Triassic stratigraphy in the northern part of the Culpeper basin, Virginia and Maryland: U.S. Geological Survey Bulletin 1422-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, 29 p., (parts of 16 quadrangles) scale 1:24,000.
________, 1980, Triassic-Jurassic geology of the northern part of the Culpeper basin and the Barboursville basin, Virginia: U.S. Geological Survey Open-File Report 80-468, 19 p., (parts of 18 quadrangles) scale 1:24,000.
Lindholm, R. C., 1977, Geology of Jurassic-Triassic Culpeper basin, north of Rappahannock River, Virginia (abs): American Association of Petroleum Geologists Bulletin. v. 61, no. 5, p. 809.
________, 1978, Triassic-Jurassic faulting in eastern North American—A model based on pre-Triassic structures: Geology, v. 6, no. 6, p. 365-368.
Lindholm, R. C., Hazlett, J. M., and Fagin, S. W., 1979, Petrology of Triassic-Jurassic conglomerates in the Culpeper basin, Virginia: Journal of Sedimentary Petrology, v. 49, no. 4, p. 1245-1262.
Neuschel, S. K., 1965, Natural gamma aeroradioactivity of the District of Columbia and parts of Maryland, Virginia, and West Virginia: U.S. Geological Survey Geophysical Investigations Map, GP-475, scale 1:250,000.
Stromswold, D. C., and Kosanke, K. L., 1977, Calibration and error analysis for spectron radiation detectors: IEEE Transactions: Nuclear Science, v. NS-25, p. 782-786.
U.S. Geological Survey, 1980, Aeroradioactivity map of Fairfax County, Virginia: U.S. Geological Survey Open File Report 80-812, scale 1:48,000.
Virginia Division of Mineral Resources, 1963, Geologic map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000
________, 1981, Aeroradiometric contour map—total count: Virginia Division of Mineral Resources, open file, scale 1:62,500. Eleven maps, one each for the Barboursville, Gainesville, Germanna Bridge, Gordonsville, Leesburg, Manassas, Nokesville, Quantico, Rapidan, Sterling, and Warrenton quadrangles.

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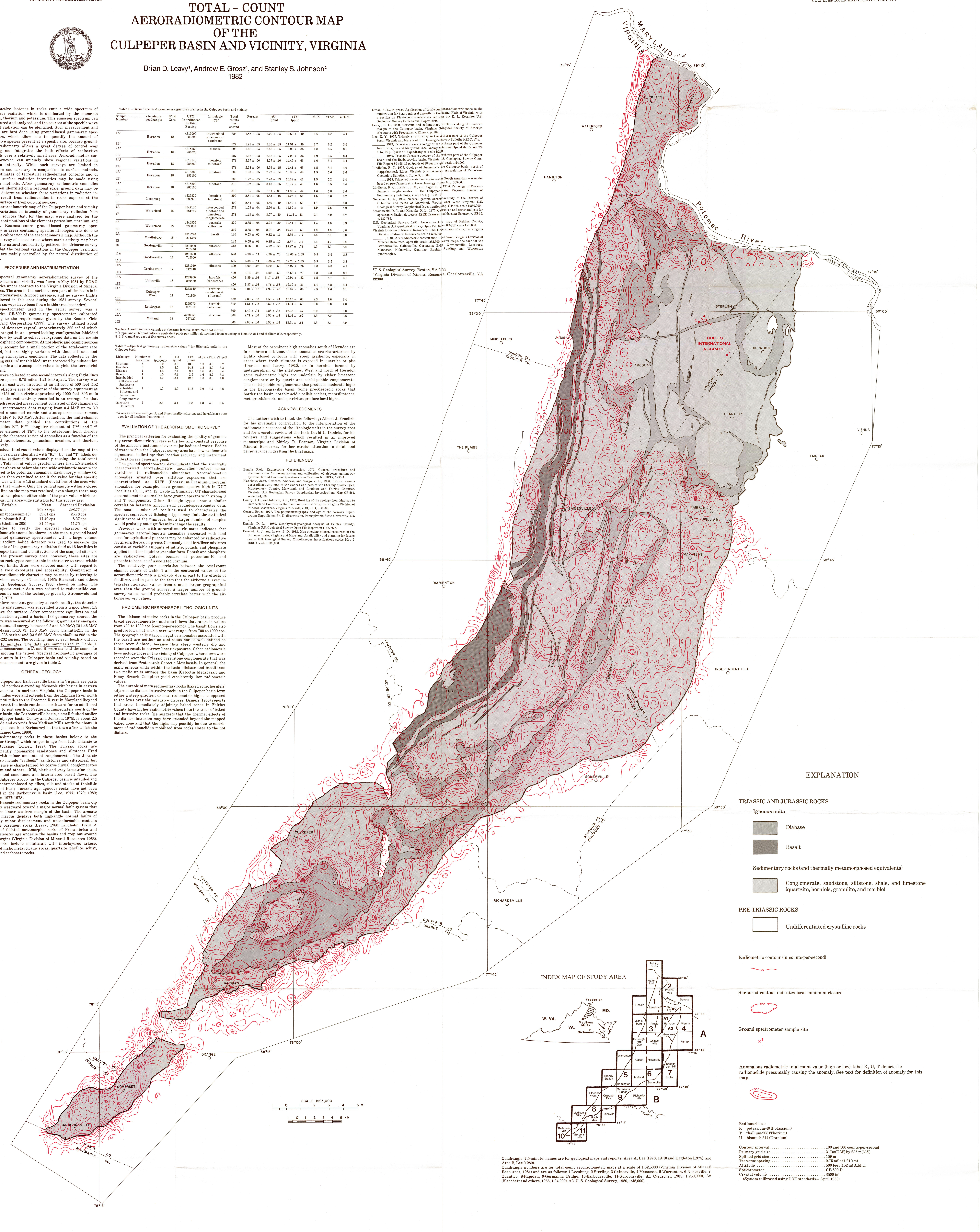

Quadrangle (7.5-minute) names are for geological maps and reports: Area A, Lee (1978, 1979) and Eggleton (1975); and Area B, Lee (1980).
Quadrangle numbers are for total count aeroradiometric maps at a scale of 1:62,5000 (Virginia Division of Mineral Resources, 1981) and are as follows: 1-Leesburg, 2-Sterling, 3-Gainesville, 4-Manassas, 5-Warrenton, 6-Nokesville, 7-Quantico, 8-Rapidan, 9-Germanna Bridge, 10-Barboursville, 11-Gordonsville, A1 (Neuschel, 1965, 1:250,000), A2 (Blanchett and others, 1966, 1:24,000), A3 (U. S. Geological Survey, 1980, 1:48,000).

EXPLANATION

TRIASSIC AND JURASSIC ROCKS

Igneous units

Diabase

Basalt

Sedimentary rocks (and thermally metamorphosed equivalents)

Conglomerate, sandstone, siltstone, shale, and limestone (quartzite, hornfels, granulite, and marble)

PRE-TRIASSIC ROCKS

Undifferentiated crystalline rocks

Radiometric contour (in counts-per-second)

Hachured contour indicates local minimum closure

Ground spectrometer sample site

Anomalous radiometric total-count value (high or low); label K, U, T depict the radionuclide presumably causing the anomaly. See text for definition of anomaly for this map.

Radionuclides:
K potassium-40 (Potassium)
T thallium-208 (Thorium)
U bismuth-214 (Uranium)

Contour interval	100 and 500 counts-per-second
Primary grid size	317m(E-W) by 635 m(N-S)
Splined grid size	159 m
Traverse spacing	0.75 mile (1.21 km)
Altitude	500 feet (152 m) A.M.T.
Spectrometer	GR 800-D
Crystal volume	3500 in³

(System calibrated using DOE standards—April 1980)